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RISK FACTORS FOR RECURRENT LUMBAR DISK HERNIATION

FATORES DE RISCO PARA HÉRNIA DE DISCO LOMBAR RECORRENTE

FACTORES DE RIESGO PARA LA HERNIA DISCAL LUMBAR RECURRENTE

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ABSTRACT

Objective: to investigate the frequency of recurrent lumbar disk herniation (rLDH) and evaluated risk factors of rLDH in Russian population. Methods: this was a retrospective clinical study. From January 2015 to March 2022, 218 patients having single-level LDH at three institutes were included in this clinical study and who were then observed for a minimum of 5 years postoperatively. All the patients or relatives gave informed consent to participate in this study. The levels of disk herniation were L4-L5 in 132 cases (60.5 %), and L5-S1 in 86 cases (39.4 %). Results: The rLDH group was composed of 31 male and 12 female, whose ages ranged from 18 to 57 years (34.8±9.5 years). The non-rLDH group was composed of 97 male and 78 female, whose ages ranged from 19 to 73 years (47.5±9.8 years). According to the constructed binary logistic model, body mass index (p=0.021), current smoking (p=0.017), stage of disk degeneration (p=0.043), facet tropism (p=0.037), disk height index (p=0.018) and apparent diffusion coefficient (p=0.009) are significantly associated with incidence of rLDH. Conclusions: patients with these risk factors should be paid more attention for prevention of rLDH. ***Level of Evidence III; Retrospective Study.***

Keywords: Intervertebral Disk Herniation; Diskectomy; Risk Factors; Clinical Study; X Ray Radiology, Diagnostic.

RESUMO

Objetivo: investigar a frequência de hérnia de disco lombar recorrente (rLDH) e avaliar os fatores de risco de rLDH na população russa. Métodos: este foi um estudo clínico retrospectivo. De janeiro de 2015 a março de 2022, 218 pacientes com LDH de nível único em três institutos foram incluídos neste estudo clínico e que foram observados por um período mínimo de 5 anos no pós-operatório. Todos os pacientes ou familiares deram consentimento informado para participar deste estudo. Os níveis de hérnia de disco foram L4-L5 em 132 casos (60,5%) e L5-S1 em 86 casos (39,4%). Resultados: o grupo rLDH foi composto por 31 homens e 12 mulheres, cujas idades variaram de 18 a 57 anos (34,8±9,5 anos). O grupo não-LDH foi composto por 97 homens e 78 mulheres, cujas idades variaram de 19 a 73 anos (47,5±9,8 anos). De acordo com o modelo logístico binário construído, índice de massa corporal (p=0,021), tabagismo atual (p=0,017), estágio de degeneração do disco (p=0,043), tropismo facetário (p=0,037), índice de altura do disco (p=0,018) e o coeficiente de difusão aparente (p=0,009) estão significativamente associados à incidência de rLDH. Conclusões: pacientes com esses fatores de risco devem receber mais atenção para prevenção de rLDH. ***Nível de evidência III; Estudo Retrospectivo.***

Descritores: *Deslocamento do Disco Intervertebral; Discotomia; Fatores de Risco; Estudo Clínico; Diagnóstico Radiológico por Raios X.*

RESUMEN

Objetivo: investigar la frecuencia de hernia de disco lumbar recurrente (rLDH) y evaluar los factores de riesgo para rLDH en la población rusa. Métodos: se trata de un estudio clínico retrospectivo. Desde enero de 2015 hasta marzo de 2022, 218 pacientes con LDH de un solo nivel en tres institutos se inscribieron en este estudio clínico y se observaron durante un mínimo de 5 años después de la operación. Todos los pacientes o familiares dieron su consentimiento informado para participar en este estudio. Los niveles de hernia discal fueron L4-L5 en 132 casos (60,5%) y L5-S1 en 86 casos (39,4%). Resultados: el grupo rLDH estuvo compuesto por 31 hombres y 12 mujeres, cuyas edades oscilaron entre 18 y 57 años (34,8±9,5 años). El grupo no HDH estaba formado por 97 hombres y 78 mujeres, cuyas edades oscilaban entre 19 y 73 años (47,5±9,8 años). Según el modelo logístico binario construido, índice de masa corporal (p=0,021), tabaquismo actual (p=0,017), estadio de degeneración discal (p=0,043), tropismo facetario (p=0,037), índice de altura del disco (p =0,018) y el coeficiente de difusión aparente (p=0,009) se asocian significativamente con la incidencia de rLDH. Conclusiones: Los pacientes con estos factores de riesgo deberían recibir más atención para prevenir la rLDH. ***Nivel de evidencia II; Estudio Retrospectivo.***

Descriptores: *Desplazamiento del Disco Intervertebral; Discectomía; Factores de Riesgo; Estudio Clínico; Diagnóstico Radiológico por Rayos X.*

Study conducted by the Burdenko National Medical Research Center of Neurosurgery, Moscow, Russia and at the Irkutsk State Medical University, Irkutsk, Russia.
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INTRODUCTION

Currently, surgical treatment of lumbar disk herniation (LDH), which is a persistent pain syndrome, can effectively help the patient.[1,2] The frequency of excellent and good results reaches 90–95 %.[2,3] However, in some cases, insufficient and subjective prediction of the outcome of treatment can lead to unsatisfactory results. These are the formation of clinically significant epidural fibrosis, instability and recurrence LDH (rLDH). They are registered in 5–15 % of patients and are one of the most common reasons for repeated surgical intervention, especially in the first two years. It is important to analyze the risk factors of rLDH to prevent recurrence.[3–5]

Risk factors for rLDH are increasingly being investigated. Many estimated risk factors have been reported in previous studies, such as age, gender, body mass index (BMI), smoking, herniation type, diabetes, and herniation level.[6–8] However, results in these previous studies were not always consistent. Due to inconsistent results, reliable conclusions could not be drawn on these risk factors. In addition, data on studies investigated the effects of biomechanical factors, such as disk height index (DHI), sagittal range of motion (sROM), facet orientation (FO), facet tropism (FT) and some pelvic parameters, on rLDH appear only rarely in the literature.[9,10]

In this retrospective study we investigated the frequency of rLDH and evaluated risk factors of rLDH in Russian population.

METHODS

Study design

The inclusion criteria were: LDH at L4-L5 or L5-S1 levels, single level primary diskectomy. The exclusion criteria were: a combination of LDH with degenerative stenosis of the spinal canal, degenerative or isthmic spondylolisthesis, and traumatic lesions of the lumbar spine. The patients with recurrence of pain due to stenosis of the spinal canal, segmental instability without re-herniation, peridural fibrosis, LDH at a different level or contralateral rLDH, were excluded from the analysis.

Patient population

This was a retrospective clinical study. From January 2015 to March 2022, 218 patients having single-level LDH at three institutes (Burdenko National Medical Research Center of Neurosurgery (Moscow, Russia), Irkutsk State Medical University (Irkutsk, Russia) and Kharlampiev Clinic (Irkutsk, Russia)) were included in this clinical study and who were then observed for a minimum of 5 years postoperatively. All the patients or relatives gave informed consent to participate in this study (protocol N 51/1, 12 Jan 2012). The levels of disk herniation were L4-L5 in 132 cases (60.5 %), and L5-S1 in 86 cases (39.4 %).

Surgical procedure

Surgery was done by two neurosurgeons using via a standard microdiscectomy techniques.[11] The lamina was resected partially and partial discectomy was done after retracting the nerve root medially. Surgical procedure was done with a small square window through the annulus fibrosus, measuring a side about 3-5 mm, and removed the herniated disk and about $^1/_3$ of contained disk material. Neurosurgeons leaved the annular window open without any covering after surgery. The type of herniation was classified as protrusion, extrusion, and sequestration after review of surgical records.

MRI assessment

A magnetic resonance imaging (MRI) with diffusion-weighted imaging (DWI) was recommended for all postoperative patients experiencing persistent or recurrent leg pain. rLDH was defined as a disk herniation at the same level, regardless of ipsilateral or contralateral herniation, in a patient who experienced a pain-free interval of at least 6 months after prior spine surgery. Patients with herniation recurrence at other level, inability to have MRI exam, recent cerebrovascular arrest or psychological and cognitive disorders, amputation history, active infection, Paget's disease or spinal metastasis in the involved segments, severe back arthritis and neuropathic disease other than diabetes were excluded.

Data collection and outcome evaluations

The patients were divided into a rLDH group and a non-rLDH group in this clinical study. We compared their clinical parameters (age, gender, body mass index (BMI), current smoking, diabetes, sports activity, occupational lifting, occupational driving, trauma history, preoperative visual analogue scale (VAS), procedures) and preoperative radiologic parameters (herniation type, grade of disk degeneration, DHI, FO, FT, sROM and ADC).

The stage of intervertebral disk degeneration and ADC were assessed on preoperative T2 scans and DWIs (Figure 1) (1.5-T MRI, Hitachi Ltd., Tokyo, Japan) using the Pfirrmann grading system.[12] Lumbar radiography (DEFINIUM 8000, General Electric Medical Systems, Waukesha, Wis.) was performed in the neutral anteroposterior and neutral lateral planes with the patient standing. DHI was calculated on lateral radiographs using the Kim method.[4] (Figure 2) ROM was calculated as the difference in angulation between extension and flexion. FO is the angle of the facet joint in the transverse plane relative to the sagittal plane. The facet joint angle relative to the sagittal plane at L3-S1 was measured on the axial MRI or CT images using bone windows by using the method described by Noren et al.[13] (Figure 3) On an axial scan that bisected the intervertebral disk, one line was drawn in the midsagittal plane of the vertebra and one through each facet joint tangential to the superior articular process. FT is defined as asymmetry of the left and right facet-joint angles, with one joint having a more sagittal orientation than the other (Figure 3).

Statistical analysis

The statistical analysis was performed using SPSS 15.0 (IBM Corp. Armonk, N.Y.) and Statistica 8.0 (StatSoft Inc., Tulsa, Okla.) software. Quantitative data are presented as means and standard deviations (M±SD). The non-parametric Mann–Whitney *U* test and χ^2

Figure 1. 43 y.o. male patient with left sided L5–S1 rLDH with compressed nerve root (arrows) on ADC map and T2-WI (explanation in text).[22]

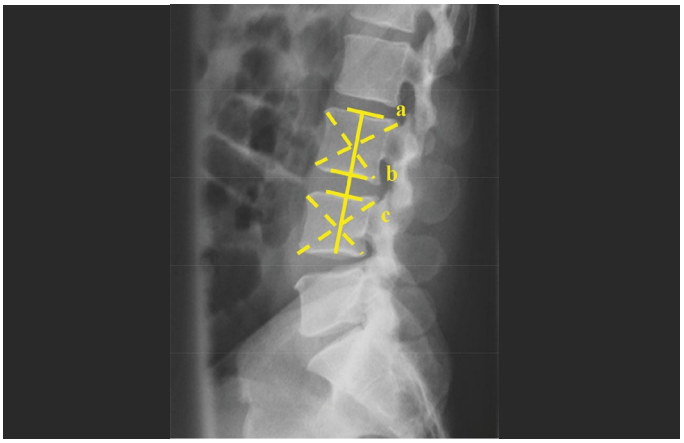

Figure 2. Calculation of the disk height index. The heights of the vertebral body and disk are measured at the midvertebral line (the line passing through the centers of L4 and L5). The center of each vertebral body is the point where the two diagonal lines joining opposite corners cross each other. Disk height index=ab/bc.[8]

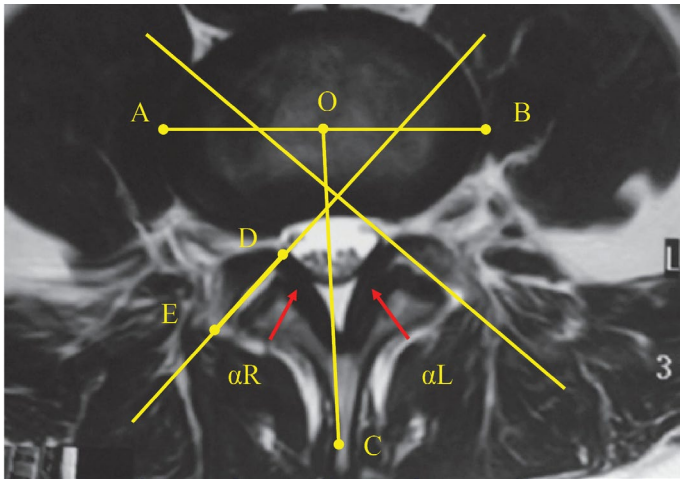

Figure 3. Diagram of the method used to measure the facet joint angle. The facet line is drawn between the 2 peaks of each of the superior articular facets (D and E). The midline is drawn through the center of the lumbar vertebral body (O, AO = OB) and the middle point of the base of the spinous process (C). The angle between the midsagittal line and facet line was measured for each side of the lumbar vertebral body (αR=right facet angle, αL=left facet angle). Facet orientation=(αR+αL)/2; Facet tropism=|αR-αL|.[8,13]

test were used to perform comparisons between the groups. Multiple logistic regression analysis was used to identify independent risk factors for rLDH. Univariate and multiple logistic regression analysis was used to evaluate the effect of each factor on the rLDH. The overall assessment of the calculation model and data returns was assessed using the Hosmer–Lemeshow test. The threshold level of statistical significance was set at $p<0.05$.

RESULTS

Patient characteristics

All cases in the clinical study were followed up for more than 5 years postoperatively (median 87 months, range 67-112 months). The rLDH group was composed of 31 male and 12 female, whose ages ranged from 18 to 57 years (34.8±9.5 years). The non-rLDH group was composed of 97 male and 78 female, whose ages ranged from 19 to 73 years (47.5±9.8 years). Of the 43 rLDH clinical cases, ipsilateral and contralateral rLDH happened in 29 and 14 cases, respectively (Table 1).

Univariate analysis

An univariate analysis of the influence of various clinical (age, gender, BMI, diabetes, current smoking, sports activity, occupational lifting, occupational driving, trauma history, preoperative VAS, procedures) and radiologic parameters (herniation type, grade of disk degeneration, DHI, FO, FT, sROM, ADC) on the risk of rLDH showed the following results. Gender ($p=0.029$), age ($p=0.037$), current smoking ($p=0.024$), BMI ($p=0.032$), trauma history ($p=0.016$), LDH type ($p=0.008$), grade of disk degeneration ($p=0.007$), DHI ($p=0.015$), FT ($p=0.019$), sROM ($p=0.014$) and ADC ($p=0.005$) are associated with incidence of rLDH (Table 2).

Multiple logistic regression analysis

Based on the results of a univariate analysis, a binary logistic regression model was constructed with the inclusion of parameters that are statistically significantly associated with incidence of rLDH. According to the constructed model, BMI ($p=0.021$), current smoking ($p=0.017$), stage of disk degeneration ($p=0.043$), FT ($p=0.037$), DHI ($p=0.018$) and ADC ($p=0.009$) are significantly associated with incidence of rLDH. The Hosmer–Lemeshov test demonstrated a high degree of consistency between the constructed model and the data obtained ($\chi^2=4.115$, $p=0.479$).

Table 1. Preoperative patient characteristics and risk factors for rLDH using univariate analysis.

Characteristic	rLDH group (n = 43)	non-rLDH group (n = 175)	p
Gender, male/female	31/12	97/78	0.029
Age, years	34.8±9.5	43.5±9.8	0.037
BMI, kg/m^2	29.0±6.1	27.0±4.3	0.032
Current smoking, n (%)	21 (48.8)	35 (20)	0.024
Alcohol, n (%)	4 (9.3)	17 (9.7)	0.674
Diabetes mellitus, n (%)	7 (16.2)	24 (13.7)	0.328
Occupational lifting, n (%)	19 (44.1)	26 (14.8)	0.419
Occupational driving, n (%)	8 (18.6)	25 (14.2)	0.605
Sports activity, n (%)	13 (30.2)	26 (14.8)	0.262
Trauma history, n (%)	28 (65.1)	34 (19.4)	0.016
Preoperative VAS score for leg	5.4±1.4	6.1±1.5	0.775
Preoperative VAS score for back	3.1±1.1	3.9±1.5	0.811
Surgical procedure type, n (%)			0.127
Microdiscectomy with laminotomy	35 (81.3)	162 (92.5)	
Microdiscectomy with hemilaminotomy	7 (16.2)	11 (6.2)	
Microdiscectomy with total laminotomy	1 (2.3)	2 (1.1)	
LDH type, n (%)			0.008
Protrusion	5 (11.6)	10 (5.7)	
Extrusion	30 (69.7)	149 (85.1)	
Sequestration	8 (18.7)	16 (9.2)	
Grade of disk degeneration, n (%)			0.007
I	1 (2.3)	2 (1.1)	
II	3 (6.9)	5 (2.8)	
III	12 (27.9)	69 (39.4)	
IV	26 (60.6)	95 (54.5)	
V	1 (2.3)	4 (2.2)	
DHI	0.36±0.06	0.28±0.05	0.015
sROM, deg	13.1±1.61	7.03±1.78	0.014
FO, deg	43.2±4.85	48.4±6.01	0.305
FT, deg	5.95±2.2	3.19±1.64	0.019
ADC, mm^2/sec	998.9±117.4	1275.6±224.8	0.005

LDH, recurrent lumbar disk herniation; BMI, body-mass index; VAS, visual analogue scale; DHI, disc height index; sROM, sagittal range of motion; FO, facet orientation; FT, facet tropism; ADC, apparent diffusion coefficient.

Table 2. Risk factors for rLDH using multiple logistic regression analysis.

Characteristic	OR	95 % CI	p
Gender, male/female	1.422	1.214–1.652	0.376
Age, years	0.515	0.154–0.987	0.632
BMI (≥25), kg/m^2	1.206	1.195–1.325	0.021
Current smoking, n (%)	0.898	0.512–1.481	0.017
Trauma history, n (%)	1.108	1.054–1.347	0.819
LDH type (extrusion), n (%)	1.025	0.783–1.461	0.372
Grade of disk degeneration (III), n (%)	0.937	0.169–1.572	0.043
DHI	1.606	1.087–2.013	0.018
sROM, deg	0.889	0.054–1.009	0.457
FT, deg	1.465	1.103–1.918	0.037
ADC (<1200), mm^2/sec	2.345	1.875–3.025	0.009

OR, odds ratio; 95 % CI, 95 % confidence interval; LDH, recurrent lumbar disk herniation; BMI, body-mass index; DHI, disc height index; sROM, sagittal range of motion; FT, facet tropism; ADC, apparent diffusion coefficient.

DISCUSSION

This clinical study was to investigate the current evidence on risk factors for rLDH. In our study body mass index, current smoking, stage of disk degeneration, facet tropism, disk height index and apparent diffusion coefficient are significantly associated with incidence of rLDH. Previous studies have explored many potential risk factors for rLDH, such as age, gender, BMI, current smoking, diabetes mellitus, type of LDH, DHI, and so on.[6–10] For example, Cinotti et al.[14] reported that some risk factors were found to be associated with rLDH; male patients with marked degenerated discs were more likely to experience IDH, particularly after an isolated injury or a precipitating event. Suk et al.[15] reported young age, male gender, current smoking, and traumatic events as risk factors for rLDH. Carragee et al.[16] found that the degree of annular competence after microdiscectomy and the type of herniation were correlated with the recurrent rates after microdiscectomy. Belykh et al.[9] noted that seven parameters were significant predictors of rLDH at the level of the previous microdiscectomy: BMI, DHI, hypermobility of the spinal motion segment, flattening of lumbar lordosis, current smoking, disc protrusion, and Pfirrmann grade III disc degeneration. Huang et al.[10] in their meta-analysis showed that smoking, disc protrusion, and diabetes were predictors for rLDH. However, we demonstrated that only BMI, current smoking, stage of disc degeneration, FT, DHI and ADC had significantly association with rLDH.

The exact mechanism why smoking leads to rLDH is still incompletely understood. Previous studies have explored the potential mechanism.[10,17,18] The defect in the annulus fibrosus and posterior longitudinal ligament after microdiscectomy is thought to heal in normal physiological conditions. However, toxins generated by cigarette smoking may impair or delay these normal conditions.[17] Previous study demonstrated that nicotine affected disk annulus nutrition and oxygenation. Gill et al.[18] compared the ligament healing process in passively smoking mice with nonsmoking mice and found that cellular density in the injured ligament was significantly lower in the smoking mice. Also, the smoking mice exhibited lower type I collagen expression in the injured ligament, which was identified as the major structural component of extracellular matrix. Besides cellular and molecular changes, repetitive cough caused by smoking increased intervertebral pressure, which may also partly contribute to rLDH.[19]

The association of disc degeneration stage with the risk of rLDH was previously suggested by Kim et al.[20] and also confirmed in our clinical study. There were only grades 4 and 3 recorded in our study, and grade 3 had higher odds of recurrence than grade 4. Grade 4 is associated with disc collapse, and such patients either had not presented with rLDH or were treated with fusion and were not included in our study. Pfirrmann grade 1 is roughly normal and is not characteristic of rLDH, while grade 2 disks have clear differentiation between the nucleus and annulus with normal or slightly decreased disc height.

The results of this clinical study are aligned with the results of basic biomechanical studies of the rLDH development. In biomechanical *ex vivo* models, rLDH was produced by a highly compressive load at high flexion angles due to the rupture of collagen fibers of the annulus at the site of attachment to the vertebral endplate. Endplate changes may also contribute to decreased collagen fiber attachment to the annulus and may explain the increased risk of rLDH. The study findings indicate that increased DHI and increased sROM are significant risk factors of rLDH. From the biomechanical point of view, larger disc height before discectomy could lead to a higher disc height decrease after nucleus removal and increased segmental mobility.[21,22]

As well known, quantitative and qualitative evaluation of ADC mapping may provide additional useful information regarding the fluid dynamics of the degenerated spine and may complement standard MRI imaging protocol for the comprehensive assessment of surgical patients with lumbar spine pathology. ADC maps were advantageous in differentiating reactive bone marrow changes, and more precise assessment of the disc degeneration state.[23] To the best of our knowledge, we did not find studies which investigated the role of ADC as a risk of rLDH developing after microdiscectomy. In this study we noted that ADC ($<$1200 mm^2/sec) had significantly association with rLDH. ADC mapping of disc as a risk of rLDH showed promise but requires further investigation on a larger cohort of patients.

Study limitations

There are several limitations of this study. First, this was a retrospective clinical study, and the number of patients with rLDH in this study was relatively small. Second, the sROM was checked only from the sagittal view. Multidirectional measurement of the lumbar segment was desirable, but we obtained only flexion and extension views. In addition, we did not assess patients who underwent discectomy at the L1-L2 and L3-L4 levels because there were no rLDH at this level. Thus, our results should be extrapolated at theL1-L2 and L3-L4 levels with caution.

CONCLUSIONS

This retrospective clinical study showed that a high DHI, a large FT, a high stage of disk degeneration and a small ADC are radiologic risk factors of rLDH. The results also suggested being current smoking and higher BMI are increase a risk of rLDH after microdiscectomy. Patients with these risk factors should be paid more attention for prevention of rLDH.

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REFERENCES

1. van der Windt DA, Simons E, Riphagen II, Ammendolia C, Verhagen AP, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. Cochrane Database Syst Rev. 2010;17(2):CD007431. doi:10.1002/14651858.CD007431.pub2.
2. Rogerson A, Aidlen J, Jenis LG. Persistent radiculopathy after surgical treatment for lumbar disc herniation: causes and treatment options. Int Orthop. 2019;43(4):969-73. doi:10.1007/s00264-018-4246-7.
3. Kim M, Lee S, Kim HS, Park S, Shim SY, Lim DJ. A Comparison of Percutaneous Endoscopic Lumbar Discectomy and Open Lumbar Microdiscectomy for Lumbar Disc Herniation in the Korean: A Meta-Analysis. Biomed Res Int. 2018;2018:9073460. doi:10.1155/2018/9073460.
4. Camino Willhuber G, Kido G, Mereles M, Bassani J, Petracchi M, Elizondo C, et al. Factors associated with lumbar disc hernia recurrence after microdiscectomy. Factores asociados a recidiva de hernia de disco lumbar luego de una microdiscectomía. Rev Esp Cir Ortop Traumatol. 2017;61(6):397-403. doi:10.1016/j.recot.2017.07.002.
5. Ahsan MK, Hossain MR, Khan MSI, Zaman N, Ahmed N, Montemurro N, et al. Lumbar revision microdiscectomy in patients with recurrent lumbar disc herniation: A single-center prospective series. Surg Neurol Int. 2020;11:404. doi:10.25259/SNI_540_2020.
6. Kim KT, Park SW, Kim YB. Disc height and segmental motion as risk factors for recurrent lumbar disc herniation. Spine. 2009;34(24):2674-8. doi:10.1097/BRS.0b013e3181b4aaac.
7. Li Z, Yang H, Liu M, Lu M, Chu J, Hou S, et al. Clinical Characteristics and Risk Factors of Recurrent Lumbar Disk Herniation: A Retrospective Analysis of Three Hundred Twenty-One Cases. Spine. 2018;43(21):1463-9. doi:10.1097/BRS.0000000000002655.
8. Belykh E, Krutko AV, Baykov ES, Giers MB, Preul MC, Byvaltsev VA. Preoperative estimation of disc herniation recurrence after microdiscectomy: predictive value of a multivariate model based on radiographic parameters. Spine. 2017;17(3):390-400. doi:10.1016/j.spinee.2016.10.011.
9. Huang W, Han Z, Liu J, Yu L, Yu X. Risk Factors for Recurrent Lumbar Disc Herniation: A Systematic Review and Meta-Analysis. Medicine (Baltimore). 2016;95(2):e2378. doi:10.1097/MD.0000000000002378.

10. Truumees E, Geck M, Stokes JK, Singh D. Lumbar Microdiscectomy. JBJS Essent Surg Tech. 2016;6(1):e3. doi:10.2106/JBJS.ST.N.00093.
11. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N. Magnetic resonance classification of lumbar intervertebral disc degeneration. Spine. 2001;26(17):1873-8. doi:10.1097/00007632-200109010-00011.
12. Noren R, Trafimow J, Andersson GB, Huckman MS. The role of facet joint tropism and facet angle in disc degeneration. Spine. 1991;16(5):530-2. doi:10.1097/00007632-199105000-00008.
13. Cinotti G, Roysam GS, Eisenstein SM, Postacchini F. Ipsilateral recurrent lumbar disc herniation. A prospective, controlled study. J Bone Joint Surg Br. 1998;80(5):825-32. doi:10.1302/0301-620x.80b5.8540.
14. Suk KS, Lee HM, Moon SH, Kim NH. Recurrent lumbar disc herniation: results of operative management. Spine. 2001;26(6):672-6. doi:10.1097/00007632-200103150-00024.
15. Carragee EJ, Han MY, Suen PW, Kim D. Clinical outcomes after lumbar discectomy for sciatica: the effects of fragment type and anular competence. J Bone Joint Surg Am. 2003;85(1):102-8.
16. Møller AM, Pedersen T, Villebro N, Munksgaard A. Effect of smoking on early complications after elective orthopaedic surgery. J Bone Joint Surg Br. 2003;85(2):178-81. doi:10.1302/0301-620x.85b2.13717.
17. Gill CS, Sandell LJ, El-Zawawy HB, Wright RW. Effects of cigarette smoking on early medial collateral ligament healing in a mouse model. J Orthop Res. 2006;24(12):2141-9. doi:10.1002/jor.20234.
18. Nemoto Y, Matsuzaki H, Tokuhasi Y, Okawa A,Uematu Y, Nishimura T, et al. Histological changes in intervertebral discs after smoking and cessation: experimental study using a rat passive smoking model. J Orthop Sci. 2006;11(2):191-7. doi:10.1007/s00776-005-0987-4.
19. Kim JM, Lee SH, Ahn Y, Yoon DH, Lee CD, Lim ST. Recurrence after successful percutaneous endoscopic lumbar discectomy. Minim Invasive Neurosurg. 2007;50(2):82-5. doi:10.1055/s-2007-982504.
20. Hampton D, Laros G, McCarron R, Franks D. Healing potential of the anulus fibrosus. Spine. 1989;14(4):398-401. doi:10.1097/00007632-198904000-00009.
21. Osti OL, Vernon-Roberts B, Fraser RD. 1990 Volvo Award in experimental studies. Anulus tears and intervertebral disc degeneration. An experimental study using an animal model. Spine. 1990;15(8):762-7. doi:10.1097/00007632-199008010-00005.
22. Belykh E, Kalinin AA, Patel AA, Miller EJ, Bohl MA, Stepanov IA, et al. Apparent diffusion coefficient maps in the assessment of surgical patients with lumbar spine degeneration. PLoS One. 2017;12(8):e0183697. doi:10.1371/journal.pone.0183697.