

Surgical treatment of degenerative lumbar spinal stenosis

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Abstract

Degenerative lumbar spinal stenosis is the most common indication for lumbar spine surgery in adults over the age of 65. Although some studies have claimed improvement with conservative treatment, several comparative studies have shown better outcomes for surgical treatment for patients with moderate to severe stenosis. As the life expectancy of the elderly population increases, and by virtue of modern neuro-imaging, physicians and particularly neurosurgeons are being increasingly confronted with older patients suffering from disabling lumbar spinal stenosis. Many of these patients become candidates for corrective surgical procedures, because, despite advanced age, surgical decompression may lead to significant pain relief and improve the individual's quality of life. Traditionally, the surgical treatment of acquired lumbar stenosis has been wide laminectomy, which allows decompression of the neural structures by unroofing the spinal canal. The success rate of the procedure, however, is only 64%.

The frequent surgical failures have been attributed to local tissue trauma, and to postoperative spinal instability, which has led to a dramatic increase in lumbar fusion surgery. Increasing knowledge of the pathoanatomy, coupled with high-resolution imaging, has allowed a precise localization of nerve compression, which usually occurs at the level of the intervertebral space and the bulging yellow ligaments. Various authors have proposed more tailored and less invasive techniques in the treatment of acquired lumbar stenosis. In this review, five recent published papers regarding the management of lumbar spinal stenosis are presented and analyzed.

This review tries to present to the readers the current surgical treatment options and trends, analyzing their features, their outcomes, and highlighting their impact on patients suffering lumbar spinal stenosis, who are generally adults over the age of 65 years with associated comorbidities.

(1) TRENDS, MAJOR MEDICAL COMPLICATIONS, AND CHARGES ASSOCIATED WITH SURGERY FOR LUMBAR SPINAL STENOSIS IN OLDER ADULTS (JAMA. 2010 Apr 7; 303(13):1259-65)

Information

In recent decades, the fastest growth in lumbar surgery has occurred in older patients with spinal stenosis. Trials indicate that for selected patients, decompressive surgery offers an advantage over nonoperative treatment, but surgeons often recommend more invasive fusion procedures. Individual surgeon preferences may outweigh patient and disease characteristics in choosing procedures. Such choices are important because greater invasiveness is associated with greater complications, greater use of health care resources, and higher mortality but generally similar clinical benefit. Comorbidity is common in

older patients, so benefits and risks must be carefully weighed in the choice of surgical procedure. The assessment of therapeutic safety often requires observational data, because randomized trials may exclude high-risk patients, be too short to identify some risks, or be too small to detect rare events. The authors of this paper examine the trends in the use of different types of stenosis surgery techniques and the association of complications and resource use with surgical complexity. They design a retrospective cohort analysis of Medicare claims for 2002-2007, focusing on 2007 to assess complications and resource use in US hospitals. Operations for Medicare recipients (adults ≥ 65 years, who receive federal health insurance coverage) undergoing surgery for lumbar stenosis ($n=32,152$ in the first 11 months of 2007) were grouped into 3 gradations of invasiveness: decompression alone, simple fusion (1 or 2 disk levels, single surgical approach), or complex fusion (more than 2 disk levels or combined anterior and posterior approach).

The main outcome measures that the authors assessed in those three groups were the rate of major complications (major medical complications and wound complications), postoperative mortality (within 30 days of hospital discharge, including in-hospital death), and resource use (in terms of length of hospital stay, hospital charges, and rehospitalizations within 30 days). The authors report that surgical rates declined slightly from 2002-2007, but the rate of complex fusion procedures increased 15-fold, from 1.3 to 19.9 per 100,000 beneficiaries. Lifethreatening complications increased with increasing surgical invasiveness, from 2.3% among patients having decompression alone to 5.6% among those having complex fusions. After adjustment for age, comorbidity (using the comorbidity index of Quan), previous spine surgery, and other features, the odds ratio (OR) of life-threatening complications for complex fusion compared with decompression alone was 2.95 (95% confidence interval [CI], 2.50-3.49). A similar pattern was observed for rehospitalization within 30 days, which occurred for 7.8% of patients undergoing decompression and 13.0% having a complex fusion (adjusted OR, 1.94; 95% CI, 1.74-2.17). Adjusted mean hospital charges for complex fusion procedures were US \$80,888 compared with US \$23,724 for decompression alone.

The authors conclude that, between 2002 and 2007, the frequency of complex fusion procedures for spinal stenosis increased while the frequency of decompression surgery and simple fusions decreased. In 2007, compared with decompression, simple fusion and complex fusion were associated with increased risk of major complications and of 30-day mortality, and increased resource use. The authors comment that it is unclear why more complex operations are increasing. Moreover, they view as implausible the notion that the number of patients with the most complex spinal pathology has increased 15-fold in just 6 years. Evidence for greater efficacy of more complex procedures for lumbar stenosis is lacking, and their study shows the clinically important consequences of these choices.

Analysis

Among spine surgeons, there is a poor consensus on indications for surgery or the choice of particular procedures to treat lumbar spine stenosis. Evidence for greater efficacy of more complex procedures for lumbar stenosis is lacking. For patients who also have spondylolisthesis or scoliosis, spinal fusion may improve

outcomes over decompression alone, but in the absence of these two conditions, trials suggest an equivalent efficacy for decompression alone vs decompression and fusion. In spite of these data, the authors confirm that the frequency of complex fusion procedures for spinal stenosis is increasing, while the frequency of decompression surgery is progressively decreasing. This interesting study confirms previous findings that fusion is associated with greater complications and postoperative mortality than decompression alone. We agree with the authors that decompression surgery without fusion is the best choice for patients with lumbar spine stenosis, even leaving aside economic and efficiency data.

(2) OUTCOME AFTER LESS INVASIVE DECOMPRESSION OF LUMBAR SPINAL STENOSIS: A RANDOMIZED COMPARISON OF UNILATERAL LAMINOTOMY, BILATERAL LAMINOTOMY, AND LAMINECTOMY (J NEUROSURG SPINE 2005 AUG;3 (2): 129-41)

Information

Recently, limited decompression procedures have been proposed in the treatment of lumbar stenosis. The authors undertook a prospective study to compare the safety and outcome of unilateral and bilateral laminotomy with laminectomy. One hundred and twenty consecutive patients (mean age 68 ± 9 years) with 207 levels of lumbar stenosis were randomized to three treatment groups: bilateral laminotomy, unilateral laminotomy, and laminectomy. The patients recruited to the study had symptoms of neurogenic claudication or radiculopathy refractory to conservative treatment and associated to radiological evidence of degenerative lumbar stenosis in absence of pathological entities such as disc herniations or instability, and no history of surgery for lumbar stenosis or lumbar fusion. Preoperatively, all patients underwent a standardized neurological and clinical assessment to evaluate walking distance, and pain was measured separately for the low back and the legs according to the VAS scale. Disability was assessed using the RMS scale. Physical and mental health status was measured using the SF-36 health survey. Possible depressive symptoms, known to influence outcome following spinal surgery, were assessed using the ADS scale. Radiological studies included MR imaging, myelography, and postmyelography CT scanning for identification of the involved segments. In the majority of patients the authors observed multisegmental stenosis, which required decompression of 207 levels overall (mean $1,7 \pm 0,7$ per patient). The L3-4 and the L4-5 levels were most commonly involved (in 40.1% and 45.9% of cases, respectively).

Before randomization of the recruited patients (forty patients randomized for each group), all of them underwent surgery, each surgical technique being performed in a standardized manner. Special care was taken in all three groups to minimize facet joint resection. Postoperative CT scans were acquired in all patients before discharge to evaluate the adequacy of the decompression. Standardized self-assessment questionnaires were used at follow-up examinations 3, 6, and 12 months after surgery. VAS score, walking distance, RMS scores, and subjective overall success rate were recorded.

The SF-36 was used for assessment at the 12-month follow-up examination. To evaluate outcomes of low-back pain and leg pain separately and to differentiate

between resting conditions and walking, improvement of these parameters was analyzed on a self-assessment five-point scale. To evaluate patient satisfaction with the postoperative result, the authors used the PSI scale. Patients presenting with significant residual or recurrent symptoms underwent postoperative MR imaging and flexion–extension radiography. In cases of instability, residual or adjacent-level stenosis, or lumbar facet syndrome, surgical intervention was performed and documented. Statistical analysis to compare differences in the preoperative clinical and demographic characteristics, intraoperative and clinical outcome variables between the three groups of treatment were performed with the Student's t test, Mann–Whitney rank-sum test, chisquare test, and Fisher exact test. The paired Student t-test and Wilcoxon signed-rank test were used to analyze changes over time within each group. Based on the VAS preoperative overall pain was $7,5 \pm 2,3$.

The patients suffered from neurogenic claudication for a mean of $20,2 \pm 29,7$ months, and walking distance was reduced to 250 ± 370 m. The overall RMS disability score was 17 ± 4.3 . There were no significant intergroup differences in the preoperative characteristics. Cases of severe stenosis were evenly distributed among groups. Spinal canal decompression was adequately achieved in all cases, according to the surgeon. With regard to surgery-induced morbidity, unintended durotomy occurred on all surgically treated levels. The laminectomy group had the highest rate of unintended durotomy, but no subsequent postoperative CSF fistula was observed. An epidural hematoma requiring reoperation was documented on MR imaging in two patients of the unilateral laminotomy group, and two patients of the laminectomy group presented postoperative urinary retention. No patient in group 1 (bilateral laminotomy), three patients in group 2 (unilateral laminotomy), and two patients in group 3 (laminectomy) experienced symptomatic complications. Overall, the perioperative morbidity rate, including the incidental durotomies, was lower in group 1 (5.0%) than in group 3 (22.5%) and group 2 (17.5%). Surgical decompression resulted in a dramatic reduction of overall pain in all three groups ($p < 0.001$). Compared with that observed in Group 1, however, significantly more residual pain was documented in Groups 2 and 3— 3.6 ± 2.7 (Group 2) and 4 ± 1 (Group 3) compared with 2.3 ± 2.4 (Group 1) at the 12-month follow-up evaluation ($p , 0.05$).

Differentiating between low-back pain and leg pain during resting conditions and walking revealed that superior pain relief occurred in Group 1 patients, particularly during walking and especially in the legs. The most prominent symptom of lumbar stenosis, neurogenic claudication improved in 92% of patients in Group 1 compared with 74 and 68% in Groups 2 and 3 ($p , 0.05$), respectively. Walking distance varied greatly among individual patients, but overall ambulation recovered rapidly after decompression and remained stable during the follow-up period. There was no significant difference among groups compared with preoperative distances at 12 months in Groups 1, 2, and 3, respectively. The same was true for the RM scale; postoperative scores presented no statistically significant difference among groups but there was a marked difference ($p < 0.001$) compared with preoperative scores. Comparison of pre- and postoperative SF-36 scores demonstrated a marked and significant improvement, particularly of the physical component but also of most mental subscales, in all three groups. Again, scores were highest in Group 1 patients, with the most pronounced and significant benefit in the bodily pain subscale compared with Groups 2 and 3. Overall patient satisfaction scores were

significantly superior after bilateral laminotomy. Overall 2.7%, 25.6%, and 26.5% of patients of Groups 1, 2, and 3, respectively, were unsatisfied after 12 months ($p < 0.01$).

This difference remained stable within the first postoperative year and is also reflected by a self-reported success rate of approximately 80% in Group 1 compared with approximately 65% in Groups 2 and 3. In general, patients were more satisfied with the reduced pain levels than with the improvement in everyday activities. Postoperative CT scanning demonstrated adequate decompression in all patients, and in no patient was reoperation for residual or recurrent spinal stenosis at the same segment(s) required within 12 to 18 months. Adjacent level stenosis requiring decompression occurred in one Group 3 patient. Facet joint denervation was successfully performed in two patients who presented with lumbar facet syndrome. In five patients (three in Group 3 and two in Group 2), postoperative instability developed requiring instrumentation assisted fusion. Overall, the reoperation rate did not differ among groups.

Analysis

The authors of this paper present the results of the first randomized prospective study to compare the safety and outcome of uni- and bilateral laminotomy compared with laminectomy in 120 patients with lumbar spinal stenosis. All three procedures yielded highly significant improvement in symptoms and scores; however, significantly superior outcome was demonstrated after bilateral laminotomy.

The other two surgical procedures yielded comparable results. In our opinion, this study has been carefully performed and analyzed, and it demonstrates that bilateral and unilateral laminotomy allow adequate and safe decompression of the spinal canal in patients with lumbar stenosis. These limited decompression procedures result in a highly significant reduction of symptoms and disability and improve health-related QOL.

Outcome after unilateral laminotomy is comparable with that after laminectomy. Bilateral laminotomy was associated with a significant benefit in most outcome parameters during a minimum follow-up period of 12 months and thus constitutes a promising treatment alternative.

(3) BIOMECHANICAL ASSESSMENT OF MINIMALLY INVASIVE DECOMPRESSION FOR LUMBAR SPINAL CANAL STENOSIS. A CADAVERIC STUDY (J SPINAL DISORD TECH. 2009 OCT;22 (7): 486-91)

Information

Minimally invasive posterior decompression using a microscope or an endoscope is becoming popular for elderly patients with lumbar spinal canal stenosis. An advantage of the technique is that the cauda equina and nerve roots are in clear view and the facet joints, paravertebral muscles, and spinous process are well preserved. Moreover, the hypertrophied ligamentum flavum has been acknowledged as one of the contributors to lumbar spinal canal stenosis, and this surgical technique allows removal of the ligamentum flavum without destroying

the facet joints during the decompression. The facet joints have an important role in stabilizing the lumbar joints, especially in axial rotation. By preserving the facet joints, there should be less postoperative instability, and fusion may be avoided. The authors designed a biomechanical study on the cadaveric human lumbar spine, focused on a biomechanical comparison of the changes on motion segments after a minimally invasive decompression and after a conventional medial facetectomy. Eight human lumbar motion segments (4 segments of L2-3 and 4 segments of L4-5) were used in this study. Each specimen was tested by the authors in a materials testing machine (MTS 858 Mini-Bionix Test System, Minneapolis, MN) according to the following loading protocol: axial compression, flexion, extension, lateral bending to the right and to the left and axial rotation to the right and to the left.

This loading protocol was applied to each motion segment after the following surgical interventions: left fenestration (1), bilateral decompression via unilateral approach (2), medial facetectomy (3), and total facetectomy (4). The relative stiffness of the motion segments was determined and compared with a normalized stiffness for the specimen when intact. The authors observed that there were significant differences between intact and total facetectomy in compression ($p < 0.05$), extension ($p < 0.01$), and right and left axial rotations ($p < 0.01$). In addition, the ratios of stiffness for both left fenestration and bilateral decompression via unilateral approach were about 80% in all motions and none of the differences in the ratio of stiffness between these two groups were significant. On the other hand, the ratio of stiffness for bilateral decompression group was significantly greater than that for medial facetectomy group in extension and axial rotation. Comparing L2-3 with L4-5, for L2-3 the ratio of stiffness for bilateral decompression was significantly greater than that for medial facetectomy, but only in axial rotation, but there were no significant differences in stiffness for any of the loading modes at L4-5. Based on these results, the authors highlight that bilateral decompression via unilateral approach introduces less biomechanical instability (measured by changes in stiffness) than conventional medial facetectomy, especially in extension and axial rotation, and this technique leaves the spine more than 80% as stiff as the intact spine.

So, they conclude that these results support the argument for a minimally invasive bilateral decompression, which preserves the facet joints and produces less postoperative instability.

Analysis

This paper is the first biomechanical study on the cadaveric human lumbar spine focused on minimally invasive decompression. In our opinion, this paper should be interpreted carefully because few conclusions can be taken from it. The methodology in this study is limited to some extent by the lack of active muscle function in cadaveric motion segments and the analysis of isolated motion segments.

In our opinion, this study lacks two things; the authors initially develop and apply 5 surgical techniques on each on motion segment, but they only analyze and compare 2 of them. More conclusions could be taken if all the techniques were analyzed. Moreover, they study two non- consecutive motion segments, L2-

L3 and L4-L5. We think that conclusions derived from two consecutive motion segments would give more information and be more relevant.

Despite such limitations, we appreciate the efforts of the authors in carrying out this analysis, which supports the concept that bilateral decompression via unilateral approach (using either a microscope or an endoscope) induces less biomechanical instability and it is an optimal surgical technique for lumbar spinal canal stenosis.

(4) CLINICAL OUTCOMES OF MICROENDOSCOPIC DECOMPRESSIVE LAMINOTOMY FOR DEGENERATIVE LUMBAR SPINAL STENOSIS (EUR SPINE J. 2009; 18: 672-678)

Information

The goal of surgical treatment for degenerative lumbar spinal stenosis (LSS) is to effectively relieve the neural structures by various decompressive techniques. Microendoscopic decompressive laminotomy (MEDL) is an attractive option because of its minimally invasive nature. The aim of this prospective study was to investigate the effectiveness of MEDL by evaluating the clinical outcomes of patients who were treated with the MEDL technique between December 2005 and April 2007. The indications for surgery were moderate to severe stenosis, persistent neurological symptoms, and failure of conservative treatment. Patients with mechanical back pain, more than grade I spondylolisthesis, or radiographic signs of instability were not included. A total of 53 patients (36 women and 17 men, mean age 62.0) were included. Forty-five patients (84.9%) were satisfied with the treatment result after a follow-up period of 15.7 months (12–24). The clinical outcomes were evaluated with the Oswestry disability index (ODI) for overall disability and the Japanese Orthopedic Association (JOA) score for clinical symptoms and signs. Of the 50 patients providing sufficient data for analysis, the ODI improved from 64.3 ± 20.0 to 16.7 ± 20.0 . The JOA score improved from 9.4 ± 6.1 to 24.2 ± 6.0 . The improvement rate was $73.9 \pm 30.7\%$ and 40 patients (80%) had good or excellent results. The surgical complications were five cases of dural tear, two cases of wrong level operation, and transient neuralgia in 4 patients. Although the prevalence of pre-operative comorbidities was very high (69.8%), there was no serious medical complication.

There was no post-operative instability at the operated segment as evaluated with dynamic radiographs at final follow-up. No progression of pre-existing spondylolisthesis or scoliosis was observed. The authors concluded that MEDL is a safe and very effective minimally invasive technique for degenerative lumbar spinal stenosis, and that with appropriate patient selection, the risk of post-operative instability is minimal.

Analysis

Microendoscopic decompressive laminotomy (MEDL) was developed in 2002 for the treatment of lumbar spinal stenosis. It has replaced the classic decompressive procedure and become the standard in many countries. By using a tubular retractor with the incorporated fibro-optic endoscopic system, this minimally invasive decompressive technique usually involves less blood loss, less

muscle dissection, and less injury to the stabilizing structures. The goal of the authors was to evaluate the clinical outcomes of MEDL and the possibility of avoiding post-operative instability after decompressive surgery. In this paper, the MEDL technique is well documented, and the prospective study is well designed, using appropriate inclusion and exclusion criteria, and with a good follow-up with objective evaluation tools. There are however, some limitations to this study. First, there is no control group for comparison. Second, the follow-up is not long enough to draw conclusions about the long-term benefits, because the initial benefits of surgical decompression might deteriorate over time.

Moreover, because patients with higher-grade spondylolisthesis or patients with mechanical low back pain were excluded in the cohort selection, the conclusion that MEDL can preserve pre-operative stability can only be applied to selected patients. The authors recognized these shortcomings, and they accept them as a limitation when extrapolating the results of the study to the general population. There are two concepts that we found interesting in this article and which we want to highlight; the first one is that, in spite of the very high prevalence of pre-operative comorbidities, there was no major medical complication. This fact emphasizes the value of minimally invasive surgical procedures in the elderly population, which frequently associates a high prevalence of pre-operative comorbidities. The other is that post-operative instability developed in only one patient, who did not have pre-operative spondylolisthesis or scoliosis. A follow-up MRI showed the decompressive procedure involved excessive invasion to the facet joint complex. This supports the argument that by preserving the facet joints, we can avoid postoperative instability. This study demonstrates that MEDL is a good surgical option to decompress the stenosis and very effective in relieving the neurological symptoms and improving patients' quality of life. We agree with the authors of this paper that MEDL may be a good option for elderly patients, who tend to have more severe stenosis involving multiple levels, and more pre-operative comorbidities.

(5) DEGENERATIVE LUMBAR SPINAL STENOSIS. DECOMPRESSION WITH AND WITHOUT ARTHRODESIS (J BONE JOINT SURG AM. 1995 JUL;77 (7): 1036-41.

Information

Decompression of the stenotic segment of the spine is the recommended treatment for patients who have severe clinical symptoms that have not responded to conservative treatment. Simultaneous arthrodesis has been advocated by those who believe that the pain is related to osteoarthrotic changes at the intervertebral joints and that decompressed segments tend to become unstable later on. The authors designed this prospective study to evaluate the results of decompression of the spine, with and without arthrodesis, for the treatment of lumbar spinal stenosis without instability. Forty-five patients (twenty-one men and twenty-four women) were randomly assigned to one of three treatment groups (fifteen patients in each group) according to when they were admitted to the hospital. Group I was treated with decompression with laminotomy and medial facetectomy; Group II, with decompression and arthrodesis of the most stenotic segment; and Group III, with decompression and arthrodesis of all of the decompressed vertebral segments.

All of the operations were performed by the same surgeon. The average duration of follow-up was twenty-eight months (range, twenty-four to thirty-two months). All three groups had a significant improvement in the distance that the patients were able to walk at the time of the latest follow-up examination compared with before the operation ($p < 0.001$ for Group I, $p < 0.002$ for Group II, and $p < 0.005$ for Group III). There were no significant differences in the results among the three groups with regard to the relief of pain ($p = 0.25$ for Group I compared with Group II, $p = 0.36$ for Group II compared with Group III, and $p = 0.92$ for Group I compared with Group III).

The authors of this study conclude that, in the absence of segmental instability, arthrodesis is not necessary after decompression of the lumbar spine in patients who have degenerative lumbar spinal stenosis, provided that the stabilizing posterior elements of the spine are preserved during the operation.

Analysis

Decompression of the neural elements changes the natural history of lumbar spinal stenosis and improves the quality of life by relieving pain. The main challenge in the operative treatment of spinal stenosis is to provide adequate decompression while maintaining stability. The stability of the decompressed spine can be maintained with meticulous operative technique. In this study, the increased distance that the patients could walk and the relief of pain postoperatively were very significant in all three groups. There were no significant differences between the results as evaluated by an independent examiner. These clinical results support the findings of experimental studies that symptomatic segmental instability does not develop after a partial medial facetectomy. We agree with the authors of this paper that arthrodesis is not justified in the absence of radiologically detectable segmental instability when treating lumbar spinal stenosis.

Synthesis

Acquired lumbar stenosis is the most common indication for lumbar spinal surgery in elderly patients (age > 65 years) and will continue to gain in importance as life expectancy increases and perioperative management improves. Decompressive laminectomy is the standard surgical treatment in these patients, but it is successful in only 64% of cases. In particular, spinal instability has been implicated as a cause of surgical failures, because wide posterior decompression significantly alters spinal anatomy and biomechanics, thus prompting many spine surgeons to perform fusion procedures to treat lumbar stenosis. Although numerous studies have been conducted to address the impact of fusion on outcome, overall results after decompression alone have not been surpassed. The frequency of fusion surgery, however, has been steadily increasing in the treatment of degenerative lumbar disease despite numerous concerns. Instead of combining fusion with decompression and thus maximizing surgery and associated perioperative risks, some surgeons have attempted to decrease the operative failure rate by minimizing the invasiveness of the decompressive procedure. Multiple decompressive techniques (fenestration, laminotomy, etc) have been developed in this way. The reported results have been encouraging, with success rates as high as 90%. These techniques provide an adequate and safe decompression and faster post-operative recovery, by avoiding an extensive resection of the posterior bone and muscular structures,

with less soft tissue dissection, less intraoperative blood loss and less associated morbidity. We support the use of these minimally invasive techniques for the treatment of degenerative lumbar spinal stenosis. We favour performing a bilateral lumbar decompression with the use of a unilateral minimally invasive approach, either with microscope or endoscope. We would like to highlight the special interest of these techniques in the elderly population (most lumbar spinal stenosis cases), which usually associates pre-operative comorbidities and where loss of blood, post-operative pain, and prolonged postoperative recovery can increase medical morbidity related to deep venous thrombosis, pulmonary embolism, pneumonia, urinary tract infections, ileus, or exacerbations of their preoperative comorbidities.

Papers Reviewed

(1) TRENDS, MAJOR MEDICAL COMPLICATIONS, AND CHARGES ASSOCIATED WITH SURGERY FOR LUMBAR SPINAL STENOSIS IN OLDER ADULTS (JAMA. 2010 Apr 7; 303(13):1259-65)

(2) OUTCOME AFTER LESS INVASIVE DECOMPRESSION OF LUMBAR SPINAL STENOSIS: A RANDOMIZED COMPARISON OF UNILATERAL LAMINOTOMY, BILATERAL LAMINOTOMY, AND LAMINECTOMY (J NEUROSURG SPINE 2005 AUG;3 (2): 129-41)

(3) BIOMECHANICAL ASSESSMENT OF MINIMALLY INVASIVE DECOMPRESSION FOR LUMBAR SPINAL CANAL STENOSIS. A CADAVERIC STUDY (J SPINAL DISORD TECH. 2009 OCT;22 (7): 486-91)

(4) CLINICAL OUTCOMES OF MICROENDOSCOPIC DECOMPRESSIVE LAMINOTOMY FOR DEGENERATIVE LUMBAR SPINAL STENOSIS (EUR SPINE J. 2009; 18: 672-678)

(5) DEGENERATIVE LUMBAR SPINAL STENOSIS. DECOMPRESSION WITH AND WITHOUT ARTHRODESIS (J BONE JOINT SURG AM. 1995 JUL;77 (7): 1036-41.