SPINE Volume 28, Number 6, pp 573–581
©2003, Lippincott Williams & Wilkins, Inc.

Management of Isthmic Spondylolisthesis with Posterolateral Endoscopic Foraminal Decompression

Martin Knight, FRCS, and Anukul Goswami, MS, MCh(Orth), DNB

Study Design. Prospective evaluation of 24 consecutive patients with isthmic spondylolisthesis with chronic back, buttock, and leg pain treated by endoscopic foraminal decompression and followed for a minimum of 2 years.

Objectives. To assess the efficacy of endoscopic foraminal decompression and mobilization of the exiting and transiting nerves, discectomy, ablation of osteophytes, and impinging pars as a means of treatment by the posterolateral approach.

Summary of Background Data. Open decompression with or without fusion is a commonly accepted procedure for symptomatic isthmic spondylolytic spondylolisthesis in patients who fail to respond to conservative treatment. There is no published data on the outcome of endoscopic procedures for this condition.

Methods. Endoscopic foraminal decompression achieved with laser-assisted bone and soft-tissue ablation was performed on 12 males and 12 females with an average age of 42.4 years (36–72 years) followed for an average period of 34 months (28–46 months). The average preoperative duration of symptoms was 6.1 years (3–9 years).

Results. One hundred percent cohort integrity was maintained at the final follow-up. Results were analyzed using the percentage change in Oswestry Disability Scores and in Visual Analogue Pain scores. Using a percentage change in Oswestry Disability Score of 50 or more plus VAP scores of 50 or more to determine good and excellent outcomes, 79% (19 out of 24) exceeded this value.

Conclusion. Laser-assisted endoscopic foraminal decompression provides a minimalist means of exploring the extraforaminal zone, the isthmic defect, the foramen and its contents, the disc and the epidural space. It allows adequate resection with decompression and discectomy, without the need for open decompression and fusion, and targets the symptomatic level effectively in patients with Grade I–III isthmic spondylolisthesis. [Key words: decompression, discectomy, endoscopy, foraminoplasty, fusion, spondylolisthesis] **Spine 2003;28:573–581**

Clinically, in adults, the distinction between isthmic and congenital spondylolisthesis is considered to be theoretical and anatomic.[18,43] We have used the term isthmic spondylolisthesis for those adults who have presented with an isthmic defect in the pars to distinguish them from patients with attenuated pars interarticularis and patients with degenerative olisthesis, postsurgical, posttraumatic, pathologic spondylolistheses that occur in patients with widespread or localized infection or destructive bone lesions.

After failure of conservative treatment, patients with isthmic spondylolisthesis, back pain, and referred symptoms are usually treated with decompression with or without fusion.[11,31] Reports of good to excellent outcomes following surgery have varied from 70% to 90%.[7,11,29,33] Results of endoscopic spinal interventions performed in an aware state for disc prolapse and degenerative disc disease have been reported in the literature.[6,8,16,17,19,26,28,29,30,39,40,44] However, none has reported the outcome of endoscopic foraminal decompression in isthmic spondylolisthesis.

The technique of endoscopic laser foraminoplasty (ELF)[19,23,24] provides a comprehensive means of decompressing and mobilizing the structures within the intervertebral foramen. It includes a visual examination of the extraforaminal, foraminal, intradiscal, and intraspinal zones in the partially sedated but communicative patient providing feedback during surgery.[21,24,44] The first 250 patients undergoing ELF for chronic lumbar spondylosis or failed back surgery have had encouraging results.[24] In this prospective, independently evaluated study with 97% cohort integrity, the outcome was analyzed using the Oswestry Disability Index (ODI),[27] and Visual Analogue Pain (VAP) scores. A clinically appreciable change was observed in 73%. Using the percentage change of the Oswestry Disability score of 50 or more to determine good and excellent outcome, 60% exceeded this score.

This report presents the outcome of a prospectively designed study of minimalist endoscopic foraminal decompression with foraminoplasty and discectomy in chronically symptomatic patients presenting with Grade I–III isthmic spondylolisthesis.

Materials and Methods

Twenty-four consecutive patients with Grade I–III isthmic spondylolisthesis presenting with back pain and buttock pain with or without leg pain were included in the study. All had back and buttock pain. Twenty-five had associated leg pain.

The average age of the patients was 42.4 years (SD 13.9). The age range was 22 to 72 years. The minimum follow-up period was 24 months, and the maximum was 46 months (average 34 months, SD 5.9 months).

From the Spinal Foundation, Arbury Consulting Centre, Rochdale, United Kingdom.
Acknowledgment date: May 22, 2002. First revision date: August 14, 2002. Acceptance date: August 15, 2002.
The device(s)/drug(s) is/are FDA approved or approved by a corresponding national agency for this indication.
No funds were received to support this work. One or more of the author(s) has/have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript: *e.g.*, honoraria, gifts, consultancies.
Address correspondence and reprint requests to Martin Knight, FRCS, The Spinal Foundation, Arbury Consulting Centre, Manchester Road, Rochdale, OL 11 4LZ, United Kingdom; E-mail: mknight@spinal-foundation.org

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

Study Construct. The study was designed prospectively and consisted of 24 consecutive patients presenting with back, buttock, and leg pain in association with Grade I–III isthmic spondylolisthesis treated between March 1994 and December 1998.

Inclusion Criteria. Patients older than 21 years presenting with Grade I–III isthmic spondylolisthesis with at least a 1-year history of disabling low back and buttock pain with or without referred pain, unresponsive to conservative management of at least 6 months, were included in the study. Conservative treatment included mandatory muscle balance (kinetic control) physiotherapy[13,14] for a period of 3 months.

Exclusion Criteria. Patients with associated severe congenital abnormalities of the lumbar spine, congenital kyphosis, generalized osteoporosis, postsurgical, posttraumatic, pathologic spondylolisthesis, arthrogryposis, localized bone infection, destructive lesions of the spine, and degenerative spondylolisthesis were excluded.

Data Acquisition. Full details of history and symptoms were recorded in a questionnaire that included a pain manikin, a VAP scale, and Oswestry Disability questionnaire. Patients were evaluated at 6, 12, and 26 weeks following surgery and at yearly intervals unless clinical symptoms required closer supervision.

Twenty-one of the 24 patients in this series have been presented in the independently evaluated and peer-reviewed data published on the first 250 patients treated by ELF for chronic back and referred pain.[24]

Clinical data were ascertained by a physiotherapist. Self-reporting questionnaires were completed and data were entered by a nonmedical data-inputting clerk.

Clinical Evaluation. Full clinical neurologic and postural analysis was performed together with plain anteroposterior (AP) and neutral lateral weight-bearing radiographs and a dynamic series of digitized "instability" radiographs including flexion and extension, both sitting and standing views. This served to identify the degree of spinal movement at the defect and adjacent site.[9] All patients were evaluated with magnetic resonance (MR) scans.

Surgical Protocol. Spinal probing and discography[19,20,21,23] was carried out at more than one level. Unambiguous reproduction of concordant symptoms during probing and discog-

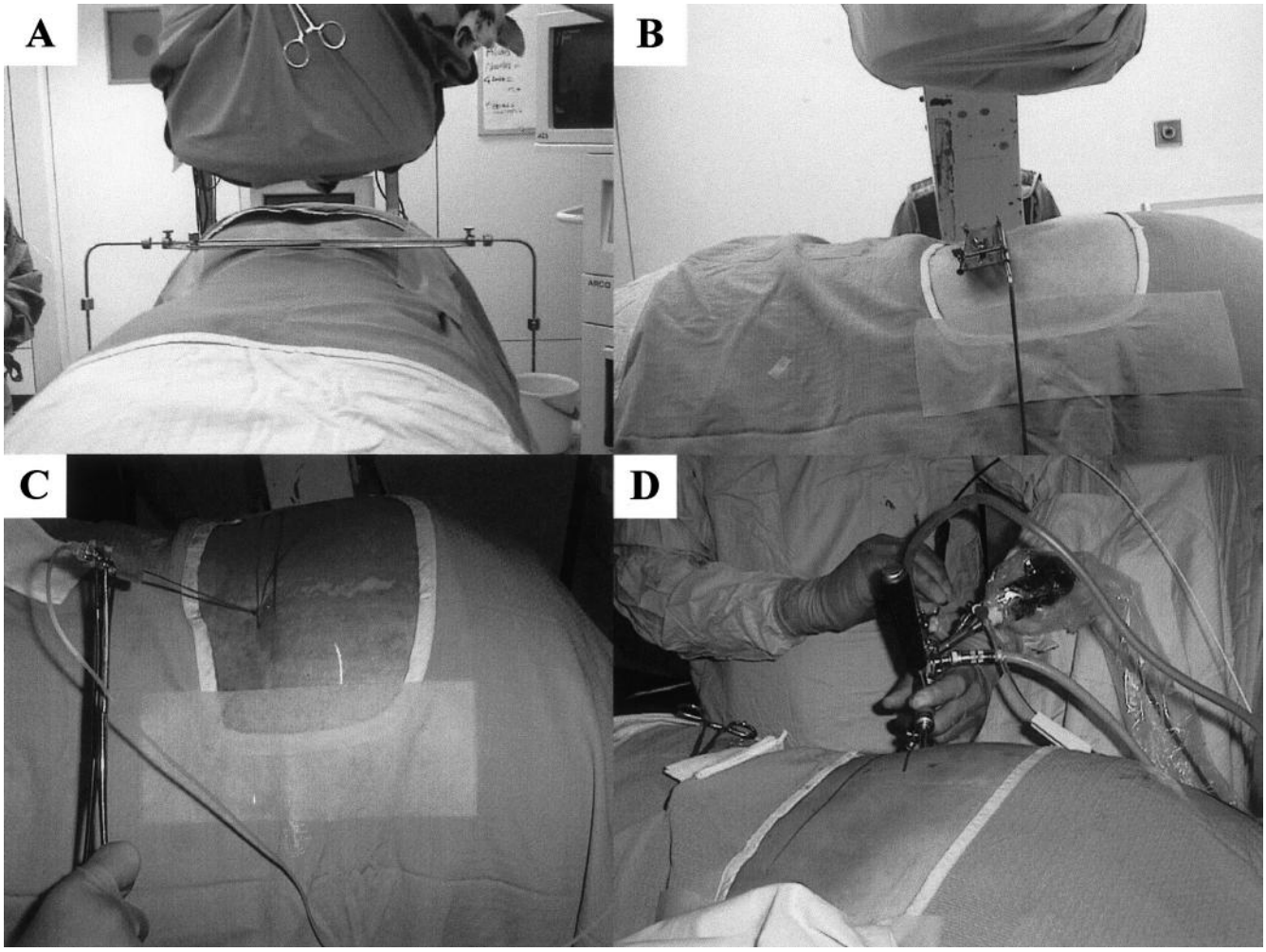


Figure 1. **A** and **B,** The radiograph jig assists locating site of entry into the spinal foramen. **C,** The figure shows the site and portal of entry determined by the radiograph jig. The spinal needle and the spinal cannula as an assembly are directed into the foramen with the assistance of the image intensifier. **D,** The endoscope, camera, lighting, irrigation, and suction drain assemblage used during the procedure of endoscopic laser foraminoplasty.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

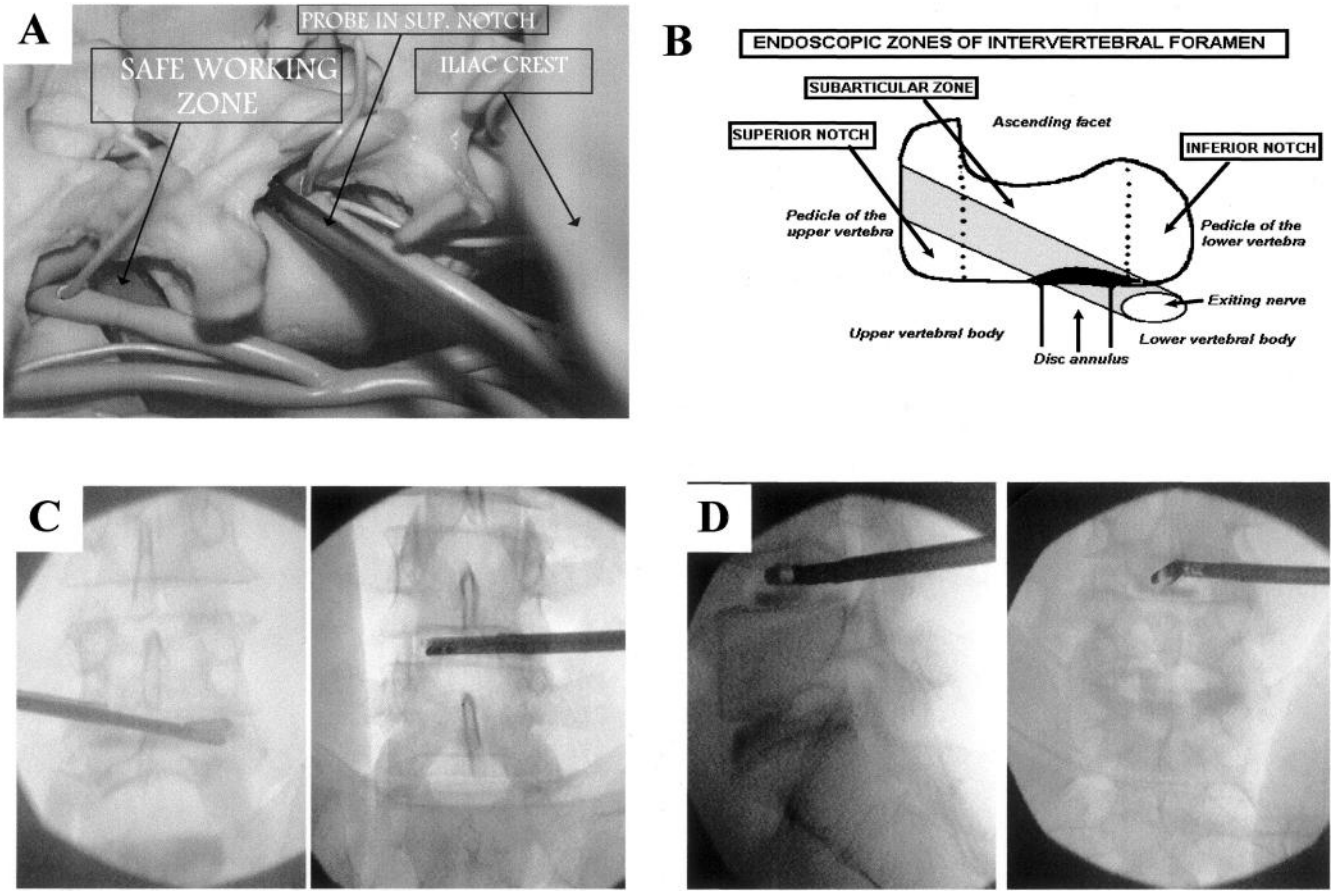


Figure 2. **A** and **B,** The endoscopic operative zone and the anatomic zones of the foramen. **C** and **D,** Adequate access to the disc and epidural space is facilitated by foraminal decompression and mobilization of exiting nerve. With appropriate instrumentation, "tight corners" may be approached by undercutting and bulging or protruding discs may be removed.

raphy confirmed the level with the isthmic defect for endoscopic foraminal decompression in the conscious state.[25] Endoscopy allowed additional visualized probing of the foraminal structures and mechanical factors causing neural irritation and/or compression.[23,24]

Operative Technique

Spinal Probing and Discography. The posterolateral approach was conducted under image-intensifier control. The entry portal was selected using a specially designed jig,[20] which ensured optimal alignment of the approach line to the foramen (Figures 1A–C).

Lasing Technique. Once concordant symptoms were reproduced at a single level by spinal probing and discography, a 5.2 × 4.6-mm elliptical endoscope with an eccentrically placed 2.1-mm working channel and 2 irrigation channels was inserted. A 2.0-mm diameter side-firing laser probe with internal irrigation was inserted through the endoscope (Figure 1D). Under saline irrigation, Holmium:YAG laser pulses were used to ablate, resect, and divide bone and soft tissues to a depth of 0.2 mm and 0.4 mm, respectively. An image intensifier was used to monitor the correct positioning of the endoscope and the laser probe. The safety of laser application was ensured by: 1) performing the procedure under saline irrigation, which provided a clear view of the foraminal contents and prevented any unwanted rise in local temperature[12] during lasing; 2) a red Helium guide beam defined the pathway and target of the Holmium:YAG beam and ensured avoidance of neural tissues.

Endoscopic laser clearance demonstrated the foraminal anatomy and the status of the contents, disc, nerves, and scarring (Figures 2A, 2B, 7, and 8) the pars defect, the facet joint, ligamentum flavum, the superior foraminal ligament,[10,21,36]

Table 1. Outcome Indices and Scores

Oswestry disability score change	$= \frac{\text{Preoperative score} - \text{postoperative score}}{\text{preoperative score}} \times 100$
Visual analogue pain change	$= \frac{\text{Preoperative score} - \text{postoperative score}}{\text{preoperative score}} \times 100$

Table 2. Site and Grade of Symptomatic Spondylolisthesis Levels

Grades	L4–5	L5–S1
I	6	8
II	4	5
III	0	1
Total	10	14

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

Table 3. Surgical Outcome in Terms of the Percentage Change in Oswestry Disability Scores

Grade	Excellent (100%)	Good (50–99%)	Fair (49–25%)	Poor (0–25%)	Worse
I	3	9	1	1	—
II	1	5	—	1	2
III	—	1	—	—	—
Total	4	15	1	2	2

— = not applicable.

the intervertebral disc, and the exiting and transiting nerve. Individual sites were probed or manipulated to identify the distribution of pain elicited. Elements causing distortion, compression, traction, or irritation of the nerve[21] were ablated. The exiting and transiting nerve roots were mobilized and decompressed (Figures 2A and 2B) until the root of the exiting compressed nerve at the apex of the distorted quadrangular zone (Figures 7 and 8) was displayed. The nerve was cleared of perineural fibrosis by laser ablation directed at right angles away from the nerve (Figure 9A). Clearance was extended along the bone margin of the superior notch (Figure 2B). The superior foraminal ligament[10,21] was freed from the nerve and resected. Distorted, protruding degenerate disc compressing or displacing the exiting or transiting nerve was removed in the midline and foramen (Figures 2C and 2D). Adequate decompression was ascertained by painless active extension of the level by the patient during surgery[24,26] and resolution of preoperative symptoms at the end of the surgery.

Follow-up. Patients were discharged the morning following surgery. The muscle balance (kinetic control) physiotherapy regime[35] was recommenced on the first day following surgery and amplified with neural mobilization drills.

Outcome Instruments

Percentage Change in Oswestry Disability Scores. The functional outcome was measured by the percentage change in Oswestry Disability Score as expressed in Table 1. A change of 100% was deemed an excellent result, >50% good, >20% improved, whereas <20% was considered poor and negative values were deemed a worse result.

Percentage Change in Visual Analogue Pain Scores. Preoperative and follow-up VAP levels were measured separately for back, buttock, and leg[45] using a VAP scale with the following guidelines to patients: pain level 10 = excruciating pain, unbearable for any time; 9 = horrible pain bearable for only a short time; 6 = distressing pain bearable for some time; 3 = mild pain; 0 = no pain. The outcome was measured by the percentage change in the VAP score as expressed in Table 1 and the percentage change interpreted as for the Oswestry Disability Score.

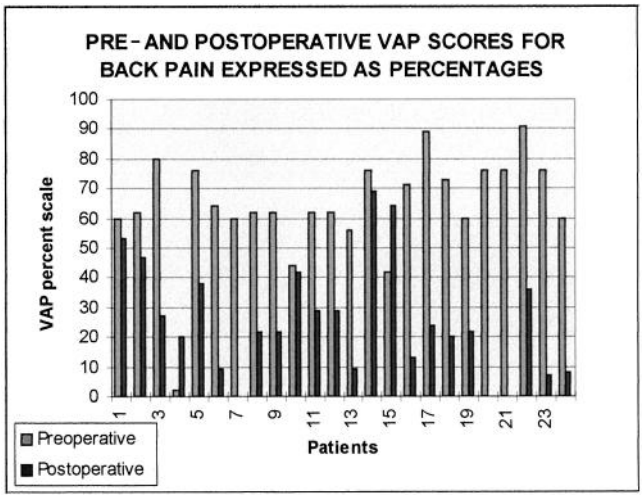


Figure 3. Pre- and postoperative VAP scores for back pain expressed as percentages.

■ Results

Disc degeneration was noted at the level of spondylolisthesis in all the patients. Nineteen patients also had degenerate or "black discs" at adjacent levels. The average preoperative duration of symptoms was 73 months (36–108 months). All patients had bilateral back buttock and leg pain. The intervention was carried out on the side of maximum symptoms. The intervertebral level with the isthmic spondylolisthesis was found to be the predominant site of pain in 24 patients as confirmed by spinal probing and discography.

In the symptomatic isthmic level group, there were 12 males and 12 females: 14 patients had Grade I, 9 had Grade II, and 1 had Grade III isthmic spondylolisthesis. Their distribution is shown in Table 2.

The L4–L5 level demonstrated pain associated with isthmic spondylolisthesis in 10 patients, and pain was elicited in 14 patients at the L5–S1 spondylolisthetic level.

Table 4. Statistics: Preoperative and Postoperative Oswestry and Pain Scores

	Oswestry			VAP Back		VAP Buttock		VAP Leg	
	Preop	Postop	Change	Preop	Postop	Preop	Postop	Preop	Postop
Average	68.83	21.21	66.33	64.25	25.42	59.88	17.58	54.00	17.54
Maximum	90.00	66.00	100.00	91.00	69.00	89.00	67.00	93.00	67.00
Minimum	46.00	0.00	−43.00	2.00	0.00	18.00	0.00	0.00	0.00
Standard deviation	12.04	19.82	36.54	17.83	18.37	16.50	19.66	22.88	20.49
P value	<0.001			<0.001		<0.001		<0.001	

Values are %.
VAP = Visual Analogue Pain.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

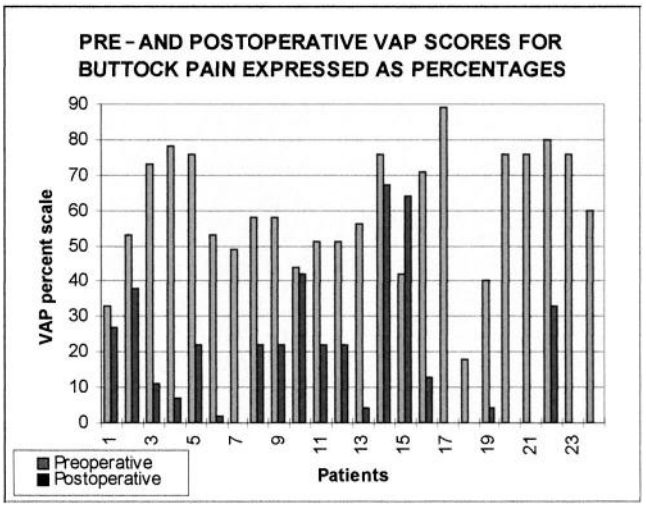


Figure 4. Pre- and postoperative VAP scores for buttock pain expressed as percentages.

Percentage Change in Oswestry Disability Score

At the final follow-up, 12 out of 14 patients (82%) with Grade I spondylolisthesis demonstrated a good to excellent outcome (more than 50% change). The outcome was graded fair in one and poor in one. Six out of 9 patients with Grade II spondylolisthesis demonstrated a good to excellent outcome (60%). One patient with Grade III spondylolisthesis benefited significantly with a 76% change, thus reaching the good to excellent category (Table 3).

Percentage Change in Visual Analogue Score

The reduction in pain followed the same pattern as the percentage change in the Oswestry Disability Score (Table 4; Figures 3, 4, 5, and 6).

The postoperative VAP scores demonstrated that 5 (21%) were pain free, 15 (63%) had achieved a good result with a change in VAP score of ≥50%, whereas 8% were poor and 8% were worse at their 2-year review.

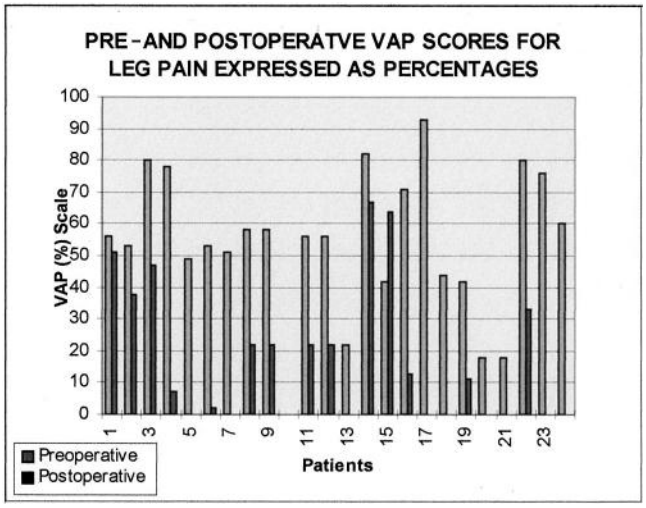


Figure 5. Pre- and postoperative VAP scores for leg pain expressed as percentages.

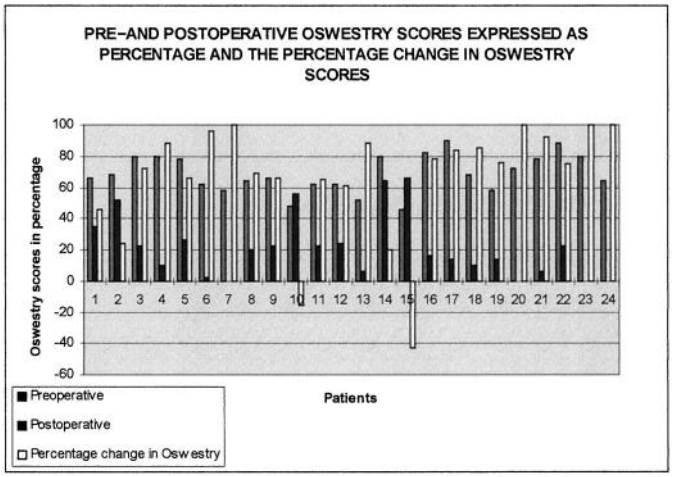


Figure 6. Pre- and postoperative Oswestry scores expressed as percentages and the percentage change in scores.

Statistical Analysis

As the preoperative data consisting of ODI and the VAP scores were normally distributed, paired *t* test was performed to analyze the outcome. Significant improvement ($P < 0.001$) was observed in disability and pain scores (Table 4; Figures 3, 4, 5, and 6).

Morphologic features and mechanical factors identified in the foramen that directly compressed or mechanically irritated the nerve are given in Table 5 and Figure 6.

Complications

There was no occurrence of infection, discitis, paresis, dysesthesia, dural tears, vascular injury, or systemic complications.

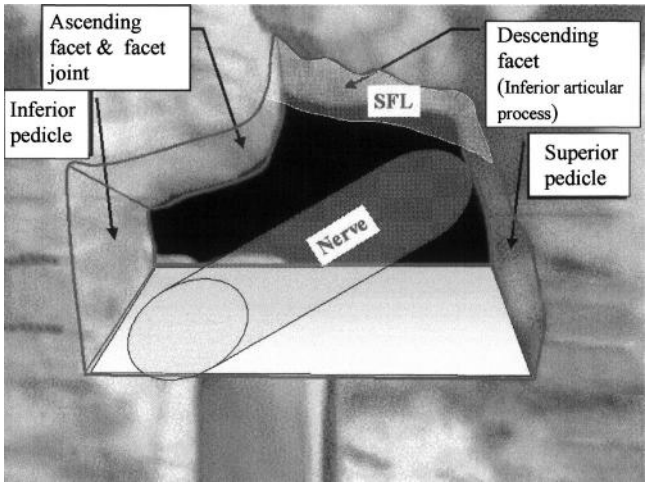


Figure 7. The intervertebral foramen represents a modified quadrangle. The concept of endoscopic foraminoplasty is the surgical expansion of the foraminal volume, mobilization and the clearance of the contents, and ablation of factors irritating to the nerve within the quadrangular zone. In patients with isthmic spondylolisthesis, the foramen is distorted. This adds to the compression arising from the displaced pars element, disc, and fibrous defect. The final aims remain decompression and removal of factors that limit normal neural mobility.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

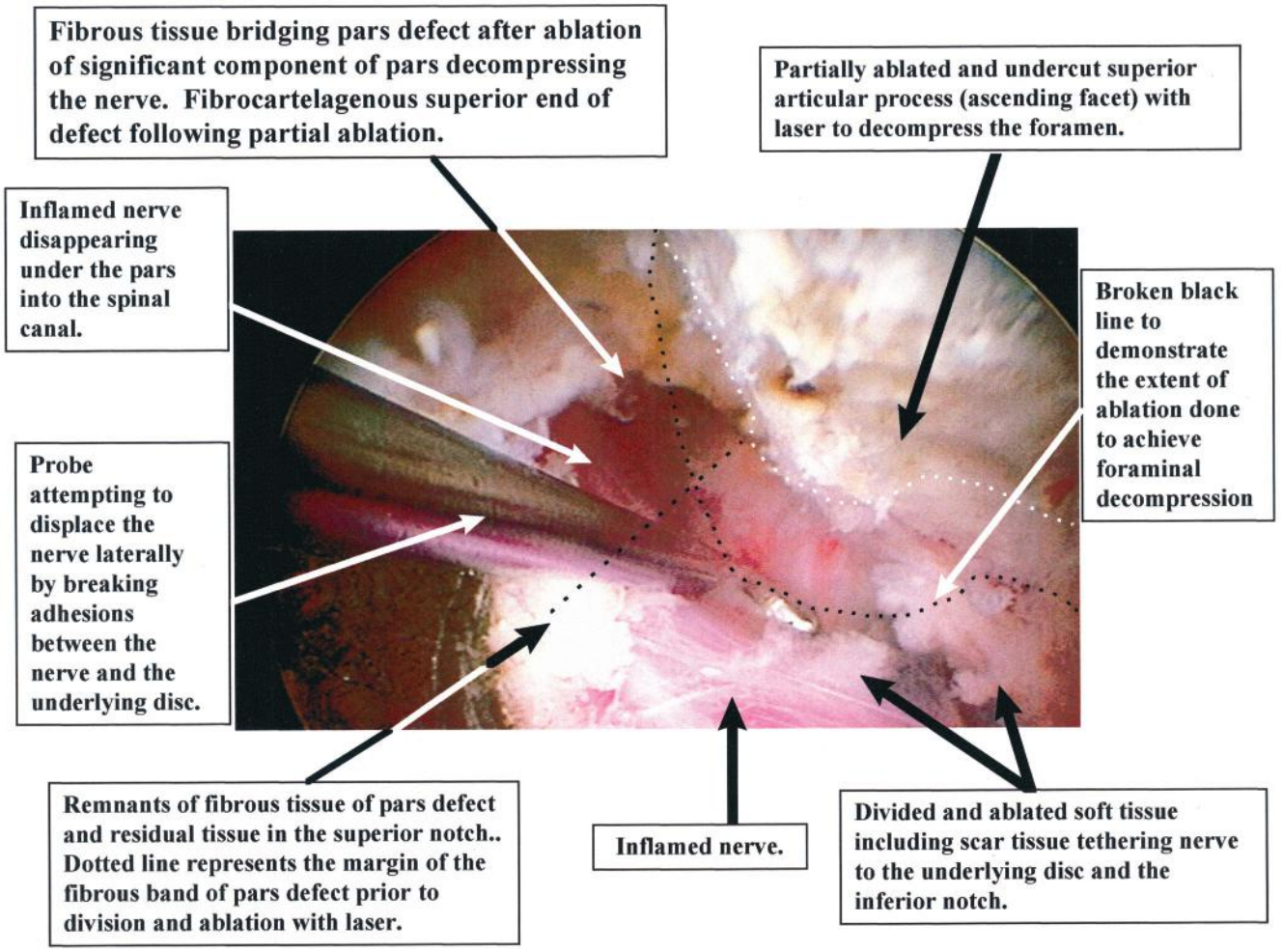


Figure 8. An "irritable" hyperemic nerve, reproducing symptoms on probing, is being mobilized by a nerve hook. The nerve is usually found to be adherent to the fibrous pars defect and the facet joint in the superior notch. Soft tissues and osteophytes from the edge of the facet joint and the ascending (superior) facet have been undercut to decompress and free the exiting nerve.

Revisions

At the final follow-up, the two patients with "worse" outcomes had spinal fusion operations performed elsewhere. These patients improved significantly following the fusion operations.

■ Discussion

The outcome of this prospective study was based on the percentage gain in the performance measured by Oswestry Disability scores plus the percentage reduction in pain. In patients with symptomatic Grade I–III isthmic spondylolisthesis, clinically relevant improvement (more than 20% gain) was achieved by foraminal decompression with ELF in 20 out of 24 (83%) patients. Endoscopic laser foraminoplasty resulted in sustained good to excellent outcome (more than 50% gain) in 19 out of 24 patients (79%). The outcome was independent of olisthesis grade. Outcome in patients with Grade III olisthesis should be guarded, as there was only one patient in this group.

Among those with poor or worse outcomes, two patients improved with fusion, one is contemplating decompression and fusion, and one demonstrated considerable improvement in the "deep nagging pain" in his legs, but the back pain remains unaltered. This was reported as an improvement in the ODI from 30% to 26%. The patient accepted the residual symptoms and declined open or minimalist intervention. This highlights the importance of stratifying regional pain evaluation[45] when interpreting outcomes.

Failure occurred in one patient with marked bilateral leg and buttock pain in whom ELF ameliorated the symptoms on the operated side. Following the lack of contralateral benefit, this patient chose open surgery rather than additional contralateral ELF. In the remaining failures, deterioration followed initial benefit and is presumed to be due to inadequate decompression. No additional slippage was noted on weight-bearing flexion–extension radiographs, and clinical and radiologic investigations failed to reveal any other cause.

Spinal probing and discography[21,23] was used to confirm the index level. In the absence of correlation between specific radiologic factors and clinical symptoms[2,32] of back, buttock, and leg pain, discography

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

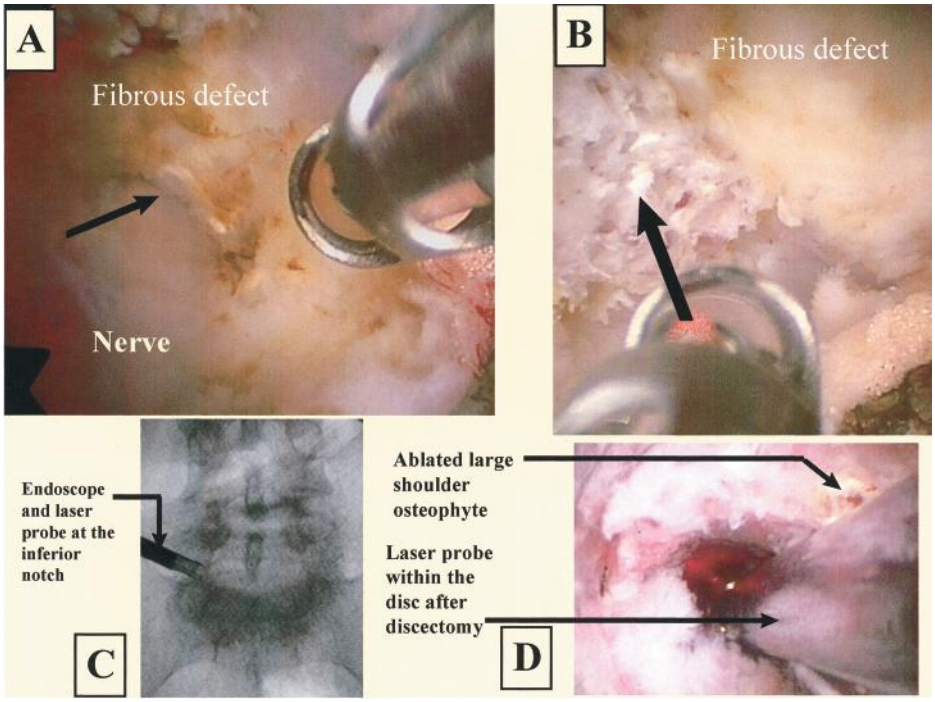


Figure 9. **A, B**, and **D** are the endoscopic views during endoscopic laser foraminoplasty. Figure 10 has been provided to facilitate orientation. **A,** This view shows the semicircular edge created by lasing during the resection of the impinging elements of the fibrous interarticularis defect. The highly magnified view of the body of the nerve can be visualized under the fibrous defect. **B,** This view shows the site of the pars defect where a large hook like spike of bone is being ablated. The fibrous defect has been partially concealing the spike. The laser probe delivers the laser beam that is reflected off a mirror placed at 45° within the probe. This deflects and directs the beam at right angles to the probe. Direction of the arrow represents the direction of the laser beam. A concurrent visible red Helium beam of light demonstrates the track to be followed by the laser beam and facilitates the accurate targeting of the laser energy. **C,** Radiographic confirmation of the positioning of the endoscope and the laser probe is necessary during the procedure. **D,** This view shows the laser probe inserted into the disc through the portal created in the anulus during discectomy. The laser is directed in the transverse plane to avoid laser trauma to the end plates.

with reproduction of "concordant" symptoms to date remains an accepted diagnostic method of identifying the segmental level causing pain.[2,3,4,5,37]

Endoscopy revealed impaction on the exiting nerve by the displaced bony and fibrous elements of the pars defect. Neural displacement and compression were accentuated by the deformed disc and necessitated discectomy and annuloplasty in addition to foraminal widening with clearance. During decompression, removal of bone revealed neural adhesions to surrounding structures, maintaining the distortion of the nerve. Endoscopic decompression of the lateral recess consisted of widening of the foramen, resecting the displaced and impinging bony and fibrous elements of the pars defect, excising the distorted posterior anular remnant, and mobilizing the nerve from the point of impaction. Endoscopic palpation of the sec-

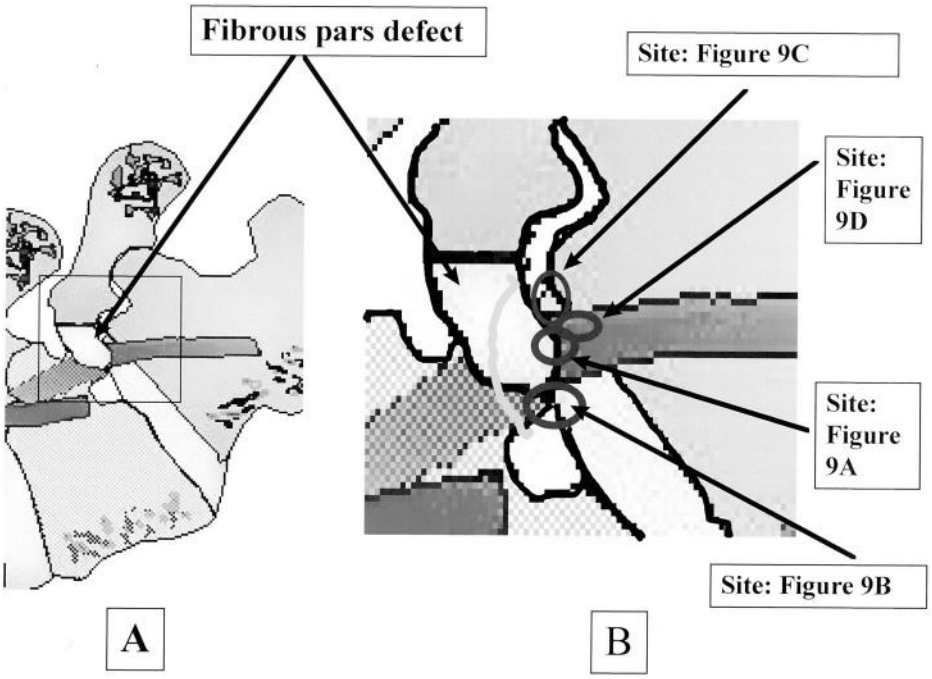


Figure 10. **A** and **B,** Diagrammatic representation of endoscopic views during the foraminoplasty procedure shown in Figure 9.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.



Figure 11. Diagrammatic representation of the stages of foraminal decompression for spondylolytic spondylolisthesis.

tion of the nerve that was distorted and irritated by the impacting factors produced concordant pain in back, buttock, and leg. On the contrary, endoscopic palpation of the healthy segment of nerve did not induce concordant symptoms. For this reason, spinal probing and discography proved to be a useful provocative test.

Previously reported endoscopically assisted surgery achieved spinal decompression by discectomy alone or occasionally in association with instrumented excision of vertebral osteophytes.[16,40] However, endoscopic foraminal decompression differs in that it specifically seeks to target provocative mechanical irritants in the foraminal zone while simultaneously increasing the foraminal volume by widening the boundaries, mobilizing the nerve, removing factors impinging or tethering the nerve, and permitting discectomy (Figures 7, 9, and 11).

Endoscopic laser foraminoplasty obviated the need for open intervention in 21 out of 24 (88%) significantly disabled patients with an average preoperative ODI of 68.8% presenting with isthmic spondylolisthesis. Those who failed to respond sufficiently to these minimally invasive techniques improved significantly following open decompression. Endoscopic laser foraminoplasty may fail, but it does not seem to diminish the prospects of subsequent decompression and/or fusion.

This minimally invasive intervention performed on patients in the conscious state (aware state)[25] minimizes the morbidity associated with open interventions and yet provides comparable outcomes.[15,24,39,44] It is performed as a 12- to 18-hour or overnight stay and can be performed on the elderly and infirm.[24] Conventional management of Grade I and II isthmic spondylolisthesis favors conservative management. The cohort of patients with a mean evaluation of symptoms for 3.9 years had been advised to undergo fusion surgery. This study indicated that ELF might offer a minimalist alternative treatment.

Endoscopic inspection of the foramen deformed by the isthmic defect and olisthesis demonstrates the presence of mechanical factors irritating and compressing the exiting nerve. These factors include the impacting elements of pars defect, the impacting portion of the fibrous band bridging the pars defect, the distorted bulging disc, and the entrapment of the nerve.[9,15,21,23,33,34,38,42] The role of these factors is confirmed by the fact that their clearance causes sustained relief of the patients' pain, confirmed by immediate feedback on the operating table. Sustained beneficial outcome suggests a "biologic plausibility" that the mechanically irritating factors were causal or inductive of the presenting symptoms or pain.[1,41]

The buttock pain described by the patients is clearly and repeatedly evoked by palpation of the medial border of the exiting nerve root, whereas the palpation of the core of the nerve caused radicular pain. The point of elicitation coincides with the site of impact of the superior bony end of the pars defect or the fibrous band. These cause the nerve to be compressed on to the side of the disc or the posterolateral corner of the inferior vertebra (Figure 10). Removal of this compression relieves the buttock pain. Discrete removal of such causative impinging factors and local tethering offers a simple remedy without the need for fusion. There were no complications in this cohort of patients. The procedure requires dedicated spinal endoscopic training and when fulfilled is attended by a very low incidence of complications.[22]

In adult isthmic spondylolisthesis, the degree of olisthesis seldom increases, and therefore the need for stabilization and fusion is seldom required to prevent progression of the malalignment. The development of a minimalist technique to effectively address the predominant presenting symptoms without the need for fusion or wide midline decompression would appear apposite.

■ Conclusion

Minimally invasive endoscopic foraminal decompression achieved by ELF resulted in sustained clinical improvement in 20 out of 24 (83%) patients with a painful isthmic spondylolisthesis. The beneficial outcome of the foraminal decompression using ELF prevented open intervention and needless fusion in 22 out of 24 (90%) of the patients. This procedure was performed as a 12- to 18-hour stay and may be used in the elderly and infirm.

■ Key Points

- Foraminal decompression achieved by the minimally invasive posterolateral ELF produced sustained clinical and functional improvement in 83% of patients with Grade I–III isthmic spondylolisthesis.
- The outcome of endoscopic foraminal decompression and neural mobilization is comparable to that reported for open decompression and fusion in the management of Grade I–III isthmic spondylolisthesis.
- Minimalist endoscopic intervention avoided open decompression and needless fusion in 92% of these patients.

References

1. Bradford Hill A, Hill ID. Statistical evidence and inference. In: Principles of Medical Statistics. 12th ed. London: Edward Arnold; 1991:270–9.
2. Carragee E. Award-winning study finds that current diagnostic techniques cannot identify pain of discogenic origin. Back Lett 2000;15:6.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

3. Carragee EJ, Chen Y, Tanner CM, et al. Provocative discography in patients after limited lumbar discectomy: a controlled, randomized study of pain response in symptomatic and asymptomatic subjects. Spine 2000;25:3065–71.
4. Carragee EJ, Tanner CM, Khurana S, et al. The rates of false positive lumbar discography select patient without low back pain. Spine 2000:25:1373–81.
5. Colhoun E, McCall IW, Williams L, et al. Provocation discography as a guide to planning operations on the spine. J Bone Joint Surg Br 1988;70B:267–71.
6. Casper GD. Laser foraminoscopic surgery. In: Lasers in Musculoskeletal System. Gerber BE, Knight M, Siebert WE, eds. Berlin: Springer-Verlag; 2001.
7. DeWald RL, Faut MM, Taddonio RF, et al. Severe lumbosacral spondylolisthesis in adolescents and children: Reduction and staged circumferential fusion. J Bone Joint Surg Am 1981;63A:619–26.
8. Frank E. Endoscopically assisted open removal of laterally herniated lumbar discs. Surg Neurol 1997;48:430–4.
9. Fujiwara A, An HS, Lim TH, et al. Morphologic changes in the lumbar intervertebral foramen due to flexion-extension, lateral bending and axial rotation. An in vitro anatomic and biomechanical study. Spine 2001;26: 876–82.
10. Goswami A, Knight M. Anatomical concepts in applied surgery of the lumbar spine: an endoscopic view. In: Lasers in Musculoskeletal Systems. Gerber BE, Knight M, Siebert WE, eds. Heidelberg: Springer-Verlag; 2001:209–19.
11. Grobler LJ, Robertson PA, Novotny JE, et al. Decompression for degenerative spondylolisthesis and spinal stenosis at L4–5. The effects of facet joint morphology. Spine 1993;18:1475–80.
12. Hafez MI, Zhou S, Coombs RRH, et al. The effect of irrigation on the peak temperatures in nerve root, dura and intervertebral disc during laser assisted foraminoplasty. Lasers Surg Med 2001;29:1–5.
13. Hides JA, Stokes MJ, Saidae M, et al. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute and subacute low back pain. Spine 1994;19:165–72.
14. Hodges P, Richardson C. Contraction of the abdominal muscles associated with movements of the lower limb. Phys Ther 1997;77:132–144.
15. Hoyland JA, Freemont AJ, Jayson MIV. Intervertebral foramen venous obstruction. A cause of periradicular fibrosis? Spine 1989;14:538–68.
16. Kambin P. Posterolateral percutaneous laser discectomy and decompression. In: Arthroscopic Micro-discectomy, Minimal Intervention in Spinal Surgery. Parviz Kambin, ed. Baltimore, MD: Urban & Schwarzenburg; 1991:67–99.
17. Kambin P, Casey K, O'Brien, et al. Transforaminal arthroscopic foraminal decompression of lateral recess stenosis. J Neurosurg 1996;84:462–7.
18. Kirkaldy-Willis WH. Pathology and pathogenesis of low back pain. Management of Low Back Pain. Kirkaldy-Willis WH, Barnard TJ Jr, eds. Philadelphia, PA: Churchill Livingstone; 1999:82–3.
19. Knight M. Endoscopically determined pain sources in the lumbar spine. In: Lasers in Musculoskeletal Systems. Gerber BE, Knight M, Siebert WE, eds. Berlin: Springer-Verlag; 2001.
20. Knight MTN. An x-ray jig to facilitate the percutaneous posterolateral approach to the lumbar spine. In: Lasers in Musculoskeletal Systems. Gerber BE, Knight M, Siebert WE, eds. Heidelberg: Springer Verlag; 2001: 277–82.
21. Knight MTN. Lumbar foraminal pain sources: an aware state analysis. In: Millenium Laser Book. Zlatko Simunovic, ed. Locerno: Zlatko Simunovic; 2001:233–51.
22. Knight MTN, Ellison DR, Goswami A, et al. Review of safety in endoscopic laser foraminoplasty for the management of back pain. J Clin Laser Med Surg 2001;19:147–57.
23. Knight MTN, Goswami AKD. Aware state endoscopic laser foraminoplasty: a treatment concept, outcome and complications. In: Millenium Laser Book. Zlatko Simunovic, ed. Locerno: Zlatko Simunovic; 2001:253–75.
24. Knight MTN, Goswami A, Patko JT, et al. Endoscopic foraminoplasty: a prospective study on 250 consecutive patients with independent evaluation. J Clin Laser Med Surg 2001;1973–81.
25. Knight MTN, Krishnan A. Spinal surgery. In: Principles and Practice of Sedation. Whitwam JG, McLoy RF, eds. London: Blackwell Science Ltd.; 1998:178–81.
26. Knight MTN, Vajda A, Jakab GV, et al. Endoscopic laser foraminoplasty on the lumbar spine— early experience. Minim Invas Neurosurg 1998;41:5–9.
27. Little DG, MacDonald. The use of percentage change of Oswestry Disability Index score as an outcome measure in lumbar spinal surgery. Spine 1994; 19:2139–43.
28. Mathews HH. Transforaminal endoscopic microdiscectomy. Neurosurg Clin North Am 1996:59–63.
29. Maxwell KM. Spinal endoscopy: clinical indications and outcomes. Presented at: Current Concepts in Spinal Surgery; August 27–28; Williamsburg, Virginia.
30. Mayer HM, Brock M. Percutaneous endoscopic discectomy: surgical technique & preliminary results compared to microsurgical discectomy. J Neurosurg 1993;78:216–25.
31. Moller H, Hedlund. Surgery versus conservative management in adult isthmic spondylolisthesis-a prospective randomized study: part 1. Spine 2000; 25:1711–5.
32. Mooney V. Presidential address: International Society for the Study of the Lumbar Spine, Dallas, 1986. Where is the pain coming from? Spine 1987; 12:754–9.
33. Olmarker K, Myers RR. Pathogenesis of sciatic pain: role of herniated nucleus pulposus and deformation of spinal nerve root and dorsal root ganglion. Pain 1998;78:99–105.
34. Pope MH. Biomechanics of spinal stenosis. In: Lumbar Spinal Stenosis. Gunzburg R, Szpalski M, eds. Philadelphia, PA: Lippincott Williams and Wilkins; 2000:35–42.
35. Richardson C, Jull G, Hodges P, et al. Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain: Scientific Basis and Clinical Approach. Londong: Churchill Livingstone; 1999.
36. Roy PV, Barbaix E, Clarijs JP. Anatomy of lumbar canal, foramen and ligaments, with references to recent insights. In: Lumbar Spinal Stenosis. Gunzburg R, Szpalski M, eds. Philadelphia, PA: Lippincott Williams and Wilkins; 2000:7–26.
37. Saifuddin A, Emanuel R, White J, et al. An analysis of radiating pain at lumbar discography. Eur Spine J 1998;7:358–62.
38. Schneiderman GA, McLain RF, Hambly MF, et al. The pars defect as a pain source: a histologic study. Spine 1995;20:1761–4.
39. Siebert WE. Endoscopic foraminoscopic surgery with laser supplementation. In: Proceedings of the First European Spinal Surgery Forum. Manchester 1996, Abstract No. 26.
40. Shepperd JAN. Percutaneous and minimal intervention spinal fusion. In: Arthroscopic Micro-discectomy, Minimal Intervention in Spinal Surgery. Parviz Kambin, ed. Baltimore, MD; Urban & Schwarzenburg; 1991:127–9.
41. Spitzer WO, Horwitz SM. Selected Nonexperimental Methods: An Orientation in Principles and Practice of Research: Strategies for Surgical Investigators. 2nd ed. New York, NY: Springer Verlag; 1991:104–13.
42. Vanderlinden RG. Subarticular entrapment of the dorsal root ganglion as a cause of sciatic pain. Spine 1984;9:19–22.
43. Wiltse LL, Rothman SLG. Lumbar and lumbosacral spondylolisthesis: classification, diagnosis and natural history. In: The Lumbar Spine. Vol 2. Wiesel SW, Weinstein JN, Herkowitz H, et al, eds. Philadelphia, PA: WB Saunders; 1996:621–54.
44. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: Surgical technique, outcome, and complications in 307 consecutive cases. Spine 2002;27:722–31.
45. Zanoli G, Stromqvist B, Jonsson B. Visual analogue scales for interpretation of back and leg pain intensity in patients operated for degenerative lumbar spine disorders. Spine 2001;26:2375–80.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.