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ORIGINAL

# SPINAL INSTABILITY FOLLOWING SURGERY FOR DEGENERATIVE LUMBAR STENOSIS

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**Background:** Recognition that total laminectomy may perpetuate or cause segmental instability heralded the introduction of less invasive techniques of decompression in lumbar spinal stenosis surgery.

**Aim:** Our aim was to compare formal laminectomy and minimally invasive decompressive procedures in terms of safety and clinical outcome, specifically in respect to the development of postoperative spinal instability.

**Methods:** A retrospective analysis of medical records was performed for 73 patients operated on for lumbar spinal stenosis (22 patients after laminectomy and 51 patients after minimally invasive decompression), with available follow-up data. Basic variables were analyzed in respect to clinical outcome and in regard to development of radiological instability.

**Results:** Radiologic instability was present in 27.3% of patients after laminectomy, as compared to only 2.0% after laminotomy ($p<0.001$). Regression analysis identified presence of preoperative slip ($p=0.0056$) and type of surgery ($p=0.0204$) as sole predictors of instability after surgery. Clinical outcome analysis (laminectomy vs. laminotomy) revealed favorable outcome in both treatment groups, although significantly in favor of the laminotomy group (VAS $p= 0.013$ and RM $p=0.031$). Finally, difference in outcome was affected by whether radiologic instability was present or not ($p=0.04$ and $p=0.09$ for difference in outcome graded by VAS and RM values respectively)

**Conclusion:** Our results suggest that laminctomy was associated with higher incidence of the radiological signs of the postoperative instability when compared to the minimally invasive decompression techniques. That was probably the major cause of unfavorable clinical outcome in the laminectomy group. Furthermore, patients undergoing laminectomy experienced less favorable clinical outcome when compared to those undergoing minimally invasive decompression surgeries.

**Keywords:** lumbar stenosis surgery, instability, clinical outcome

## INTRODUCTION

Until fairly recently total laminectomy was considered the standard method of decompression for lumbar spinal stenosis. Recognition that total laminectomy may perpetuate or cause segmental instability [1, 2] has led to a more conservative approach, preserving lamina and removing only those portions actually accountable for stenosis. More limited decompressive surgical alternatives to laminectomy have been devised to further minimize removal of normal, non-compressing structures and thereby minimize the risk of postoperative instability. Such procedures include unilateral or bilateral hemilaminotomy [3, 4, 5, 6, 7, 8]. Reported results with these techniques have been encouraging, with success rates ranging as high as 90%, but most of these clinical series suffered methodological flaws. Several comparative studies disclosed higher complication rates [9, 10, 11] with these minimally invasive techniques.

The aim of this study was to compare formal laminectomy and minimally invasive decompressive procedures in terms of safety and short-term clinical outcome, specifically in respect to the development of spinal instability following decompression for lumbar stenosis in the short-term.

## CLINICAL MATERIAL AND METHODS

Over a period of one year 85 consecutive patients underwent first-time decompressive surgery (either laminectomy or laminotomy) for degenerative lumbar spinal stenosis at the Clinic of Neurosurgery Clinical Center Tuzla. The decision regarding the type of surgery performed (laminectomy or laminotomy) was left at surgeons discretion. Inclusion criteria were: 1) MRI and/or CT evidence of degenerative lumbar stenosis, defined as follows: spinal canal AP diameter less than 10 mm for absolute and less than 12 mm for relative stenosis and/or lateral recess width less than 3 mm for absolute and less than 5 mm for relative stenosis and/or intervertebral foramen height less that 8 mm; 2) symptoms

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of neurogenic claudication or radiculopathy resistant to at least 12 weeks of conservative treatment and 3) absence of associated pathological entities such as disc herniations, instability or spondylolisthesis graded as Mayerding grade 2 or higher. Patients with prior lumbar surgery or those whose symptoms were primarily related to disc herniation and not due to central canal or lateral gutter stenosis related to spondylosis were excluded. Patients with significant instability, defined as sagittal-plane translation of 5 mm or more documented on flexion–extension radiography [12], were also excluded. Medical records of the remaining 81 eligible patients were reviewed and data regarding preoperative neurological evaluation, preoperative functional status and pain intensity assessed by the Roland-Morris Low Back Pain and Disability Questionnaire (RM) [13] so as Visual Analogue Scale (VAS) [14] were recorded. Each patient had preoperative plain anteroposterior and lateral lumbar spine films, MRI and /or CT scans and flexion-extension radiographs. Radiological parameters deemed significant and considered as potential predictors of postoperative instability were: 1) presence of grade I spondylolisthesis (patients with higher grade slip were excluded from the study) 2) facet angles measured as specified by Naderi [15]; 3) presence of traction spurs and 4) preoperative lumbar lordosis angle. Surgeries were performed by several authors in a highly standardized fashion. Postoperative functional status and pain reduction were evaluated by reductions in RM and VAS values, respectively, a 6 and 12-month follow-up visits (only 12-month follow-up data were included as an ultimate outcome measure). Medical records were reviewed in regard to 6-month and 12-month follow-up VAS and RM values and 8 patients lost to follow-up were excluded from the study, leaving 73 patients with complete follow-up data that constituted two separate study groups: group 1 encompassed 22 patients after laminectomy and group 2 encompassed 51 patients after unilateral or bilateral laminotomy. Bilateral laminotomy as described by Tsai [4] was performed in 23 patients and unilateral laminotomy for bilateral decompression as described by Mariconda [7] and Polleti [8] was performed in remaining 28 patients. Postoperative plain and flexion-extension films were evaluated for 1) postoperative progression of spondylolisthesis defined as a 2-mm or more increase in slippage and 2) radiological signs of instability as defined by White and Panjabi [12]. Unpaired Student t-test, Mann–Whitney rank-sum test, chi square test, and Fisher exact test were used as applicable to analyze differences in the preoperative clinical and demographic characteristics, in the intraoperative variables and in clinical outcome variables between groups (VAS, RM). The paired Student t-test and Wilcoxon signed-rank test were used to analyze changes over time within each group. Logistic regression analysis was used to determine relative effect of potential prognostic factors on develoment of instability.

## RESULTS

Our study sample encompassed 73 patients, (37 male and 36 female patients, respectively), with the mean age of 55,8 years (SD 8,9 years). The vast majority (80,9%) of our study population presented with neurogenic claudications, with the mean duration of symptoms of 31 months (SD 43,1). Approximately one fifth of patients (16 patients or 21, 9%) presented with motor deficit, most commonly graded as mild (10 patients). In half of those patients presenting with motor weakness dorsal foot flexion was primarily affected (8 patients). In 15,1% of patients urinary retention/incontinence was present upon presentation. Over half of our patients (50,7%) presented with negative or terminally positive SLR (straight leg raising test).

Basic demographic and clinical parameters in respect to the type of surgery (laminectomy or laminotomy) are depicted in table1.

Even though there is a marked difference between laminectomy and laminotomy groups in terms of preoperative motor deficit (45,5 % vs. 11,3% for laminectomy and laminotomy groups respectively) it should be noted that in most patients muscle weakness was graded as mild as assessed by Medical research council scale (4+/5).

**Table 1.** Basic preoperative demographic and clinical characteristics for patients undergoing laminectomy (group 1) or laminotomy (group 2)

| Parameter | Group 1- Laminectomy | Group 2- Laminotomy | p |
|---|---|---|---|
| Age (average, years) | 55,82±14,9 | 55,68±4,69 | NS |
| Male gender | 59,1% | 47,05% | NS |
| BMI | 25,06 (3,17) | 26,5 (3,65) | NS |
| Smoker | 34,2% | 30,1% | NS |
| Diabetes | 9,1% | 5,9 % | NS |
| Duration of symptoms (mo) | 28,36 | 33,47 | NS |
| Presenting with claudication | 77,3% | 82,4% | NS |
| Urinary retention/incontinence | 22,7% | 11,8% | NS |
| Muscle weakness | 45,5 % | 11,3% | 0,001 |
| SLR test negative | 59,1% | 35,3% | NS |
| VAS prior to surgery | 63,64 (19,6) | 58,43 (18,1) | NS |
| RM prior to surgery | 11,59 (4,67) | 12,24 (3,03) | NS |

Patients were usually operated after an advanced disease was verified by neuroradiological studies (78, 1% of patients presented with severe stenosis, as assessed by CT and/or MRI scan) and only 9,6% of patients presented with mild (Mayerding grade I) spondylolisthesis. Differences between patients undergoing laminectomy or laminotomy in regard to radiographic parameters are depicted in table 2.

Almost one third of our patients had more than 1 level addressed surgically (28,8 %), while multiple level surgeries were significantly more common among patients undergoing laminectomy (table 3).

Radiological instability defined as either 1) postoperative progression of spondylolisthesis defined as a 2-mm or more increase in spondylolisthetic slip and 2) radiological signs of instability as defined by White and Panjabi [12] was present in 7 patients (6 of those patients were in the laminectomy group).

Regression analysis was applied in order to identify factors affecting development of postoperative radiological instability. Following factors were evaluated as probable predictors: number of previous surgeries, number of levels surgically addressed, type of surgery (laminectomy vs. laminotomy), presence of preoperative type I slip, facet angles, preoperative lumbar lordosis value, presence of traction spurs and preoperative sagittal plane displacement. After removing independent variables with a regression coefficient that is not significantly different from 0 (P>0.05), only two variables remained in the model, as depicted in table 4.

Since type of surgery was one of two variables affecting development of postoperative instability, further analysis relating postoperative instability to the type of surgery was performed, as depicted in table 5, revealing that 6 patients (27,3%) experienced postoperative instability after laminectomy, as compared to only one patient (2,0%) after laminotomy.

Outcome in terms of pain and functional capabilities was assessed by analyzing reduction in VAS and RM values, respectively, 6 months and one year postoperatively (as compared to preoperative values). Mean reduction (irrespective of the treatment modality) in VAS value was 40,68 (SD 23,82) and mean reduction on RM scale was 9,19 (SD 4,2). Further subgroup analysis (laminectomy vs. laminotomy) revealed favorable outcome in both treatment groups, although significantly in favor of the laminotomy group (table 6).

**Table 2.** Basic preoperative radiographic features for patients undergoing laminectomy (group 1) or laminotomy (group 2)

| **Parameter** | **Group 1- Laminectomy** | **Group 2- Laminotomy** | **p** |
|---|---|---|---|
| Stenosis type | | | |
| Central | 95,5 % | 58,8% | |
| Lateral recess | 0,0% | 11,8% | 0,021 |
| Combined | 4,5% | 29,4% | |
| Stenosis severity | | | |
| Relative | 18,2% | 23,5% | NS |
| Absolute | 81,8% | 76,5% | |
| Preoperative spondylolisthesis | 18,2% | 5,9 % | NS |
| Mean sagital plane displacement | 0,155 | 0,135 | NS |
| Preoperative lumbar lordosis (º) | 35,45 (9,6) | 36,82(14,34) | NS |
| Facet angle (º) | | | |
| L5/S1 | 42 | 41 | |
| L4/L5 | 46,45 | 52,47 | NS |
| L3/L4 | 62 | 59 | |

**Table 3.** Multiple level surgeries

| Number of levels decompressed | Group 1- Laminectomy | Group 2- Laminotomy | p |
|---|---|---|---|
| One level | 45,5% | 82,4% | 0,001 |
| Multiple levels | 54,5% | 17,6% | |

**Table 4.** Factors affecting postoperative development of instability

| **Factor** | **Coefficient** | **Std err** | **p** |
|---|---|---|---|
| Preoperative slip | 3,4725 | 1,2528 | **0,0056** |
| Type of surgery | 3,0522 | 1,3160 | **0,0204** |

**Table 5.** Radiological instability in respect to type of surgery

| Group Parameter | Laminectomy | | | Laminotomy | | | Diff p** value |
|---|---|---|---|---|---|---|---|
| | Baseline | 1-year | P* | Baseline | 1-year | P* | |
| VAS | 63,6 (19,6) | 36,3(23,8) | <0,05 | 58,4 (18,1) | 13,9(12,5) | <0,05 | 0,013 |
| RM | 11,5(4,67) | 5,9(5,6) | <0,05 | 12,24(3,1) | 3,2(2,2) | <0,05 | 0,031 |
| PSI | | 83,5(9,7) | | | 91,5 (10,2) | | 0,083 |

**Table 6.** Clinical course in regard to the type of surgery

| **Group Parameter** | **Laminectomy** | | | **Laminotomy** | | | **Diff p** value** |
|---|---|---|---|---|---|---|---|
| | Baseline | 1-year | P* | Baseline | 1-year | P* | |
| VAS | 63,6 (19,6) | 36,3(23,8) | <0,05 | 58,4 (18,1) | 13,9(12,5) | <0,05 | 0,013 |
| RM | 11,5(4,67) | 5,9(5,6) | <0,05 | 12,24(3,1) | 3,2(2,2) | <0,05 | 0,031 |
| PSI | | 83,5(9,7) | | | 91,5 (10,2) | | 0,083 |

All values are illustrated as means (Standard deviation within brackets), but nonparametric tests were used for statistical analyses. The significance of the difference between baseline and one year follow-up within each group was calculated with the Wilcoxon Signed Rank test.*
The difference between groups after one year was analyzed with the Mann Whitney U Test**

As evident from figure 1 (that pertains to the temporal profile of clinical changes over a 1-year period) outcome after 6 months was quite similar to a 1-year results (mean VAS values after 6 months were 34,09 and 12,75 for laminectomy and laminotomy groups, respectively, while mean RM values were 6,1 and 2,9 points for laminectomy and laminotomy groups, respectively)

Adjacent segment disease requiring surgery developed in 2 patients (one in laminectomy one in laminotomy groups) during the follow-up period. Table 7 correlates clinical outcome to radiological instability.

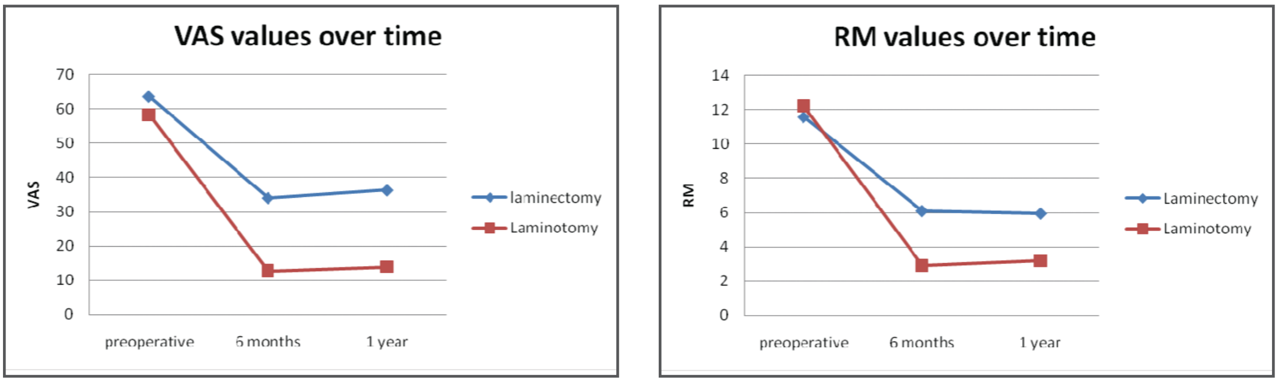


**Figure 1.** Temporal profile of clinical changes as assessed by VAS and RM

**Table 7.** Clinical course in respect to radiological instability

| **Group Parameter** | **Instability (7 patients)** | | | **No instability(66 patients)** | | | **Diff p** value** |
|---|---|---|---|---|---|---|---|
| | Baseline | 1-year | P* | Baseline | 1-year | P* | |
| VAS | 67,1 (22,8) | 58,5(25,4) | NS | 59,2 (18,1) | 16,6 (13,8) | <0,001 | **0,004** |
| RM | 11,5(5,6) | 10,3(6,8) | NS | 12,8 (3,4) | 3,3 (2,5) | <0,001 | **0,009** |

All values are illustrated as means (Standard deviation within brackets), but nonparametric tests were used for statistical analyses. The significance of the difference between baseline and one year follow-up within each group was calculated with the Wilcoxon Signed Rank test.*
The difference between groups after one year was analyzed with the Mann Whitney U Test**

Of those 7 patients experiencing postoperative instability 3 were subjected to subsequent transpedicular instrumented stabilization/fusion surgery (all three from the laminectomy group), another two patients were offered surgery (that was declined), while remaining two patients (including the one from laminotomy group) were referred for further conservative treatment, due to relatively minor pain intensity.

**DISCUSSION**

Since a recent landmark randomized controlled study (Sport) conducted by Weinstein et al. [16] unequivocally proved a superiority of surgery for lumbar spinal stenosis over conservative treatment and concluded a debate on the matter, another controversy regarding surgery for spinal stenosis emerged; the one pertaining to the extent of resection. For decades a decompressive laminectomy has been considered a standard of care for surgical treatment of spinal stenosis patients [17, 18, 19], but recently its effectiveness has been brought into the question, with meta-analysis revealing 64% success rates [20]. In a retrospective review of 88 patients undergoing laminectomy for spinal stenosis, Katz and associates found that the long-term outcome was generally less favorable than had been previously reported [19]. In particular, spinal instability has been implicated as a cause of surgical failures [21, 22], because wide posterior decompression significantly alters spinal anatomy and biomechanics thus prompting many spine surgeons to perform fusion procedures to treat lumbar stenosis. Given the additional blood loss and fusion- related risk instrumentation augmented fusion use as an adjunct in patients with lumbar stenosis without deformity remains controversial. Instead of combining fusion with decompression and maximizing surgery associated perioperative risks, other investigators have attempted to decrease the operative failure rate by minimizing the invasiveness of the decompressive procedure. To spare the dorsal midline structures completely, in contrast to laminectomy techniques, fenestration or laminotomy have also been propagated [3, 4, 5, 6, 7, 8]. Our aim was to compare formal laminectomy and minimally invasive decompressive procedures in terms of safety and clinical outcome, specifically in respect to the development of spinal instability following decompression for lumbar stenosis.

We reviewed the records of 73 patients that were operated on lumbar spinal stenosis either by laminectomy (22 patients) or laminotomy (51 patients) whose follow-up records at 6 months and one year were available. Study groups (laminectomy vs. laminotomy) were relatively homogenous in terms of basic demographic parameters (age, gender, comorbidities, type and duration of complaints) and significant differences were noted only in respect to proportion of patients with motor deficit (45,5% and 11,3% for the laminectomy and laminotomy group, respectively). We recruited somewhat younger population as compared to similar studies [3, 10, 23]. The vast majority of our patients presented with severe central (78,1% of patients) or combined stenosis (only 20,5% of patients presented with predominantly lateral recess stenosis, mostly in the laminotomy group). Two patient groups (laminectomy vs. laminotomy) did not differ significantly in respect to major radiological parameters, assessed as potential outcome predictors (preoperative spondylolisthesis, mean sagital plane displacement, preoperative lumbar lordosis, facet angles). Somewhat higher incidence of preoperative grade I spondylolisthesis was noted among laminectomy patients (18,2% vs. 5,9 %) but did not reach statistical significance.

Multi-level surgeries were significantly more common in the laminectomy group (p<0,001). Event though the type of surgery performed was left at surgeon's discression multiple level laminectomies were generally avoided if (Mayerding grade I) preoperative spondylolystetic slip was present since such patients are usually managed with concomitant spinal instrumentation/fusion procedures. Patients with more pronounced spondylolystetic slips (Myerding grade II and higher) were inherently not eligible and thus were not included in the study.

Even though definition of spinal instability is still a matter of debate [24, 25] we defined radiological spinal instability as either 1) de-novo appearance or progression of previously verified spondylolisthetic slip or as 2) an abnormal motion on flexion-extension films, as defined by White and Panjabi [12]. Seven patient in our series developed instability, defined by radiological criteria. Logistic regression model was applied in order to identify factors affecting development of postoperative radiological instability. Out of 7 preoperative factors evaluated as potential predictors of postoperative instability only two were retained in the model after step-wise regression analysis: presence of preoperative slip and type of surgery. A review of both clinical and radiological features of the 124 patients performed by Fox et al. [21] found that the single most important predictor for postoperative radiological instability after decompressive surgery for degenerative lumbar spinal stenosis was the presence of anterior spondylolisthesis preoperatively. In the aforementioned study, 73% of patients with preoperative anterior spondylolisthesis experienced progression after surgery compared to 31% of patients without preoperative slippage who developed spondylolisthesis postoperatively (patients with fusions were excluded). The degree of preoperative spondylolisthesis did not correlate with the tendency or amount of postoperative slippage. Unlike our study, other investigators have implicated an extensive array of factors in the development of postoperative instability: patient's sex [26], the presence of a minimally degenerated L-4 disc or a markedly narrowed L-3 disc especially in the presence of minimal anterior column osteophytes [27, 28] and lateral lumbar curvature. One of the most common factors often cited in respect to postoperative instability after laminectomy is facet joint orientation (namely facet joint angle). Although L4/L5 facet joints were more sagitally inclined in patients that subsequently developed instability (mean angles 49,92 degrees in patients without instability and 57,57 degrees in patients who subsequently developed instability) the difference among groups did not reach statistical significance.

Instability was a relatively common occurrence, particularly in the laminectomy group (out of 7 patients with postoperative instability 6 were recruited from the laminectomy group). Thus, 27,2% of patients developed radiological signs of instability after laminectomy as compared to only 2% after laminotomy. Our findings are supported by early series encompassing solely patients after laminectomy; Fox et al. [21] reported that anterior progressive postoperative subluxation occurred in 32 of 60 patients with preoperative spondylolisthesis. In their series 20 of 64 patients without preoperative anterior subluxation developed anterior slippage postoperatively (mean 7.8 mm, range 2–20 mm). In a more recent study comparing laminectomy vs. minimally invasive decompression Thome et al. [23] disclosed that 5 out of 120 patients required stabilization/fusion surgery after decompression for lumbar spinal stenosis, but authors did not provide data on the type of surgery performed on those 5 patients.

Since radiologically defined instability had been previously shown to poorly correlate with clinical outcome, we proceeded with the outcome analysis. Primary outcome measures were reduction in preoperative VAS score and RM scores and postoperative PSI (patient satisfaction index) values. We showed that, in spite of significant reduction in both VAS and RM values in both treatment groups, outcome was more favorable for the laminotomy group (p=0,013 and p=0,031 for differences in outcome as graded by VAS and RM, respectively). Overall patient satisfaction as assessed by PSI was also higher in the laminotomy group (91,50 vs. 83,57 for the laminotomy and laminectomy groups, respectively), but the difference did not reach statistical significance. Until recently most of clinical series on this issue included small patient populations, recruited an inhomogeneous population, were retrospective, or lacked a control group. In the few comparative studies investigators did not find a significant benefit associated with a less invasive technique compared with laminectomy [9, 11, 29] but reported a higher incidence of perioperative (neurological) complications. In 2005. results of the controlled, randomized trial comparing clinical outcome after laminectomy versus minimally invasive decompressive procedures were published. Authors conclude that the adequate decompression was achieved in all patients, irrespective of the type of surgery. The overall complication rate was lowest in patients who had undergone bilateral laminotomy. After a minimum follow up of 12 months (for 94% of patients) residual pain was lowest in bilateral laminotomy group. The Roland–Morris Scale and SF-36 score results demonstrated marked improvement, most pronounced in bilateral laminotomy group. The number of repeated operations did not differ among groups. Authors concluded that in most outcome parameters, bilateral laminotomy was associated with a significant benefit and thus constitutes a promising treatment alternative to formal laminectomy. Our results adhered to figures presented by Thome et al. when it comes to temporal profile of clinical outcome changes as well (figure 1); namely adequate clinical outcome had been achieved as early as 6 months postoperatively and those remarkable results had been sustained by 1-year follow up.

Finally, we have shown that radiological instability translated to poor clinical outcome; both VAS and RM values at 1-year follow-up were diminished in patients exhibiting radiological signs of instability (difference in outcome among groups-p=0,004 for VAS and 0,009 for RM scores, respectively).

Several potential limitations of the study require further elaboration. Among them, the relatively short follow-up period and retrospective nature of the study are by far the most significant. One might argue that a 12-month follow-up period precludes conclusions regarding long-term outcome. Nevertheless, Thome et al. [23], in their landmark study (the only randomized prospective trial comparing laminectomy and minimally invasive decompression techniques to date) state that a 12 month follow-up period was used. The argument regarding a follow-up period is somewhat more relevant in respect to the radiological outcome, as stated by Fox [21]. Another, perhaps not as striking limitation of the study is the fact that laminectomy was more frequently performed among patients with pronounced muscle weakness. With these limitations in mind we believe that prospective, randomized controlled trials will need to be performed to determine more adequately the unequivocal indications for lumbar fusion in patients undergoing decompression for lumbar spinal stenosis and we plan to undertake such a study ourselves.

## CONCLUSION

Our results suggest that laminectomy is associated with higher incidence of postoperative instability as defined by radiologic criteria (almost 30%), when compared to minimally invasive decompression techniques (around 2%). The single most important factor contributing to the development of postoperative radiographic instability is preoperative spondylolisthetic slip. Furthermore, radiological instability translates to worse clinical outcome (patients with postoperative instability fare worse postoperatively than those without instability). Finally, patients undergoing laminectomy experience less favorable clinical outcome when compared to those undergoing minimally invasive decompression surgeries.

## LITERATURE

1. Herkowitz HN, Kurz LT. Degenerative lumbar spondylolisthesis with spinal stenosis. A prospective study comparing decompression with decompression and intertransverse process arthrodesis. J Bone Joint Surg Am.1991; 73:802–8.
2. Hopp E, Tsou PM. Postdecompression lumbar instability. Clin Orthop Relat Res. 1988. 227:143–51.
3. Aryanpur J, Ducker T. Multilevel lumbar laminotomies: an alternative to laminectomy in the treatment of lumbar stenosis. Neurosurgery. 1990; 26:429–33.
4. Tsai RY, Yang RS, Bray RS Jr. Microscopic laminotomies for degenerative lumbar spinal stenosis. J Spinal Disord. 1998; 11: 389–94.

5. Young S,Veerapen R, O'Laoire SA. Relief of lumbar canal stenosis using multilevel subarticular fenestrations as an alternative to wide laminectomy: preliminary report. Neurosurgery. 1988; 23:628–33.
6. Guiot BH, Khoo LT, Fessler RG. A minimally invasive technique for decompression of the lumbar spine. Spine. 2000; 227: 432–38.
7. Mariconda M, Fava R, Gatto A, Longo C, Milano C. Unilateral laminectomy for bilateral decompression of lumbar spinal stenosis: a prospective comparative study with conservativelytreated patients. J Spinal Disord Tech. 2002;15:39–46.
8. Poletti CE. Central lumbar stenosis caused by ligamentum flavum: unilateral laminotomy for bilateral ligamentectomy: preliminary report of two cases. Neurosurgery. 1995; 37:343–7.
9. Delank KS, Eysel P, Zollner J, Drees P, Nafe B, Rompe JD. Undercutting decompression versus laminectomy. Clinical and radiological results of a prospective controlled trial. Orthopade. 2002 ; 31:1048–57.
10. Postacchini F, Cinotti G, Perugia D, Gumina S. The surgical treatment of central lumbar stenosis. Multiple laminotomy compared with total laminectomy. J Bone Joint Surg. 1993; 75: 386–92.
11. Thomas NW, Rea GL, Pikul BK, Mervis LJ, Irsik R, McGregor JM. Quantitative outcome and radiographic comparisons between laminectomy and laminotomy in the treatment of acquired lumbar stenosis. Neurosurgery. 1997; 41:567–75.
12. White AA, Panjabi MM. Clinical Biomechanics of the Spine, ed 2. Philadelphia: JB Lippincott. 1990.
13. Wewers ME. & Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Research in Nursing and Health. 1990; 13, 227-36.
14. Roland MO, Morris RW. A study of the natural history of back pain. Part 1: Development of a reliable and sensitive measure of disability in low back pain. Spine 1983; 8: 141-144.
15. Naderi S,Ekinci G,Bayri Y. The role of facet joint angle in degenerative lumbosacral disorders.Neuroorthopedics. 1999; 26:49–54.
16. Weinstein JN, Tosteson TD, Lurie JD. Surgical versus nonsurgoical therapy for lumbar spinal stenosis. N Eng J Med. 2008; 358:794-810.
17. Atlas SJ, Deyo RA, Keller RB, Chapin AM, Patrick DL, Long JM, et al. The Maine Lumbar Spine Study, Part III. 1-year outcomes of surgical and nonsurgical management of lumbar spinal stenosis. Spine ; 2002; 21:1787–95.
18. Iguchi T, Kurihara A, Nakayama J, Sato K, Kurosaka M, Yamasaki K. Minimum 10-year outcome of decompressive laminectomy for degenerative lumbar spinal stenosis..Spine; 25:1754–9.
19. Katz J, Lipson S, Larson M. The outcome of decompressive laminectomy for degenerative lumbar stenosis. J Bone Joint Surg 1991;73-A:809-16
20. Turner JA, Ersek M, Herron L, Deyo R. Surgery for lumbar spinal stenosis. Attempted meta-analysis of the literature. Spine. 1992; 17:1–8.
21. Fox MW, Onofrio BM, Hanssen AD. Clinical outcomes and radiological instability following decompressive lumbar laminectomy for degenerative spinal stenosis: a comparison of patients undergoing concomitant arthrodesis versus decompression alone. J Neurosurg. 1996; 85:793–802.
22. Johnsson KE, Willner S, Johnsson K. Postoperative instability after decompression for lumbar spinal stenosis. Spine 1986; 11: 107–10.
23. Thome C, Zevgardidis D, Leheta O, Bazner H, Pockler-Sshoninger C, Wohrle J et al. Outcome after less-invasive decompression of lumbar spinal stenosis: a randomized comparison of unilateral laminotomy, bilateral laminotomy, and laminectomy. J Neurosurg: Spine. 2005; 3:129–41.
24. Yone K, Sakou T. Usefulness of Posner's definition of spinal instability for selection of surgical treatment for lumbar spinal stenosis. J Spinal Disord. 1999; 12:40–4.
25. Tuite GF, Doran SE, Stern JD, McGillicuddy JE, Papadopoulos SM, Lundquist CA, et al. Outcome after laminectomy for lumbar spinal stenosis. Part II: Radiographic changes and clinical correlations. J Neurosurg. 1994; 81:707–15.
26. Harrison MJ, Sundaresan N. Spinal instrumentation for degenerative disease of the lumbar spine. Mt Sinai J Med .1991; 58: 169–76.
27. Lombardi JS, Wiltse LL, Reynolds J. Treatment of degenerative spondylolisthesis. Spine. 1985; 10:821–7.
28. Garfin SR, Glover M, Booth RE. Laminectomy: a review of the Pennsylvania Hospital experience. J Spinal Disord. 1988; 1: 116–33.
29. Khoo LT, Fessler RG. Microendoscopic decompressive laminotomy for the treatment of lumbar stenosis. Neurosurgery. 2006;.51 (Suppl 5):146–54.