

Risk Factors of Secondary Lumbar Discectomy of a Herniated Lumbar Disc after Lumbar Discectomy

Joo Yul Beack,¹ Hyoung Joon Chun,¹ Koang Hum Bak,¹ Kyu-Sun Choi,¹ In-Suk Bae,¹ Kee D. Kim²

Department of Neurosurgery,¹ Hanyang University Medical Center, Seoul, Korea
Department of Neurological Surgery,² University of California, Davis, CA, USA

Objective : To study risk factors of secondary lumbar discectomy (LD) for recurrent herniated lumbar disc (HLD) and identify methods to lower the rate of recurrence.

Methods : Data from 160 patients who underwent primary LD were collected retrospectively. Demographic features, radiologic findings including Pfirrmann disc degeneration, and surgical information were analyzed to compare risks between revision and non-revision patients.

Results : The revision rate was 15% (24 patients), and the mean follow-up was 28.3 months. HLD recurrence was not related to any demographic characteristics. Primary and secondary LD were most common at the L4–5 level, but the level of operation was not significantly associated with revision. Primary LD most commonly had a Pfirrmann disc degeneration grade of 3, followed by 4. For recurrent HLD, Pfirrmann grade 4 was most common and was statistically significant ($p < 0.05$). A body mass index (BMI) over 30 was considered obese and was significantly related with HLD revision ($p < 0.05$).

Conclusion : Patients with high BMI or severe disc degeneration should be informed of HLD revision.

Key Words : Body mass index · Discectomy · Recurrence · Reoperation.

INTRODUCTION

Lumbar discectomy (LD) is performed in patients with radicular pain caused by a herniated lumbar disc (HLD) after failed conservative treatments including medication, physiotherapy, and various neural blocks²³. Considerable research has studied LD surgical techniques including open lumbar discectomy, microendoscopic discectomy, percutaneous endoscopic lumbar discectomy, and other modified techniques⁴.

Results of surgical LD are unsatisfactory in 3% to 19% of patients due to outcomes such as sustained pain, caudae equinae, and recurrence. By radiologic imaging, recurrent HLD is found in 5% to 15% of these patients, and unresolved symptoms might lead to a secondary operation^{17,19,23}.

Risk factors of HLD recurrence including age, sex, body mass index (BMI), symptom duration, type of herniation, level of operation, degenerative changes, disc volume, and operative technique have been studied^{3,22,37}.

• Received : April 4, 2019 • Revised : May 12, 2019 • Accepted : May 30, 2019

• Address for reprints : **Hyoung Joon Chun**

Department of Neurosurgery, Hanyang University Medical Center, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Korea

Tel : +82-2-2290-8494, Fax : +82-2-2281-0954, E-mail : tdy815@hanayang.ac.kr, ORCID : <https://orcid.org/0000-0001-9862-058X>

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

The purpose of this study was to investigate risk factors of secondary LD for recurrent HLD from a single surgeon's data.

MATERIALS AND METHODS

Owing to the retrospective nature of the study, this study was not approved by the Institutional Review Board of Hanyang University Medical Center. Our study population in-

cluded 160 patients who underwent open microscopic LD between 2009 and 2016 by a single surgeon in Hanyang University Medical Center.

Demographic information (age, sex, BMI, hypertension, diabetes mellitus, smoking, vertebral level of operation, and type of operation) and radiologic features (type of disc herniation, location of herniation, degree of disc degeneration, disc height, and height of vertebral body) were obtained retrospectively (Table 1). Postoperative magnetic resonance imaging

Table 1. Demographic features and surgical information

	Total (n=160)	Non-recurred (n=136)	Recurred (n=24)	p-value
Age	56.0 (38.5–68.5)	56.0 (38.5–66.0)	56.5 (46.0–68.5)	0.530
Sex				0.673
Male	70 (43.8)	60 (44.1)	10 (41.7)	
Female	90 (56.2)	76 (55.9)	14 (58.3)	
Hypertension	51 (31.9)	45 (33.1)	6 (25.0)	0.585
Diabetes mellitus	26 (16.2)	20 (14.7)	6 (25.0)	0.337
Smoking	32 (20.0)	25 (18.4)	7 (29.2)	0.347
Body mass index	27.2 (24.7–32.8)	26.9 (24.7–29.5)	29.8 (27.1–32.8)	0.011*
Disc type				0.270
Protrusion	54 (33.8)	46 (33.8)	8 (33.3)	
Extrusion	69 (43.1)	61 (44.9)	8 (33.3)	
Sequestration	37 (23.1)	29 (21.3)	8 (33.3)	
Pfirrmann disc degeneration grade				0.001*
Grade 2	7 (4.4)	7 (5.1)	0 (0.0)	
Grade 3	92 (57.5)	85 (62.5)	7 (29.2)	
Grade 4	61 (38.1)	44 (32.4)	17 (70.8)	
Disc height	9.4±2.0	9.4±2.1	9.5±1.7	0.747
Body height	23.0±2.2	23.0±2.2	23.3±2.2	0.621
Disc/body height	0.4±0.1	0.4±0.1	0.4±0.1	0.921
Level of operation				0.183
L1–2	1 (0.6)	1 (0.7)	0 (0.0)	
L2–3	7 (4.4)	3 (2.2)	4 (16.7)	
L3–4	14 (8.8)	10 (7.4)	4 (16.7)	
L4–5	85 (53.1)	75 (55.1)	10 (41.7)	
L5–S1	43 (26.9)	37 (27.2)	6 (25.0)	
Multilevel	10 (6.3)	10 (7.4)	0 (0.0)	
Type of operation				0.542
Partial hemilaminectomy+lumbar discectomy	98 (61.2)	83 (61.0)	15 (62.5)	
Partial hemilaminectomy+foraminotomy+lumbar discectomy	62 (38.8)	53 (39.0)	9 (37.5)	

Values are presented as mean±standard deviation, number (range), or number (%). *p value <0.05 is statistically significant by univariate logistic regression

(MRI) was performed in patients with symptoms to confirm recurrence.

By assessing axial and sagittal MRI, herniation type was classified as protrusion, extrusion, or sequestration. Protrusion was a focal protrusion with an intact annulus fibrosus. Extrusion was a penetration of the nucleus pulposus (NP) through a defect in the annulus fibrosus. Sequestration was defined as a particle-free spinal canal.

The degree of disc degeneration was graded according to the Pfirrmann disc degeneration grade from using sagittal T2-weighted MRI (Table 2). Disc height, vertebral body height and disc/vertebral body height ratio was estimated from the height of the disc and vertebral body in T2-weighted sagittal MRI. All patients were performed with discectomy and sequestration, and foraminotomy was performed in patients with foraminal stenosis on MRI finding. And the operation type was classified by degree of bone loss in the lamina and facet during primary surgery.

Statistical analysis was performed as follows. A logistic univariate regression was used to identify risk factors of HLD revision. Variables that were independent risk factors of secondary LD for recurrent HLD were analyzed by multivariate logistic regression, and the results were reported as an adjusted odds ratio (OR) and 95% confidence interval (CI). A *p*-value <0.05 was considered to indicate a risk factor of HLD recurrence. All data were analyzed with R version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria).

Probability of revision surgery was assessed using the Kaplan-Meier method and log-rank tests.

Variables with a *p*-value <0.10 were re-entered in the multivariable logistic regression model using a backward stepwise method. To evaluate risk factors for revision, a multivariate logistic regression model with a backward stepwise method

was used. ORs and 95% CI were reported for statistically significant factors (*p*-value <0.05). All data were analyzed with R, version 3.3.2 (<https://www.r-project.org/>; R Foundation for Statistical Computing).

RESULTS

One hundred sixty patients underwent primary LD during the study period, and 24 patients underwent secondary LD. Patients with revision and non- revision HLD were of similar age (56.0 vs. 56.5 years). Also, sex did not differ between groups. In total, 51 patients had hypertension, 45 in the non-recurrent group (33.1%) and six in the revision group (25.0%).

In the revision HLD group, the incidence of diabetes mellitus and smoking was more than 1.5 times higher than in the non- revision group, but the difference was not statistically significant (*p*>0.05).

Herniated discs were classified as protrusion (54 patients), extrusion (69 patients), or sequestration (37 patients). In each group, eight patients underwent a second operation for revision HLD.

The highest revision rate (41.7%) occurred at level L4–5 in 10 of 85 patients, followed by level L5–S1 in six of 43 patients (25.0%). Four patients each had revision at level L2–3 or L3–4. Ten patients had a multi-level operation with no evidence of revision. Consequently, the level of operation was not statistically significant.

Demographic features and surgical information of our patients are listed in Table 1. Symptoms due to HLD recurrence were the only complication collected from our database.

A univariate analysis reported that Pfirrmann grade and BMI differed significantly between groups.

Table 2. Pfirrmann disc degeneration grade

Grade	Structure	Distinction of nucleus and annulus fibrosus	Signal intensity	Intervertebral disc height
1	Homogenous, bright white	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
2	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
3	Inhomogeneous, gray	Unclear	Intermediate	Normal to slightly decreased
4	Inhomogeneous, gray to black	Lost	Intermediate to hypointense	Normal to moderately decreased
5	Inhomogeneous, black	Lost	Hypointense	Collapsed

We estimated disc degeneration using Pfirrmann disc degeneration grade. Most patients were grade 3 (92 patients), followed by grade 4 (61 patients) and grade 2 (seven patients). No patients were grade 1 or 5. In the revision HLD group, 17 patients (70.8%) were grade 4 and the rest were grade 3. Further analysis demonstrated that higher Pfirrmann grade was associated with an increased revision rate.

The association between BMI and HLD revision was also statistically significant ($p < 0.05$). The mean BMI of the revision HLD group was 29.8 (range, 27.1–32.8), and the mean BMI of the non-revision HLD group was 26.9 (range, 24.7–29.5). The total mean BMI was 27.2 (range, 24.7–32.8). We included overweight patients in the non-obese group. Obese patients were at 1.2-times higher risk for revision than were non-

obese patients (OR, 1.20; 95% CI, 1.06–1.37) (Table 3).

Table 4 shows the univariate and multivariate logistic regression analysis of revision surgery. Two variables remained statistically significant after adjusting for confounding factors: 1) Body mass index (OR, 1.30; 95% CI, 1.12–1.52; $p = 0.0007$) and 2) Pfirrmann disc grade (OR, 2.13; 95% CI, 1.29–2.97; $p = 0.0002$).

Fig. 1 shows the Kaplan-Meier curves of the cumulative hazards of revision surgery stratified by BMI categories. Probability of revision surgery in obese group was significantly higher than normal and overweight group (log-rank test, $p < 0.001$). With increased BMI over 30, cumulative revision risk gradually increased.

Table 3. Distribution of recurrence of a herniated lumbar disc by BMI

	BMI		
	Normal (BMI <25)	Overweight (25 ≤ BMI <30)	Obese (BMI ≥30)
Non-recurred (n=136)	23	52	61
Recurred (n=24)	3	8	13

BMI : body mass index

DISCUSSION

The rate of HLD recurrence has not been well defined. The rates of HLD recurrence have a wide range because they can include disc herniations at the same level on the ipsilateral or contralateral side as the previous LD^{28,37,38}. However, our study only included patients with recurrent HLD at the same level and on the same side, which we considered to be more appro-

Table 4. Logistic regression analysis for revision surgery

Variable	Univariate		Multivariate	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Sex	0.55 (0.10–3.03)	0.4459		
Age	1.01 (0.97–1.16)	0.5103		
Height	0.95 (0.86–1.04)	0.2282		
Weight	1.07 (0.95–1.19)	0.2858		
Body mass index	1.77 (1.13–2.41)	0.0185	1.30 (1.12–1.52)	0.0007
Disc type	0.83 (0.76–0.91)	0.9155		
Pfirrmann disc grade	3.14 (2.67–3.61)	0.0006	2.13 (1.29–2.97)	0.0002
Disc height	0.87 (0.38–1.99)	0.5904		
Body height	1.07 (0.96–1.18)	0.7193		
Disc/body height	0.80 (0.40–1.59)	0.7458		
Level of surgery	1.24 (0.58–2.65)	0.4486		
Type of surgery	0.59 (0.26–1.32)	0.6762		
Smoking	1.12 (0.92–1.33)	0.5274		
Hypertension	1.80 (0.57–3.69)	0.3154		
Diabetes mellitus	1.28 (0.30–2.23)	0.7431		

OR : odds ratio, CI : confidence interval

appropriate. And Patients with recurrent symptoms, with radiographic evidence of recurrent HLD at the same side were considered to recurrence group. The revision group was defined as the group of patients who had secondary LD for persistent symptoms after conservative treatment (Fig. 2).

Various studies have reported HLD recurrence after LD, and 5% to 15% of patients undergo secondary LD^{20,24}. Our study reported a 15% incidence of recurrence within a mean of 28.3 months. This study only includes patients with secondary LD. If we included patients who underwent spinal fusion due to back pain caused by instability, the recurrence rate would be much higher.

Proposed risk factors of HLD recurrence include age, sex, smoking, BMI, trauma, symptom duration, herniation type, level of the operation, degeneration, disc volume, and operative technique. Some researchers have found statistically significant differences based on age, sex, BMI, or degeneration. Our study found a statistically significant association with BMI and degeneration^{3,22,37}.

The intervertebral disc consists of an inner NP and an outer annulus fibrosus. The NP comprises mainly proteoglycans with type II collagen, and the annulus fibrosus comprises type I collagen. The proteoglycans, mostly aggrecans, bind with water to endure compressive loads and maintain tension on

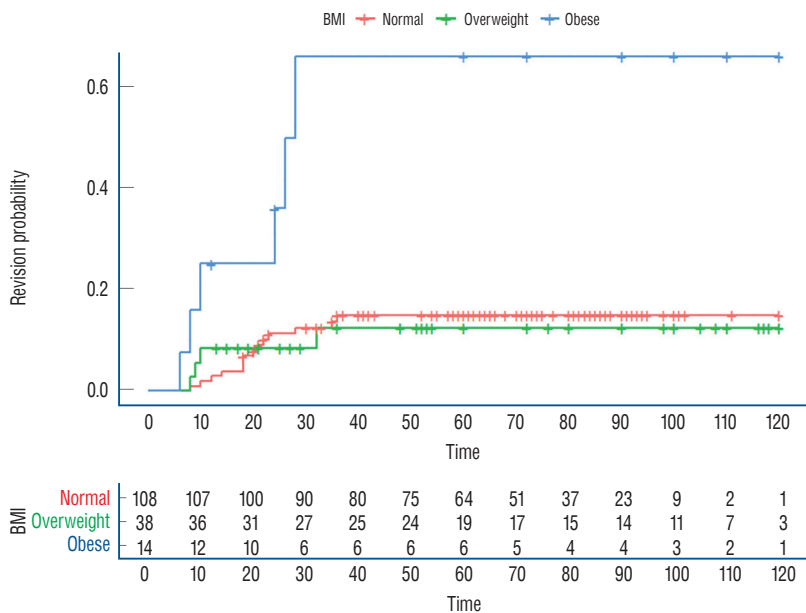


Fig. 1. Kaplan-Meier curves of cumulative hazards of revision surgery stratified by BMI categories (normal weight <25.0, overweight 25.0–30.0, obesity ≥30.0 kg/m²). log-rank test, *p*<0.001. BMI : body mass index.

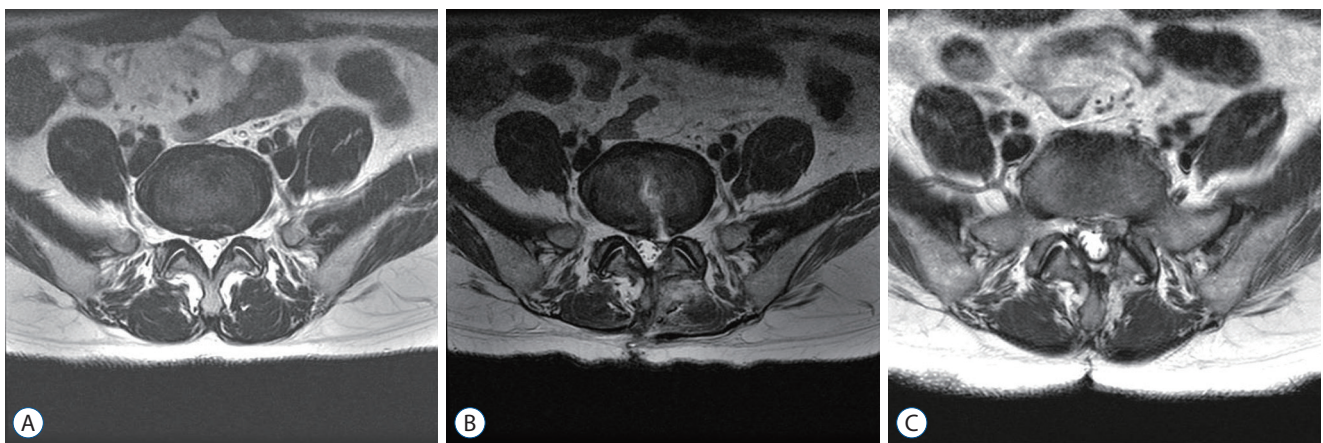


Fig. 2. A : MRI at the time of initial surgery decision. B : MRI at the time of recurrence of symptoms. C : MRI at the time of revision surgery decision. MRI : magnetic resonance image.

the annulus fibrosus^{16,33}). When disc degeneration begins, cytokine levels increase and elevate aggrecans and matrix metalloproteinases. This process results in cleavage of NP substances and leads to loss of disc height¹. Pfirrmann et al.³² studied this signal change on T2-weighted MRI, where a loss of brightness reflects proteoglycan degradation and water content^{10,12,33}).

We found a statistically significant association between disc degeneration assessed with the Pfirrmann disc degeneration grade and HLD revision ($p < 0.01$). Cinotti et al.⁵ reported that, in severe degenerative disc patients, the annulus fibrosus showed a markedly low recovery rate after primary LD, and the attenuated portion of the annulus fibrosus would aggravate recurrent HLD.

However, Dora et al.⁸ reviewed the relationship between disc degeneration assessed with five grading systems and HLD recurrence. They reported that patients with relatively low-grade disc degeneration had a greater risk of recurrence. However, they included 60 non-randomized patients into each of the study and control groups. The correlation between age and Pfirrmann grade was found to be significant by Okada et al.²⁵. Dora et al.⁸ did not consider older patients with a high Pfirrmann grade who underwent spinal fusion instead of LD due to spinal instability as a secondary operation. Therefore, a large randomized study with long-term follow-up should be considered⁸).

High BMI is a well-known negative factor in spinal health and other general conditions^{6,7,9,13,14,21,26-31,35,39}). Our study classified patients as normal (BMI under 25), overweight (BMI 25 to 30), or obese (BMI over 30). We compared obese and non-obese patients and found that obese patients were significantly more likely to have HLD revision ($p = 0.0045$). The idea that compressive loading on an intervertebral disc with a single or multiple stimuli after primary LD could result in HLD recurrence was suggested by Kelsey et al.¹⁸) and Meredith et al.²¹). In addition, biomechanical reviews have explained that repetitive increased tension on the annulus fibrosus greatly increases the risk of tearing in the posterolateral portion, leading to HLD. In obese patients, the axial load on the intervertebral disc is higher than in non-obese patients during weight bearing by the spinal column, consequently increasing HLD. Furthermore, a forward flexed position in obese patients could increase the HLD recurrence rate^{2,11,15,34,36,40}). Using BMI, which only considers height and weight, we might have misclassified

patients who had high BMI due to high muscular mass as obese.

One limitation of our study is the small number of patients from a single medical center. Moreover, the retrospective medical information could introduce selection bias. Further study is required to assess the previously discussed factors in multiple hospitals over the long term. In this study, LD was the only reoperation considered. However, other procedure to assess spinal instability due to previous operations or aging should also be considered.

CONCLUSION

In our study, Pfirrmann disc degeneration grade and BMI were statistically significantly associated with HLD revision. After LD, surgeons should counsel patients with high BMI and degeneration on risk of revision.

The total numbers of patients and patients who underwent secondary LD were small, so further evaluation should be planned to confirm these results.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

INFORMED CONSENT

This type of study does not require informed consent.

AUTHOR CONTRIBUTIONS

Conceptualization : JYB, HJC

Data curation : JYB, HJC, KDK

Formal analysis : ISB

Methodology : JYB, HJC

Project administration : HJC, KHB

Visualization : JYB, KSC

Writing - original draft : JYB, HJC

Writing - review & editing : JYB, HJC

References

1. Akyol S, Eraslan BS, Etyemez H, Tanriverdi T, Hanci M : Catabolic cytokine expressions in patients with degenerative disc disease. **Turk Neurosurg** 20 : 492-499, 2010
2. Callaghan JP, McGill SM : Intervertebral disc herniation: studies on a porcine model exposed to highly repetitive flexion/extension motion with compressive force. **Clin Biomech (Bristol, Avon)** 16 : 28-37, 2001
3. 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** 85 : 102-108, 2003
4. Cheng J, Wang H, Zheng W, Li C, Wang J, Zhang Z, et al. : Reoperation after lumbar disc surgery in two hundred and seven patients. **Int Orthop** 37 : 1511-1517, 2013
5. Cinotti G, Roysan GS, Eisenstein SM, Postacchini F : Ipsilateral recurrent disc herniation. A prospective, controlled study. **J Bone Joint Surg Br** 80 : 825-832, 1998
6. Cole JS 4th, Jackson TR : Minimally invasive lumbar discectomy in obese patients. **Neurosurgery** 61 : 539-544, 2007
7. Djurasovic M, Bratcher KR, Glassman SD, Dimar JR, Carreon LY : The effect of obesity on clinical outcomes after lumbar fusion. **Spine (Phila Pa 1976)** 33 : 1789-1792, 2008
8. Dora C, Schmid MR, Elfering A, Zanetti M, Hodler J, Boos N : Lumbar disk herniation: do MR imaging findings predict recurrence after surgical discectomy? **Radiology** 235 : 562-567, 2005
9. Dossett LA, Heffernan D, Lightfoot M, Collier B, Diaz JJ, Sawyer RG, et al. : Obesity and pulmonary complications in critically injured adults. **Chest** 134 : 974-980, 2008
10. Emanuel KS, Vergroesen PP, Peeters M, Holeywijn RM, Kingma I, Smit TH : Poroelastic behaviour of the degenerating human intervertebral disc: a ten-day study in a loaded disc culture system. **Eur Cell Mater** 29 : 330-340, 2015
11. Fabris de Souza SA, Faintuch J, Valezi AC, Sant'Anna AF, Gama-Rodrigues JJ, de Batista Fonseca IC, et al. : Postural changes in morbidly obese patients. **Obes Surg** 15 : 1013-1016, 2005
12. Farshad-Amacker NA, Farshad M, Winklehner A, Andreisek G : MR imaging of degenerative disc disease. **Eur J Radiol** 84 : 1768-1776, 2015
13. Friedman ND, Sexton DJ, Connelly SM, Kaye KS : Risk factors for surgical site infection complicating laminectomy. **Infect Control Hosp Epidemiol** 28 : 1060-1065, 2007
14. Gepstein R, Shabat S, Arinon ZH, Berner Y, Catz A, Folman Y : Does obesity affect the results of lumbar decompressive spinal surgery in the elderly? **Clin Orthop Relat Res** 426 : 138-144, 2004
15. Gilleard W, Smith T : Effect of obesity on posture and hip joint moments during a standing task, and trunk forward flexion motion. **Int J Obes (Lond)** 31 : 267-271, 2007
16. Griffith JF, Wang YX, Antonio GE, Choi KC, Yu A, Ahuja AT, et al. : Modified Pfirrmann grading system for lumbar intervertebral disc degeneration. **Spine (Phila Pa 1976)** 32 : E708-E712, 2007
17. Ito T, Takano Y, Yuasa N : Types of lumbar herniated disc and clinical course. **Spine (Phila Pa 1976)** 26 : 648-651, 2001
18. Kelsey JL, Githens PB, O'Conner T, Weil U, Calogero JA, Holford TR, et al. : Acute prolapsed lumbar intervertebral disc. An epidemiologic study with special reference to driving automobiles and cigarette smoking. **Spine (Phila Pa 1976)** 9 : 608-613, 1984
19. Keskimäki I, Seitsalo S, Osterman H, Rissanen P : Reoperations after lumbar disc surgery: a population-based study of regional and interspecialty variations. **Spine (Phila Pa 1976)** 25 : 1500-1508, 2000
20. Kim MS, Park KW, Hwang C, Lee YK, Koo KH, Chang BS, et al. : Recurrence rate of lumbar disc herniation after open discectomy in active young men. **Spine (Phila Pa 1976)** 34 : 24-29, 2009
21. Meredith DS, Huang RC, Nguyen J, Lyman S : Obesity increases the risk of recurrent herniated nucleus pulposus after lumbar microdiscectomy. **Spine J** 10 : 575-580, 2010
22. Mobbs RJ, Newcombe RL, Chandran KN : Lumbar discectomy and the diabetic patient: incidence and outcome. **J Clin Neurosci** 8 : 10-13, 2001
23. Morgan-Hough CV, Jones PW, Eisenstein SM : Primary and revision lumbar discectomy. A 16-year review from one centre. **J Bone Joint Surg Br** 85 : 871-874, 2003
24. Oh JT, Park KS, Jung SS, Chung SY, Kim SM, Park MS, et al. : Surgical results and risk factors for recurrence of lumbar disc herniation. **Korean J Spine** 9 : 170-175, 2012
25. Okada E, Matsumoto M, Fujiwara H, Toyama Y : Disc degeneration of cervical spine on MRI in patients with lumbar disc herniation: comparison study with asymptomatic volunteers. **Eur Spine J** 20 : 585-591, 2011
26. Olsen MA, Lock-Buckley P, Hopkins D, Polish LB, Sundt TM, Fraser VJ : The risk factors for deep and superficial chest surgical-site infections after coronary artery bypass graft surgery are different. **J Thorac Cardiovasc Surg** 124 : 136-145, 2002
27. Olsen MA, Mayfield J, Laurysen C, Polish LB, Jones M, Vest J, et al. : Risk factors for surgical site infection in spinal surgery. **J Neurosurg** 98 : 149-155, 2003
28. Olsen MA, Nepple JJ, Riew KD, Lenke LG, Bridwell KH, Mayfield J, et al. : Risk factors for surgical site infection following orthopaedic spinal operations. **J Bone Joint Surg Am** 90 : 62-69, 2008
29. Olsen MA, Sundt TM, Lawton JS, Damiano RJ Jr, Hopkins-Broyles D, Lock-Buckley P, et al. : Risk factors for leg harvest surgical site infections after coronary artery bypass graft surgery. **J Thorac Cardiovasc Surg** 126 : 992-999, 2003
30. Park P, Upadhyaya C, Garton HJ, Foley KT : The impact of minimally invasive spine surgery on perioperative complications in overweight or obese patients. **Neurosurgery** 62 : 693-699, 2008
31. Patel N, Bagan B, Vadera S, Maltenfort MG, Deutsch H, Vaccaro AR, et al. : Obesity and spine surgery: relation to perioperative complications. **J Neurosurg Spine** 6 : 291-297, 2007
32. Pfirrmann CW, Metzendorf A, Zanetti M, Hodler J, Boos N : Magnetic resonance classification of lumbar intervertebral disc degeneration. **Spine (Phila Pa 1976)** 246 : 1873-1878, 2001
33. Rim DC : Quantitative Pfirrmann disc degeneration grading system to overcome the limitation of Pfirrmann disc degeneration grade. **Korean**

- J Spine 13** : 1-8, 2016
34. Rodacki AL, Fowler NE, Provensi CL, Rodacki Cde L, Dezan VH : Body mass as a factor in stature change. **Clin Biomech (Bristol, Avon) 20** : 799-805, 2005
 35. Rosen DS, Ferguson SD, Ogden AT, Huo D, Fessler RG : Obesity and self-reported outcome after minimally invasive lumbar spinal fusion surgery. **Neurosurgery 63** : 956-960, 2008
 36. Schmidt H, Kettler A, Heuer F, Simon U, Claes L, Wilke HJ : Intradiscal pressure, shear strain, and fiber strain in the intervertebral disc under combined loading. **Spine (Phila Pa 1976) 32** : 748-755, 2007
 37. Suk KS, Lee HM, Moon SH, Kim NH : Recurrent lumbar disc herniation: results of operative management. **Spine (Phila Pa 1976) 26** : 672-676, 2001
 38. Swartz KR, Trost GR : Recurrent lumbar disc herniation. **Neurosurg Focus 15** : E10, 2003
 39. Tucker MC, Schwappach JR, Leighton RK, Coupe K, Ricci WM : Results of femoral intramedullary nailing in patients who are obese versus those who are not obese: a prospective multicenter comparison study. **J Orthop Trauma 21** : 523-529, 2007
 40. Yar T : Spinal shrinkage as a measure of spinal loading in male Saudi university students and its relationship with body mass index. **Saudi Med J 29** : 1453-1457, 2008