Retrospective Evaluation

The Effectiveness and Safety of Selective Lumbar Decompression in Diagnostic Doubt Patients: A Retrospective Control Study

Li Xiaochuan, MD, Cheng-Fan Zhong, MD, Jian-Hua Tang, MD, Rong-Wei Liang, MD, Shao-Jian Luo, MD, and Chun-Ming Huang, MD

From: Gaozhou People's Hospital, China

Address Correspondence:
Li Xiaochuan, MD
Gaozhou People's Hospital,
No 89, Xi-Guan Road,
Guangdong 525200, China
Email: 393414943@qq.com

Disclaimer: There was no external funding in the preparation of this manuscript. Conflict of interest: Each author certifies that he or she, or a member of his or her immediate family, has no commercial association (i.e., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

Manuscript received: 10-21-2016
Revised manuscript received: 12-11-2016
Accepted for publication: 12-14-2016

Free full manuscript: www.painphysicianjournal.com

Background: Our previous study demonstrated that selective nerve root block (SNRB) can influence decision-making in lumbar surgery by guiding the selection of nerve roots targeted for decompression in diagnostic doubt patients (DDPs). However, further studies were needed to determine whether this selective decompression (SD) procedure would result in similar clinical outcomes and reduce the perioperative parameters and postoperative complications as compared to the non-selective decompression (NSD) procedure.

Objective: The specific goal of this study is to compare clinical outcomes, perioperative parameters, and complications between SD and NSD procedures in DDPs.

Study Design: A retrospective control study.

Setting: Gaozhou People's Hospital.

Methods: From January 2009 to January 2011, 57 lumbar surgery patients with diagnostic doubt were retrospectively reviewed. Basic patient parameters, as well as perioperative and postoperative data were compared between the selective and non-selective decompression groups. Clinical outcomes were evaluated using the visual analog scale (VAS), Oswestry Disability Index (ODI), Japanese Orthopaedic Association (JOA) scores, and JOA recovery rates.

Results: Both groups showed significant improvement in VAS, ODI, and JOA scores between preoperative and postoperative measurements. The differences in VAS and ODI scores between groups were not significant at 3 and 60 months postoperatively (both $P > 0.05$). In addition, there was no significant difference in JOA recovery rate ($P = 0.659$) and survival rate ($P = 0.586$) during the 60 months following surgery. However, distinctly superior perioperative parameters (operation time and hospital stay, blood loss and drainage volume, laminectomy numbers, and fusion segment numbers) were observed in the SD group ($P < 0.001$ for each score). Moreover, the SD-treated group experienced significantly fewer adverse events postoperatively ($P = 0.036$).

Limitations: The limitations of this study lie in the size of the study and selection of patients and in the fact that it was not feasible to include all cases of diagnostic doubt.

Conclusions: On the basis of the 5-year follow-up data, we suggest that the SD procedure guided by SNRB is an effective and safe method for the surgical treatment of DDPs. This procedure produces superior perioperative parameters when compared with the conventional NSD procedure, but has a comparable clinical outcome. Moreover, the benefits of SD surgery include fewer perioperative and postoperative complications.

Key words: Lumbar spinal surgery, diagnostic doubt, selective nerve root block (SNRB), selective decompression (SD)

Pain Physician 2017; 20:E541-E550

Lumbar degenerative disease (LDD) is a globally prevalent condition that affects nearly 80% of individuals during their lives; further, it is accompanied by drastic socio-economic consequences (1,2). The pathologic progression of degeneration often leads to bulging discs, infolding of the ligamentum flavum, and osteoarthritic thickening in the facet joints around the neurovascular structures of the spine (3,4). Hence, surgical decompression is a well-established treatment for patients in whom a more conservative treatment fails to provide adequate pain relief. For some patients, however, the source of radicular pain does not correspond to typical dermatomal patterns or the location of the compressed nerve root is ambiguous; these patients are classified as diagnostic doubt patients (DDPs). The clinical picture for these patients is similar to those of multiple lumbar spinal stenosis patients, whose pain source often does not correspond to typical dermatomal patterns and failed back surgery syndrome (FBSS) patients, for whom the target pathogenesis is changing. In cases where nerve root pain does not follow a specific dermatomal pattern, the pain distribution is generally not diagnostically useful in determining the cause of radicular pain (5). Moreover, there is significant dermatomal overlap between adjacent nerve roots in 62% of patients, which may complicate the diagnostic process (6,7). Finally, the presence of mechanical compression cannot always be visualized using static imaging studies and is not always associated with painful radiculopathy (8).

Current diagnosis of pain generation relies heavily on the patients' clinical symptoms, signs, or imaging findings (9,10). For DDPs, diagnosis of radiative pain may be complicated by confounding conditions, such as equivocal, multilevel, or extraforaminal pathology and nerve root anomalies, spinal inflammation, or compression of nerve roots (8,11). Consequently, the clinical reoperation rate for spinal nerve root decompression surgery was estimated to range from 5% to 50%, emphasizing the importance of having a preoperative diagnosis of the target nerve roots (8,12,13). Since spine surgery is considered "elective" in the context of overall medical care, surgical strategy should follow the principle of minimal trauma. It is critical, therefore, to optimize the surgical strategy by establishing an accurate diagnosis of the number and location of involved nerve roots in DDPs in order to help clinicians make reasonable individual treatment decisions (14). Furthermore, for patients over 65 years, the risks and benefits of lumbar spinal decompression with or without fusion may be different from younger adults due to age-related changes in the spine and the prevalence of comorbid conditions with age (15). Thus, precision and minimized decompression and fusion procedures in the treatment of compression or inflammation of spinal nerve roots is of great importance and probable benefit to DDPs.

It is of paramount significance to precisely determine the location of the involved compressed nerve roots or pain generators preoperatively. In this respect, a selective nerve root block (SNRB) is increasingly reported to be capable of predicting the involved compressed nerve roots (9,16-19). However, the extent to which the SNRB procedure can guide the surgery and reduce perioperative parameters and postoperative complications needs to be further studied. Hence, in this case, we retrospectively assessed DDPs using strict inclusion criteria, and then compared the clinically relevant parameters between SD and NSD procedures with a minimum follow-up period of 5 years. The specific goal of this study is to compare clinical outcomes, perioperative parameters, and complications between SD and NSD procedures in DDPs.

Table 1. *The inclusion and exclusion criteria.*

Inclusion criteria: a. Patients suffering from LDD with radicular pain. b. Neither clinical findings nor radiological imaging have demonstrated diagnostic accuracy. c. The patient underwent lumbar spinal decompression surgery with a follow-up of no less than 5 years. d. All tests of VAS (0 – 10 points), ODI, and JOA score (0 – 29 points) were available.
Exclusion criteria: a. The patient had low back pain caused by spondylolisthesis, tumor, deformity, osteoporosis, and infection. b. The involved nerve roots of patients were injected on more than 2 occasions (multiple injection). c. The patient's radicular pain was bilateral. d. The patient had a history of allergy to the injection (dye, steroid, anesthetic agent, etc.)

LDD, Lumbar degenerative disease; SNRB, Selective nerve root block.

Methods

Patient Data

From January 2009 to January 2011, 84 DDPs were retrospectively reviewed and 57 DDPs were included in the study, according to the inclusion and exclusion criteria listed in Table 1. The patients were classified according to surgical procedure as part of the SD group (24 patients) or the NSD group (33 patients). The hu-

man research protocol for this study has been reviewed and approved by the Gaozhou People's Hospital Ethics Committee.

Patient Selection Process and SNRB Procedure

The positive identification of the compressed nerve root is defined by both symptom reproduction during nerve root stimulation and VAS improvement rate of pain relief ≥ 75%, where VAS improvement rate is defined as (VAS score after SNRB – VAS score before SNRB)/ VAS score before SNRB×100%. The flow diagram for inclusion of patients in the study is shown in Fig. 1. The SNRB was performed as previously described (8,20). Briefly, at one or 2 days preoperatively, patients were placed in the prone position and the skin was anesthetized with 1% lidocaine. A 12-cm, 22-gauge spinal needle was used in the approach to the suspected nerve root. The needle tip was directed to the anterosuperior aspect of the neuroforamen from a posteroinferior and paramedian approach (Fig. 2). After the needle position was checked by biplanar fluoroscopy, the patient was closely monitored for nerve root irritation to avoid impalement damage. The incidence of nerve provocation was recorded and compared with the patient's usual symptoms of pain. On the basis of the response elicited, 1 mL of 1% lidocaine was injected and the change in VAS was assessed for pain relief. If the implicated nerve root was identified, the SD surgery plan was formulated according to the positive SNRB test. Lumbar spinal decompression, with or without fusion, was performed as previously described (21-23). DDPs who underwent NSD surgery served as controls and all surgical procedures were conducted by the same experienced spinal surgery team.

Outcome Evaluation

Perioperative parameters (operation time, blood loss, drainage volume, laminectomy numbers, fusion

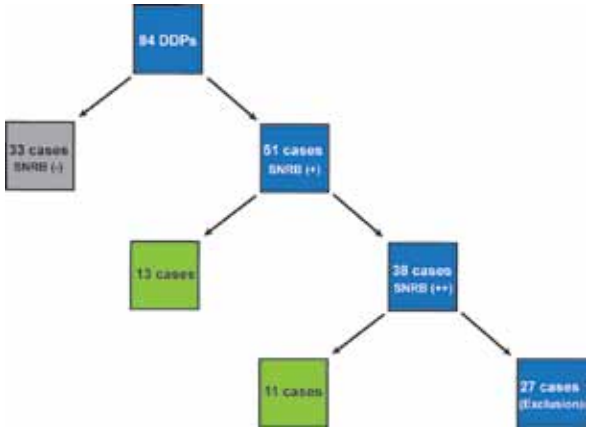

Fig. 1. *Flow diagram design to select the SD and NSD patients in the study.*

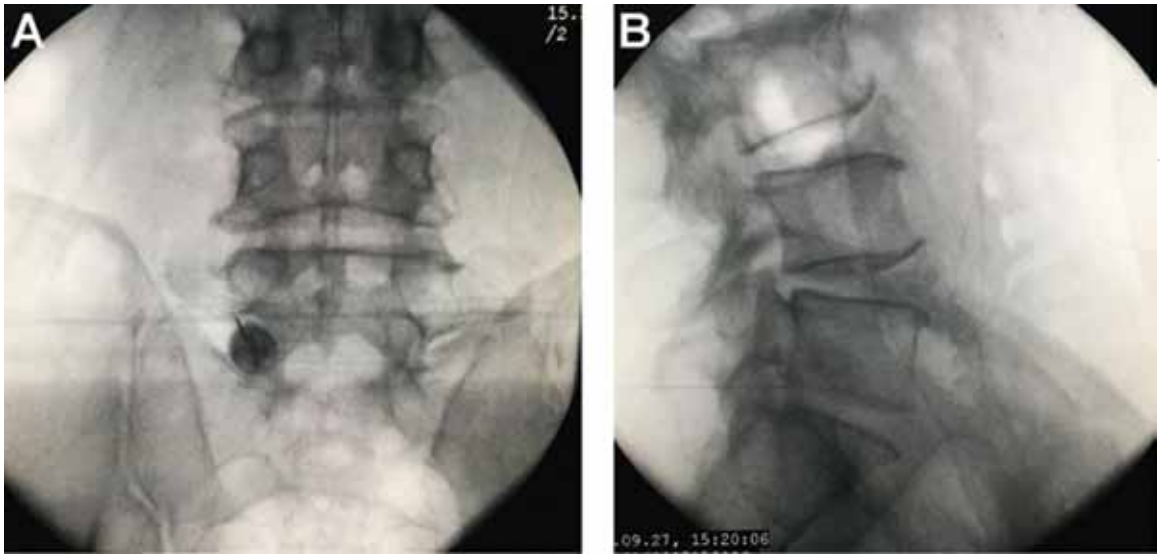

Fig. 2. *The anteroposterior and lateral view of SNRB procedure in DDPs of lumbar spine.*

segment numbers, and length of hospital stay) were collected. Oswestry disability index (ODI) was used to evaluate patients' daily life activities. Neurological status was evaluated by the Japanese Orthopedic Association (JOA) disability scale. The visual analog scale (VAS) was used to assess leg pain intensity. All patients were followed at least 5 years postoperatively. The JOA recovery rate was calculated using the Hirabayashi method (24): (postoperative score – preoperative score)/(29–preoperative score)×100%. Recovery rates were graded as follows: greater than 75%, excellent; 50% to 74%, good; 25% to 49%, fair; and less than 25%, poor. The first 2 results were considered as effective clinical outcomes. The incidence of both intraoperative and postoperative complications was also recorded.

Statistical Analysis

A Pearson χ^2 test or Fisher exact test was applied for qualitative data. A Wilcoxon test was used to assess changes between postoperative and preoperative parameters. Statistical comparisons between groups were performed using the Mann-Whitney U test. All statistical tests were completed using the Statistical Package for Social Sciences software for Windows (Version 19.0; SPSS Inc, Chicago, IL). The difference was considered to be statistically significant at $P < 0.05$.

Results

Demographic Summary

The clinical characteristics of patients in the SD and NSD groups were recorded in Table 2, including average age, men-to-women ratio, course of the disease, pain changes, levels of involved nerves, mean number of follow-up years, and VAS, ODI, and JOA scores before the operation. Comparison of results between the 2 groups showed no statistical differences ($P > 0.05$ for all items).

Diagnostic Difference between MRI and SNRB in the SD group

When comparing the diagnostic identification of

Table 2. *Patient characteristics.*

Characteristics	Group		Statistical Value	*P*
	SD (n = 24)	NSD (n = 33)		
Mean age[a]	57.8 ± 9.3	61.4 ± 7.6	310.0	0.164
Male/Female[b]	9/15	14/19	0.140	0.708
Course of the disease (years)[a]	2.6 ± 1.6	3.2 ± 2.1	331.0	0.292
Self-assessment of radicular pain[c]			1.250	0.577
Staying about the same	12	19		
Getting worse	9	8		
Other	3	6		
Stenosis level (MRI)[b]				
L1-L2[c]	1	3	0.516	0.613
L2-L3[b]	7	5	1.642	0.324
L3-L4[b]	12	20	0.635	0.589
L4-L5[c]	20	26	0.184	0.745
L5-S1[b]	15	24	0.673	0.565
Total number of stenoses(MRI)[c]			1.898	0.426
Two	3	7		
Three	15	22		
More than 3	6	4		
VAS[a]	6.8 ± 1.1	6.5 ± 1.2	331.0	0.278
ODI[a]	36.1 ± 4.97	37.2 ± 5.05	343.0	0.390
JOA[a]	11.8 ± 2.23	11.2 ± 2.54	359.5	0.551
Mean follow-up (years)[a]	5.7 ± 0.9	5.8 ± 0.9	325.6	0.496

SD = Selective decompression, NSD = Non-selective decompression; [a]Mann-Whitney U test, [b]Pearson χ^2 test, [c]Fisher exact test.

targeted positive nerve roots using magnetic resonance imaging (MRI) or SNRB, the SNRB may provide a more precise diagnosis of compressed nerve roots, leading to less invasive surgical decompression. The difference between the 2 groups was significant ($P < 0.001$, Table 3).

Table 3. *Comparing compressive nerve roots between SNRB and MRI.*

	MRI (n = 24)	SNRB (n = 24)	Statistical Value	*P*
Number of nerve roots *			37.515	< 0.001
1	0	16		
2	4	5		
3	10	0		
4	7	0		

SNRB = Selective nerve root block * Fisher exact test.

Perioperative Parameters

The average operation time, blood loss, drainage volume, laminectomy numbers, fusion segment numbers, and length of hospital stay were analyzed (Table 4). The results of the SD group showed significantly lower parameters than those of the NSD group ($P < 0.001$ for all items, Table 4).

Table 4. *Perioperative and postoperative parameters.*

Characteristics	Group		Statistical Value	*P*
	SD (n = 24)	NSD (n = 33)		
Mean operation time[a]	95.7 ± 39.1	245.4 ± 75.8	25.5	< 0.001
Laminectomy numbers[a]	1.129 ± 0.227	2.217 ± 0.299	21	< 0.001
Fusion segments numbers[a]	1.495 ± 0.289	2.704 ± 0.359	8.5	< 0.001
Mean blood loss[a]	204.8 ± 171.7	682.6 ± 558.9	64.5	< 0.001
Mean drainage volume[a]	130.5 ± 110.5	372.2 ± 292.4	93	< 0.001
Mean hospital stay[a]	12.2 ± 4.71	17.5 ± 5.04	87	< 0.001

SD = Selective decompression, NSD = Non-Selective decompression; [a]Mann-Whitney U test.

VAS Scores

The mean VAS scores over time showed that both SD and NSD groups exhibited a significant VAS recovery at the 60-month follow-up (both groups $P < 0.01$, Fig. 3). However, there were no significant differences between the 2 groups at the 3- and 60-month follow-ups, respectively ($P = 0.101$ and $P = 0.63$, Fig. 3).

ODI Scores

As compared with preoperative data, SD and NSD groups showed significant ODI improvements at the 60-month follow-up ($P = 0.009$ and $P = 0.005$, Fig. 4). However, there were no significant differences between the SD and NSD groups in ODI score improvement at 3 and 60 months postoperatively, as depicted in Fig. 4 ($P = 0.61$ and 0.49, respectively).

JOA Recovery Rate

At the 60-month follow-up, the SD group shared similarly effective clinical outcomes with the NSD group ($P = 0.659$, Table 5). When comparing the 60-month survival data, both groups showed similarly effective clinical outcomes and excellent JOA recovery rates, with no significant difference between the 2 groups (clinical outcomes, $P = 0.586$; excellent JOA recovery rate $P = 0.789$, Fig. 5).

Complications

Fewer perioperative complications were identified in the SD group than in the NSD

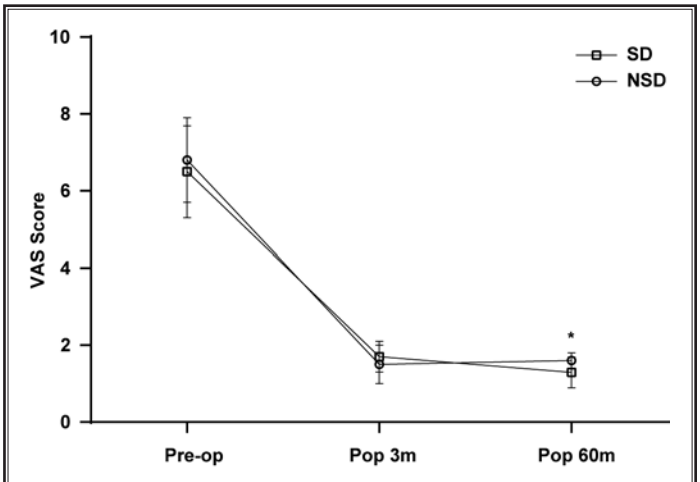

Fig. 3. *Comparison of VAS scores in both SD and NSD groups at pre-operation, 3 months, and 60 months post operation.*

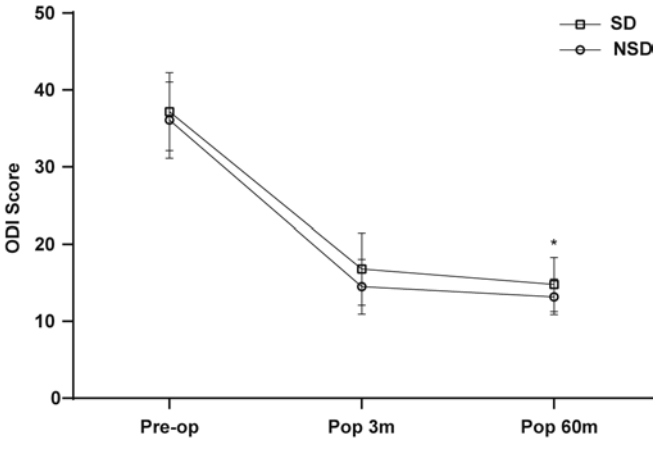

Fig. 4. *Comparison of ODI scores in both SD and NSD groups at pre-operation, 3 months, and 60 months post operation.*

Table 5. *Japanese Orthopedic Association Recovery Rate.*

	SD (n = 24)	NSD (n = 33)	Statistical Value	*P*
Neurological recovery grade*			1.966	0.659
Excellent (≥ 75%)	10	15		
Good (50% – 74%)	9	13		
Fair (25% – 49%)	3	1		
Poor (< 25%)	2	4		

SD = Selective decompression, NSD = Non- selective decompression; * Fisher exact test.

group: One patient with pedicle burst in the SD group compared to 2 patients with pedicle burst, 2 patients with CSF leakage, 2 with dural tears, one with epidural hematoma, and 2 with infection in the NSD group (Table 6). Postoperative complications in the SD group consisted of one reoperation procedure, as compared to 3 in the NSD group. Additional postoperative complications in the NSD surgical group included one broken screw, 2 cases of nerve root irritation, one nonunion, and 2 cases of screw loosening (Table 6). In summary, as compared to the NSD group, the SD group showed a slightly lower incidence of perioperative complications (P = 0.121, Table 6) and significantly fewer postoperative events (P = 0.034, Table 6).

Discussion

This is a retrospective clinical trial, comparing the effectiveness and safety of SD and NSD procedures in the surgical treatment of DDPs. In this study, we analyzed a total of 57 DDP surgeries with 24 patients treated by SD and 33 patients treated using a NSD procedure. To the best of our knowledge, this is the first study that compared SD treatment with NSD in DDPs. Although the sample size was small, our study used

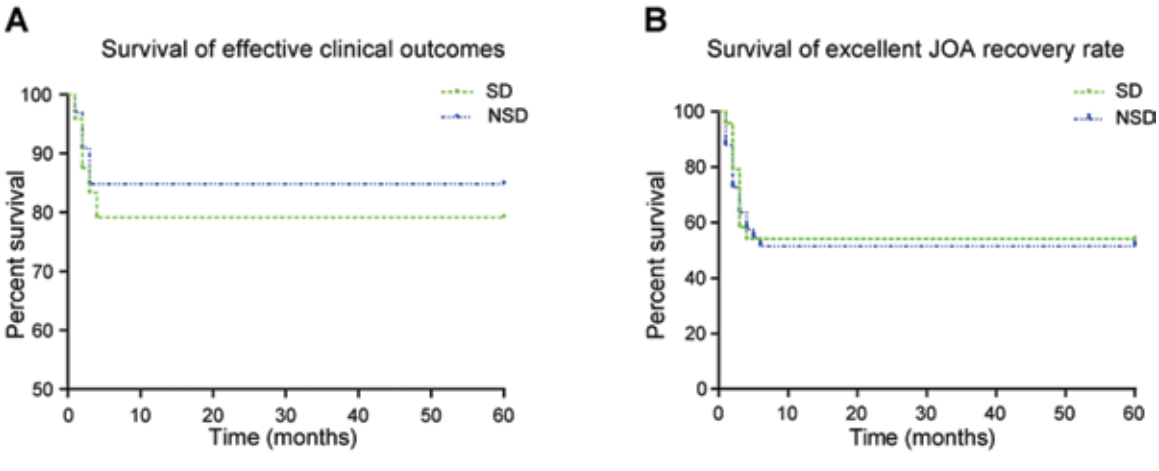

Fig. 5. *The survival analysis of effective clinical outcomes and JOA recovery rate in both SD and NSD groups.*

objective patient selection and a strict process procedure, which highlights the credibility of our findings. In our experience, SD treatment under the guidance of SNRB is a safe alternative to NSD and shows similar clinical effectiveness in VAS score, ODI score, and JOA recovery rate, but resulted in lower perioperative parameters and fewer postoperative complications.

SNRB has been used since the 1930s to confirm radicular pain prior to surgery (25). It has been proven as a safe procedure for distinguishing clinical radicular pain (7,26-28). Our study found that complications of SNRB are minor and temporary without showing progression to serious adverse events, which is in accordance with other previously published research (8,29-31). Hence, we concluded that diagnostic SNRB can safely discern the presence of lumbar radiculopathy.

SNRB has been used reliably to predict the pain-generating nerve roots with a reporting accuracy of 31% to 100% (7,9,20,32). In clinical studies, a higher cutoff value may improve the diagnostic accuracy by increasing true-negatives and false-negatives (20). Hence, in our SNRB procedure, the positive target nerve roots were strictly defined as both reproducing symptoms and producing a VAS score improvement of pain relief ≥ 75% following anesthetic infusion. Surgical procedures, including volumes and kind of anesthetic used in the injection, were as described previously, based on our clinical experience and literature reviews of studies within the Chinese population (18,19,33). This ensures consistency in the evaluation of SD procedures guided by the SNRB process, in comparison with NSD procedures in lumbar spinal nerve root decompression surgery.

When comparing SNRB with MRI, we found that SNRB decreased the number of nerve roots identified ($P < 0.001$). However, this should not be interpreted to mean that SNRB can be used in isolation, without MRI. The results shown in Table 3 reflect only cases of diagnostic doubt, where previous MRI findings were considered equivocal, multilevel, or were inconsistent with the patient's symptoms. MRI is still important in understanding the pathologic process that causes radiculopathy (8). Thus, we found that SNRB increased accuracy, and that it should be considered as a pivotal preoperative test for determining the target nerve roots in DDPs. This important finding could potentially reduce the number of levels included in the operation in DDPs when spinal surgery is planned.

Table 6. *Complications*.

	SD (n = 24)	NSD (n = 33)	Statistical Value	*P*
Perioperative complications				
Pedicle burst	0	2/33		
Dural tearing	1/24	2/33		
Cerebral fluid leakage	0	1/33		
Epidural hematoma	0	1/33		
Infection	0	1/33		
Total *	1/24	7/33	3.346	0.121
Postoperative complications				
Broken screw	0	1/33		
Nerve root irritation	0	2/33		
Screw loosening	0	2/33		
Nonunion	0	1/33		
Reoperation	1/24	3/33		
Total *	1/24	9/33	5.128	0.034

SD = Selective decompression, NSD = Non-selective decompression; * Fisher exact test.

It is widely accepted that current trends in spine surgery require that decompression procedures be precise and minimally invasive (34-36). Traditional NSD treatment, directed by imaging information, surgeon judgement, or both, can, to some extent, lead to extravagant or preventive decompressions of nerve roots in some cases (19,37,38). Furthermore, this may destroy the stability of the spine and result in unnecessary surgical trauma, muscular atrophy, and increased risk of infection (39,40). When considering the clinical results of this study, using well-selected patients and a strict surgical process, SNRB could routinely provide a high predictive accuracy validated by the significant improvements in pre- and post-surgery VAS score ($P < 0.01$) and ODI score ($P = 0.009$). As compared with the NSD group, SD guided by SNRB showed equivalent ODI, VAS, and JOA score improvements at the 60-month follow-up ($P = 0.63$, $P = 0.49$, and $P = 0.659$, respectively). In addition, the 5-year survival data showed no statistical difference between the 2 groups in terms of clinically effective outcome and JOA recovery rate ($P = 0.586$ and $P = 0.789$, Fig. 5). The SD group was superior in terms of operation time and hospital stay, blood loss and drainage volume, laminectomy numbers, and fusion segments numbers; these parameters were significantly decreased as compared to the NSD group ($P < 0.001$ in each group). The difficulties of identifying the responsible nerve roots in DDPs present a complex diagnostic

problem (19). Nevertheless, we recommended the SD procedure because it can be greatly beneficial to the patient, especially for older patients, particularly when strictly selecting patients and for preparing a comprehensive preoperative analysis.

Furthermore, when evaluating complications, the SD-treated group had fewer complication events both perioperatively (1/24 in SD group compared to 7/33 in NSD group) and long-term postoperatively (1/24 in SD group compared to 9/33 in NSD group; Table 6). The most common perioperative complications were pedicle burst and dural tearing, epidural hematoma, infection, and cerebral fluid leakage. The most common postoperative complications were screw loosening or breakage, nerve root irritation, nonunion, and reoperation. The data indicate that the SD procedure decreased the incidence of complications both perioperatively (P = 0.121) and postoperatively (P = 0.034). Although the difference in perioperative complications was not significant, this may have been due to the small sample size. One explanation for the greater number of complications in the NSD-treated group is the greater risk associated with extensive dissection, decortication of bone, longer operation times, and placement of implants in some cases (41-43). Considering the additional complications of NSD, and the rapid development of minimally invasive surgery procedures, SD shows considerable promise to greatly improve clinical effectiveness and reduce operative injury.

The limitations of this study lie in the size of the study and selection of patients. Since this is a retrospective clinical controlled trial, there is a potential for bias in the patients that were selected for surgery. Another limitation is the small population of patients that include a 5-year follow-up, which suggests that the results should be interpreted with caution. The more important limitation lies in the fact that it was not feasible to include all cases of diagnostic doubt. Confounding factors were determined and patients were excluded from the analysis if they had bilaterally present radicular pain, lower back pain was due to other causes, and other complications with the SNRB (allergy or multiple injections were necessary). Furthermore, the SNRB procedure itself incurs some risk of nerve root injury and exposure to x-rays; however, these seem to be outweighed by the benefits of additional diagnostic information. Further studies analyzing a larger population of patients could confirm the advantages of the SD procedure in cases of diagnostic doubt.

Conclusions

On the basis of the 5-year follow-up data, we suggest that SD guided by preoperative SNRB to determine the nerve roots responsible for radicular pain is an effective and safe procedure for the surgical treatment of DDPs. This procedure is associated with superior perioperative parameters when compared with the conventional NSD procedure, and has comparable clinical outcomes. Moreover, SD surgery is advantageous in being associated with fewer perioperative and postoperative complications.

References

1. Lurie J, Tomkins-Lane C. Management of lumbar spinal stenosis. *BMJ* 2016; 352:h6234.
2. Tao H, Wu Y, Li H, Wang C, Zhang Y, Li C, Wen T, Wang X, He Q, Wang D, Ruan D. BMP7-based functionalized self-assembling peptides for nucleus pulposus tissue engineering. *ACS Appl Mater Interfaces* 2015; 7:17076-17087.
3. Lubelski D, Thompson NR, Agrawal B, Abdullah KG, Alvin MD, Khalaf T, Mazanec DJ, Benzel EC, Mroz TE, Krishnaney AA. Prediction of quality of life improvements in patients with lumbar stenosis following use of membrane stabilizing agents. *Clin Neurol Neurosurg* 2015; 139:234-240.
4. Yabuki S, Fukumori N, Takegami M, Onishi Y, Otani K, Sekiguchi M, Wakita T, Kikuchi S, Fukuhara S, Konno S. Prevalence of lumbar spinal stenosis, using the diagnostic support tool, and correlated factors in Japan: A population-based study. *J Orthop Sci* 2013; 18:893-900.
5. Murphy DR, Hurwitz EL, Gerrard JK, Clary R. Pain patterns and descriptions in patients with radicular pain: Does the pain necessarily follow a specific dermatome? *Chiropr Osteopat* 2009; 17:9.
6. Bartynski WS, Kang MD, Rothfus WE. Adjacent double-nerve root contributions in unilateral lumbar radiculopathy. *AJNR Am J Neuroradiol* 2010; 31:327-333.
7. Datta S, Manchikanti L, Falco FJ, Calodney AK, Atluri S, Benyamin RM, Buenaventura RM, Cohen SP. Diagnostic utility of selective nerve root blocks in the diagnosis of lumbosacral radicular pain: Systematic review and update of current evidence. *Pain Physician* 2013; 16:S97-S124.
8. Sasso RC, Macadaeg K, Nordmann D, Smith M. Selective nerve root injections can predict surgical outcome for lumbar and cervical radiculopathy: Comparison to magnetic resonance imaging. *J Spinal Disord Tech* 2005; 18:471-478.
9. Williams AP, Germon T. The value of lumbar dorsal root ganglion blocks in predicting the response to decompressive surgery in patients with diagnostic

doubt. *Spine J* 2015; 15:S44-S49.

10. Germon T, Singleton W, Hobart J. Is NICE guidance for identifying lumbar nerve root compression misguided? *Eur Spine J* 2014; 23:S20-S24.
11. Beynon R, Hawkins J, Laing R, Higgins N, Whiting P, Jameson C, Sterne JA, Vergara P, Hollingworth W. The diagnostic utility and cost-effectiveness of selective nerve root blocks in patients considered for lumbar decompression surgery: A systematic review and economic model. *Health Technol Assess* 2013; 17:1-88, v-vi.
12. Dower A, Chatterji R, Swart A, Winder MJ. Surgical management of recurrent lumbar disc herniation and the role of fusion. *J Clin Neurosci* 2016; 23:44-50.
13. Connolly ES. Surgery for recurrent lumbar disc herniation. *Clin Neurosurg* 1992; 39:211-216.
14. Manchikanti L, Benyamin RM, Singh V, Falco FJ, Hameed H, Derby R, Wolfer LR, Helm S 2nd, Calodney AK, Datta S, Snook LT, Caraway DL, Hirsch JA, Cohen SP. An update of the systematic appraisal of the accuracy and utility of lumbar discography in chronic low back pain. *Pain Physician* 2013; 16:S55-S95.
15. McCrory DC, Turner DA, Patwardhan MB, Richardson WJ. AHRQ Technology Assessments, *Spinal Fusion for Treatment of Degenerative Disease Affecting the Lumbar Spine*. Agency for Healthcare Research and Quality (US), Rockville (MD), 2006.
16. Ito K, Yukawa Y, Machino M, Inoue T, Ouchida J, Tomita K, Kato F. Treatment outcomes of intradiscal steroid injection/selective nerve root block for 161 patients with cervical radiculopathy. *Nagoya J Med Sci* 2015; 77:213-219.
17. Manchikanti L, Kaye AD. Comment on the evaluation of the effectiveness of hyaluronidase in the selective nerve root block of radiculopathy. *Asian Spine J* 2015; 9:995-996.
18. Zhang GL, Zhen P, Chen KM, Zhao LX, Yang JL, Zhou JH, Xue QY. [Application of selective nerve root blocks in limited operation of the lumbar spine]. *Zhongguo Gu Shang* 2014; 27:601-604.
19. Li X, Bai X, Wu Y, Ruan D. A valid model for predicting responsible nerve roots in lumbar degenerative disease with diagnostic doubt. *BMC Musculoskelet Disord* 2016; 17:128.
20. Yeom JS, Lee JW, Park KW, Chang BS, Lee CK, Buchowski JM, Riew KD. Value of diagnostic lumbar selective nerve root block: A prospective controlled study. *AJNR Am J Neuroradiol* 2008; 29:1017-1023.
21. Uehara M, Takahashi J, Hashidate H, Mukaiyama K, Kuraishi S, Shimizu M, Ikegami S, Futatsugi T, Ogihara N, Hirabayashi H, Kato H. Comparison of spinous process-splitting laminectomy versus conventional laminectomy for lumbar spinal stenosis. *Asian Spine J* 2014; 8:768-776.
22. Ghogawala Z, Dziura J, Butler WE, Dai F, Terrin N, Magge SN, Coumans JV, Harrington JF, Amin-Hanjani S, Schwartz JS, Sonntag VK, Barker FG, 2nd, Benzel EC. Laminectomy plus fusion versus laminectomy alone for lumbar spondylolisthesis. *N Engl J Med* 2016; 374:1424-1434.
23. Resnick DK, Watters WC, 3rd, Mummaneni PV, Dailey AT, Choudhri TF, Eck JC, Sharan A, Groff MW, Wang JC, Ghogawala Z, Dhall SS, Kaiser MG. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 10: Lumbar fusion for stenosis without spondylolisthesis. *J Neurosurg Spine* 2014; 21:62-66.
24. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. *Spine (Phila Pa 1976)* 1981; 6:354-364.
25. Wolff AP, Groen GJ, Wilder-Smith OH, Richardson J, van Egmond J, Crul BJ. Do diagnostic segmental nerve root blocks in chronic low back pain patients with radiation to the leg lack distinct sensory effects? A preliminary study. *Br J Anaesth* 2006; 96:253-258.
26. Pfirrmann CW, Oberholzer PA, Zanetti M, Boos N, Trudell DJ, Resnick D, Hodler J. Selective nerve root blocks for the treatment of sciatica: evaluation of injection site and effectiveness: A study with patients and cadavers. *Radiology* 2001; 221:704-711.
27. Manchikanti L, Malla Y, Wargo BW, Fellows B. Infection control practices (safe injection and medication vial utilization) for interventional techniques: Are they based on relative risk management or evidence? *Pain Physician* 2011; 14:425-434.
28. Manchikanti L, Falco FJ, Benyamin RM, Caraway DL, Helm Ii S, Wargo BW, Hansen H, Parr AT, Singh V, Hirsch JA. Assessment of infection control practices for interventional techniques: A best evidence synthesis of safe injection practices and use of single-dose medication vials. *Pain Physician* 2012; 15:E573-E614.
29. Liu K, Wu W, Guo J, Wang Y, Ren D, Li L, Wang H, Tang J. [Diagnosis and limited operative treatment of multi-segmental lumbar disease]. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi* 2014; 28:529-534.
30. DePalma MJ, Bhargava A, Slipman CW. A critical appraisal of the evidence for selective nerve root injection in the treatment of lumbosacral radiculopathy. *Arch Phys Med Rehabil* 2005; 86:1477-1483.
31. Rezende R, Jacob Junior C, da Silva CK, de Barcellos Zanon I, Cardoso IM, Batista Jr JL. Comparison of the efficacy of transforaminal and interlaminar radicular block techniques for treating lumbar disk hernia. *Rev Bras Ortop* 2015; 50:220-225.
32. Wilson CA, Roffey DM, Chow D, Alkherayf F, Wai EK. A systematic review of preoperative predictors for post-operative clinical outcomes following lumbar discectomy. *Spine J* 2016; 16: 1413-1422.
33. Zhang GL, Ge BF, Zhao LX, Yang JL, Chen KM, Zhou JH, Xue QY. [Microdecompression procedure for the treatment of lumbar spinal stenosis with multilevel]. *Zhongguo Gu Shang* 2011; 24:821-823.
34. Wu H, Yu WD, Jiang R, Gao ZL. Treatment of multilevel degenerative lumbar spinal stenosis with spondylolisthesis using a combination of microendoscopic discectomy and minimally invasive transforaminal lumbar interbody fusion. *Exp Ther Med* 2013; 5:567-571.
35. Banczerowski P, Czigleczki G, Papp Z, Veres R, Rappaport HZ, Vajda J. Minimally invasive spine surgery: systematic review. *Neurosurg Rev* 2015; 38:11-26.
36. Fan G, Han R, Zhang H, He S, Chen Z. Worldwide research productivity in the field of minimally invasive spine surgery: A 20-year survey of publication activities. *Spine (Phila Pa 1976)* 2015. [EPub ahead of print]
37. Ammendolia C, Stuber K, Tomkins-Lane C, Schneider M, Rampersaud YR, Furlan AD, Kennedy CA . What interventions improve walking ability in neurogenic claudication with lumbar spinal stenosis? A systematic review. *Eur Spine J* 2014; 23:1282-1301.
38. Slatis P, Malmivaara A, Heliovaara M, Sainio P, Herno A, Kankare J, Seitsalo S, Tallroth K, Turunen V, Knekt P, Hurri H. Long-term results of surgery for lumbar spinal stenosis: A randomised controlled trial. *Eur Spine J* 2011; 20:1174-1181.

39. Li XC, Zhong CF, Deng GB, Liang RW, Huang CM. Full-endoscopic procedures versus traditional discectomy surgery for discectomy: A systematic review and meta-analysis of current global clinical trials. *Pain Physician* 2016; 19:103-118.

40. Pons T, Shipton EA. Multilevel lumbar fusion and postoperative physiotherapy rehabilitation in a patient with persistent pain. *Physiother Theory Pract* 2011; 27:238-245.

41. Milone M, Fernandez LM, Musella M, Milone F. Safety and efficacy of minimally invasive video-assisted ablation of pilonidal sinus: A randomized clinical trial. *JAMA Surg* 2016; 151:547-553.

42. Khashan M, Lidar Z, Salame K, Mangel L, Lador R, Drexler M, Sapirstein E, Regev GJ. Minimally invasive spinal decompression in patients older than 75 years of age: Perioperative risks, complications, and clinical outcomes compared with patients younger than 45 years of age. *World Neurosurg* 2016; 89:337-342.

43. Raygor KP, Than KD, Chou D, Mummaneni PV. Comparison of minimally invasive transspinous and open approaches for thoracolumbar intradural-extramedullary spinal tumors. *Neurosurg Focus* 2015; 39:E12.