Acta Neurochirurgica (2024) 166:143
https://doi.org/10.1007/s00701-024-06043-9

ORIGINAL ARTICLE

Coronal vertical fracture of vertebral body following minimally invasive lateral lumbar interbody fusion: risk factor analysis in consecutive case series

Kee-Yong Ha[1] · Young-Hoon Kim[1] · Yong-Chan Kim[2] · Hyung-Youl Park[3] · Hyun Bae[4] · Sang-Il Kim[1]

Received: 15 February 2024 / Accepted: 14 March 2024

Abstract

Background To investigate the incidence and risk factors of coronal vertical vertebral body fracture (CV-VBF) during lateral lumbar interbody fusion (LLIF) for degenerative lumbar disease.

Methods Clinical data, including age, sex, body mass index, and bone mineral density, were reviewed. Radiological assessments, such as facet joint arthrosis, intervertebral disc motion, index disc height, and cage profiles, were conducted. Posterior instrumentation was performed using either a single or staged procedure after LLIF. Demographic and surgical data were compared between patients with and without VBF.

Results Out of 273 patients (552 levels), 7 (2.6%) experienced CV-VBF. Among the 552 levels, VBF occured in 7 levels (1.3%). All VBF cases developed intraoperatively during LLIF, with no instances caused by cage subsidence during the follow-up period. Sagittal motion in segments adjacent to VBF was smaller than in others (4.6° ± 2.6° versus 6.5° ± 3.9°, $P = 0.031$). The average grade of facet arthrosis was 2.5 ± 0.7, indicating severe facet arthrosis. All fractures developed due to oblique placement of a trial or cage into the index disc space, leading to a nutcracker effect. These factors were not related to bone quality.

Conclusions CV-VBF after LLIF occurred in 2.6% of patients, accounting for 1.3% of all LLIF levels. A potential risk factor for VBF involves the nutcracker-impinging effect due to the oblique placement of a cage. Thorough preoperative evaluations and surgical procedures are needed to avoid VBF when considering LLIF in patients with less mobile spine.

Keywords Lateral lumbar interbody fusion · Complication · Vertical fracture · Nutcracker effect

Introduction

Lateral lumbar interbody fusion (LLIF) has gained popularity due to its low complication rate and short hospitalization [2, 5, 9, 13, 21]. However, LLIF procedures can result in several perioperative complications, including neurological injury, vascular injury, endplate injury, and vertebral body fracture (VBF) [1, 6, 17, 18, 25, 27]. VBF is a relatively rare intraoperative complication during LLIF. Most studies regarding VBF following LLIF have reported combined surgery using lateral plating and screws [4, 7, 15, 21, 24]. These fractures are generally unstable, necessitating a second operation such as posterior instrumented fusion for stabilization [23]. Risk factors for VBF in patients undergoing LLIF are likely multifactorial, including technique, implant material, cage size, and patient bone quality [3, 10, 26]. Tempel et al. have also reported that obesity, osteopenia, unrecognized

✉ Sang-Il Kim
sang1kim81@gmail.com

1 Department of Orthopedic Surgery, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, 222, Banpo-Daero, Seocho-Gu, Seoul 06591, Korea

2 Department of Orthopedic Surgery, Kyung Hee University Hospital at Gangdong, College of Medicine, Kyung Hee University, Seoul, Korea

3 Department of Orthopedic Surgery, Eunpyeong St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

4 Department of Orthopedic Surgery, Cedars-Sinai Medical Center, Los Angeles, CA, USA

Published online: 21 March 2024

intraoperative endplate breach, and oversized graft placement are risk factors for VBF following stand-alone LLIF [23]. VBF mainly developed in the anterior one-third (anterior column) of the vertebral body, with marked displacement of the anterior fracture fragment over time. However, reports on the pathological mechanisms of anterior column fractures are limited. Therefore, this study aimed to determine the incidence of VBF, identify its risk factors, and explore the pathomechanisms of anterior column fractures in our consecutive LLIF series.

Materials and methods

Patients

This retrospective study was approved by the Institutional Review Board. All consecutive patients who underwent LLIF for degenerative lumbar diseases at a single tertiary institute between May 2012 and December 2019 were included. To minimize bias, LLIF cases performed only by a senior surgeon (KYH) were included. Clinical data, including age, sex, body mass index (BMI), and bone mineral density (BMD), were reviewed. BMD was measured in the lumbar spine using dual-energy X-ray absorptiometry, and the mean T-score was recorded.

Surgical procedures

LLIF was performed in a minimally invasive manner by splitting the psoas muscle [13, 14, 19]. The disc materials were removed, and endplate preparation was conducted using a Cobb elevator and ring curette. Cage size was determined step-by-step using trial cages. Polyetheretherketone (PEEK) cages with demineralized bone matrix were used in all patients. After LLIF, posterolateral fusion with pedicle screws was performed. For single–level fusion, same day surgery was conducted. For multilevel fusion, staged surgery was performed at an average of 3.1 ± 2.3 days after LLIF.

Radiographic measurements

The profiles of the inserted cages, including height and lordotic angle, were recorded. The following parameters were measured for each intervertebral disc: segmental disc angle in the sagittal plane, and disc height (at the anterior and posterior corners). Positive angles indicated kyphosis, whereas negative angles indicated lordosis. The differences in height and angle between the disc and cage were calculated. Four

Table 1 Demographic data of patients with vertebral body fracture

No	Sex/Age	BMD (T-score)	BMI (kg/m^2)	Diagnosis	Medical comorbidity	Single or staged surgery	VBF	Sagittal disc angle (°)		Cobb's angle of fractured body (°)			Facet arthrosis grade (proximal/distal)	Disc height (mm)		Cage (height/angle) (mm/°)	
								Prox	Distal	Preop	Postop	Last f/u		Prox	Distal	Prox	Distal
1	F/68	-2.9	25.6	DLKS	-	Staged	L3	3.0	5.9	4.1	6.1	5.2	1/3	7.1	7.9	12/6	10/6
2	F/67	-2.9	23.0	DLKS, ASP	-	Single	L3	-2.9	-4.2	4.2	1.4	10.2	3/3	4.5	6.8	10/6	10/6
3	F/68	-2.8	28.5	DS Camptocormia	PD	Single	L4	3.8	7.2	2.5	3.5	7.7	2/2	5.0	7.2	12/6	12/12
4	F/71	-3.2	21.3	ASP	DM, HBP	Single	L4	-8.0	0.4	-4.5	-30.3	-17.9	2/3	8.6	6.3	12/12	12/12
5	F/72	-2.8	24.6	DLKS	HBP	Staged	L3	5.8	2.5	3.6	-10.0	-10.6	3/3	6.5	7.1	10/6	12/6
6	F/78	-1.4	25.4	DLKS, ASP	HBP	Staged	L4	-9.8	-4.1	-21.8	-20.7	-15.9	3/3	5.1	8.3	12/12	12/12
7	F/78	-1.6	21.3	DLKS	HBP	Staged	L3	-4.5	5.3	-13.4	-15.9	3.9	3/3	6.4	4.3	12/12	10/6

BMD, bone mineral density; BMI, body mass index; VBF, vertebral body fracture; DLKS, degenerative lumbar kyphoscoliosis; ASP, adjacent segment pathology; DS, degenerative spondylolisthesis; PD, Parkinson disease; DM, diabetes mellitus; HBP, hypertension

Table 2 Comparison of demographic data between VBF patients and non-VBF patients

No	VBF (n = 7)	Non-VBF (n = 264)	P
Age	71.5 ± 4.1	68.8 ± 5.8	NS*
Fused segments	5.6 ± 2.4	4.7 ± 1.9	NS*
LLIF at multiple: single	7:0	174:92	NS#
BMD (T-score)	-2.3 ± 0.8	-2.1 ± 1.1	NS*
BMI (kg/m^2)	24.9 ± 2.8	23.5 ± 3.5	NS*

LLIF, lateral lumbar interbody fusion; BMD, bone mineral density; BMI, body mass index

* Mann–Whitney test

\# Fisher's exact test

grades of facet joint arthritis were identified on computed tomography (CT) imaging [26].

Statistical analysis

Fisher's exact test was used to analyze categorical data, and Mann–Whitney U test was used for continuous data. Univariate logistic regression analysis was performed, and parameters with a P-value ≤ 0.10 were included in multivariate logistic regression analysis. Statistical significance was set at $P < 0.05$. All statistical analyses were performed using SPSS software (version 21.0; SPSS Inc., Chicago, IL, USA).

Results

Patient data

A total of 273 patients were included in this study, with 92 patients undergoing single-level surgery and 181 undergoing multilevel surgery. Of these patients, 552 levels were treated using LLIF. The mean age and BMI at the time of surgery were 69.1 ± 5.9 years and 23.8 ± 3.4 kg/m^2, respectively. The mean T-score of the lumbar spine was -2.2 ± 1.2. The mean number of fused levels was 4.8 ± 2.2.

Table 4 Logistic regression analysis for risk factors of VBF

	Univariate	Multivariate	
	P	OR (95% CI)	P
The degree of facet arthrosis	0.043	-	-
Sagittal motion	0.015	0.7 (0.6–0.8)	0.029

Patients with coronal vertical VBF

Seven (2.6%) out of 273 patients (552 levels) experienced coronal vertical VBF (CV-VBF). All seven patients were women, and CV-VBFs occurred in a single vertebral body: L3 in three and L4 in four patients. The mean age at index surgery was 71.5 ± 4.1 years (range, 67–78 years). BMI and BMD of the lumbar spine were 24.9 ± 2.8 kg/m^2 and -2.3 ± 0.8, respectively. The demographic details are shown in Table 1.

Characteristics of coronal vertical fracture and risk factors

There were no significant differences in age (71.5 ± 4.1 versus 68.8 ± 5.8 years, $P = 0.687$), BMI (24.9 ± 2.8 versus 23.5 ± 3.5, $P = 0.450$), or BMD (-2.3 ± 0.8 versus -2.1 ± 1.1, $P = 0.528$) between patients with and without VBF (Table 2). All CV-VBFs occurred in the anterior third of the vertebral body. When two adjacent discs (14 discs) were analyzed independently, the mean sagittal angle was 1.8° ± 5.6° at the proximal adjacent disc and -1.9° ± 4.3° at the distal adjacent disc. Although there was no significant difference in the sagittal angle between discs adjacent to VBF segments and others, the sagittal motion in discs adjacent to VBF segments was smaller than that in others (4.6° ± 2.6° versus 6.5° ± 3.9°, $P = 0.031$). There was no significant difference in the mean disc height between the VBF and non-VBF segments (Table 3). Additionally, there was no significant difference in the gap between the mean disc and cage heights of the VBF and non-VBF segments (Table 3). However,

Table 3 Comparison of radiographic data between discs adjacent VBF segments and other discs

	Discs adjacent to VBF (n = 14)	Discs adjacent to Non-VBF (n = 538)	P
Disc angle (°)			
Sagittal (in neutral position)	0.0 ± 5.4	3.9 ± 5.8	NS*
Sagittal motion	4.6 ± 2.6	6.5 ± 3.9	0.031*
Mean disc height (mm)	6.3 ± 1.4	7.1 ± 3.0	NS*
Mean disc height – Cage height (mm)	-4.2 ± 2.0	-4.5 ± 2.2	NS*
Facet joint arthrosis	2.5 ± 0.7	1.9 ± 0.5	0.045*

* Mann–Whitney test

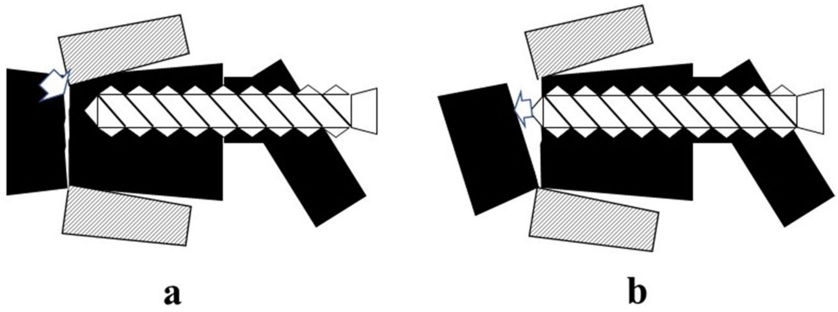

Fig. 1 Schematic figure of coronal vertical vertebral body fracture after lateral lumbar interbody fusion (LLIF). (**a**) A nutcracker was demonstrated by trialing and implantation, causing a vertical vertebral body fracture (arrow), although sometimes a VBF could not be recognized at the time of fracture despite using a C-arm imaging intensifier**.** (**b**) An unrecognized VBF might be displaced further upon inserting posterior pedicle screws into the vertebral body (arrow). This explains why vertebral body fracture is found late after LLIF. Additionally, displaced anterior fracture fragment can further progress over time due to invasion of cages into the fracture site

the facet joints adjacent to the VBF segments exhibited advanced degeneration compared to non-VBF segments (2.5. ± 0.7 versus 1.9 ± 0.5, $P = 0.045$). Univariate analysis revealed less sagittal motion (odds ratio [OR]: 0.7, 95% confidence interval [CI]: 0.6–0.8, $P = 0.015$) and a higher degree of facet joint arthrosis (OR: 2.1, 95% CI: 1.0–6.3, $P = 0.043$) as significant risk factors for VBFs (Table 4). Multivariate analysis demonstrated that lesser sagittal motion is a single risk factor (OR: 0.7, 95% CI: 0.6–0.8, $P = 0.029$) (Table 4).

Discussion

Although interbody cages are commonly used to increase mechanical stability, restore sagittal balance, and promote fusion, several LLIF-related complications have been documented [3, 8, 16, 20]. One of frequently reported complications is endplate fracture [12, 17, 18]. The incidence of VBF with or without lateral plating was reported to vary from 0.17% to 15.4% [4, 7, 15, 21, 24]. In our study, CV-VBF during LLIF occurred in 2.6% of all patients and in 1.3% of all LLIF levels.

Endplate preparation without injury is crucial to avoid endplate fractures but technically demanding in patients with adult spinal deformity due to sagittally and coronally wedge-shaped disc spaces [11]. Previous studies have reported that the incidence of endplate injury was over 20%, and the risk factors included cage profile and patient factors, regardless of the surgeon's experience [12, 22]. In our study, CV-VBF developed in two patients who underwent LLIF using a cage with dimension of 10 mm in height, 18 mm in width, and an angle of 6°, and in five patients who underwent LLIF using a cage with dimension of 12 mm in height, 22 mm in width, and an angle of 12°. A smaller disc height (6.3 mm versus 7.1 mm) and sagittal disc angle (0° versus 3.9°) could predispose to VBF because forceful endplate and intervertebral disc preparation might happen to restore intervertebral disc height with an oversized cage. Grimm et al. reported that VBF can be caused by an unrecognized intraoperative endplate violation during over-aggressive trialing and implantation of an oversized PEEK spacer [9]. Zeng et al. reported that VBF is associated with osteoporosis but may mainly result from surgical procedures [27]. Although their relationship had already been reported, the relationship between VBF and bone quality was not significant ($P = 0.528$) in our study [25, 27]. Our analysis suggests that the risk of VBF is higher in individuals with less mobile spine. Thus, it is important to determine the proper cage size to obtain sufficient intervertebral disc space, especially in stiff spine with difficulty in restoring sufficient intervertebral disc height and angle.

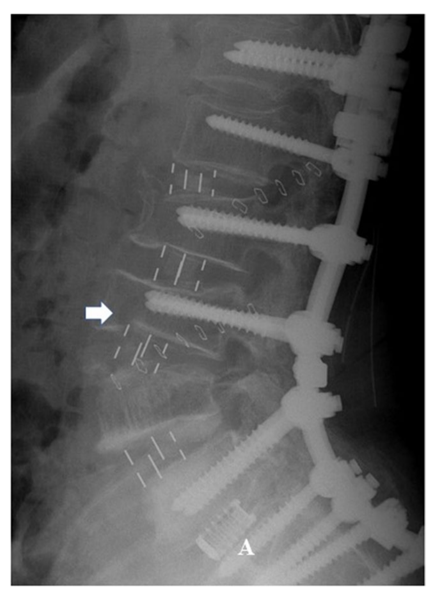

Fig. 2 An arrow indicating oblique placement of a cage resulting in vertebral body fracture by a nutcracker effect (See manuscript)

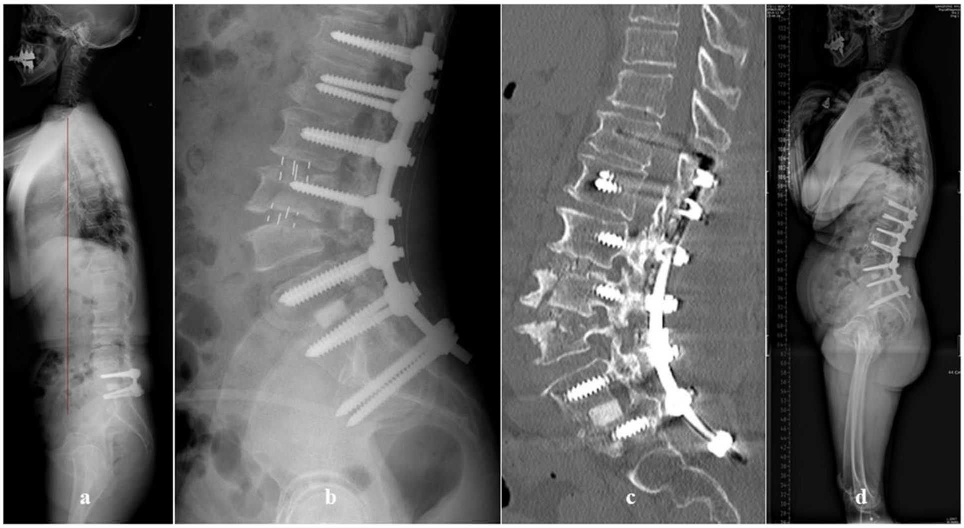

Fig. 3 A representative case with coronal vertical vertebral body fracture after lateral lumbar interbody fusion. (**a**) Preoperative radiographs showing adjacent segment pathology with flat back deformity. (**b**) Vertebral body fracture at L3 is noted with oblique placement of a cage into vertebral body. (**c**) Computed tomography taken immediately after posterior instrumentation shows a vertical fracture of L3 with anterior displacement. (**d**) At postoperative 3 years, a whole spine lateral shows well maintenance of lumbar lordosis without loss of correction is demonstrated, even though loss of lordosis at the first fractured segment is noted

The pathomechanism of CV-VBF can be explained by a nutcracker-impinging effect, in which the anterior edge of a trial or cage impinges on the upper or lower endplate of the vertebral body, leading to body fracture, as shown in Fig. 1(A) and 2. CV-VBF could sometimes be missed on intraoperative fluoroscopic images and found late during posterior instrumentation because LLIF is usually performed using an anteroposterior view of an imaging intensifier. Therefore, it is important to check lateral images during LLIF to mitigate the risk of VBF.

When pedicle screws are inserted into the vertebral body, they can displace non-visible anterior fracture fragments anteriorly (Fig. 1(B)). In accordance with our expectations, we found that a fracture at the anterior one-third of the vertebral body was subjected to anterior displacements that could be visualized on radiographs during posterior instrumentation. The anterior fragment was further displaced by nutcracker effects over time, leading to the loss of local lordosis at the index segment (Fig. 3).

The present study had some limitations. First, this was a retrospective study, making it difficult to draw definite conclusions from evidence alone with a limited number of cases. Second, we did not evaluate the clinical significance of intraoperative CV-VBF during follow-up. The VBF was generally well maintained until the latest follow-up, although slight collapse of the fracture site was observed. We believe that posterior instrumentation could prevent further fracture collapse. Third, we did not perform postoperative CT to confirm unrecognized VBF. Although our plausible explanation about the mechanism of a vertical fracture at the anterior one third of the vertebral body might be sufficient, future investigations focusing only on VBF as a hardware-associated complication are needed, as it is an important complication of LLIF.

Conclusions

The overall incidence of CV-VBF was 2.6%. Potential risk factor for VBF is the use of an oversized cage or oblique insertion of a cage into stiff disc space, leading to VBF by nutcracker effect. Thus, thorough preoperative evaluation and surgical procedure are needed to avoid VBF when considering LLIF in patients with less mobile spine.

Authors' contributions Kee-Yong Ha: conceptualization, methodology, writing.
Young-Hoon Kim: data curation, supervision.
Yong-Chan Kim: original draft preparation.
Hyung-Youl Park: investigation.
Hyun Bae: validation.
Sang-Il Kim: writing and revision.

Funding Not applicable.

Data availability The corresponding author is having the available data.

Code availability Not applicable.

Declarations

Conflicts of interest/Competing interests Not applicable.

Ethics approval Approved by IRB of our institute.

Consent to participate Not applicable.

Consent for publication Not applicable.

References

1. Abe K, Orita S, Mannoji C, Motegi H, Aramomi M, Ishikawa T, Kotani T, Akazawa T, Morinaga T, Fujiyoshi T, Hasue F, Yamagata M, Hashimoto M, Yamauchi T, Eguchi Y, Suzuki M, Hanaoka E, Inage K, Sato J, Fujimoto K, Shiga Y, Kanamoto H, Yamauchi K, Nakamura J, Suzuki T, Hynes RA, Aoki Y, Takahashi K, Ohtori S (2017) Perioperative Complications in 155 Patients Who Underwent Oblique Lateral Interbody Fusion Surgery: Perspectives and Indications From a Retrospective, Multicenter Survey. Spine 42:55–62 (Phila Pa 1976)
2. Ahmadian A, Verma S, Mundis GM Jr, Oskouian RJ Jr, Smith DA, Uribe JS (2013) Minimally invasive lateral retroperitoneal transpsoas interbody fusion for L4–5 spondylolisthesis: clinical outcomes. J Neurosurg Spine 19:314–320
3. Belkoff SM, Maroney M, Fenton DC, Mathis JM (1999) An in vitro biomechanical evaluation of bone cements used in percutaneous vertebroplasty. Bone 25:23s–26s
4. Brier-Jones JE, Palmer DK, İnceoğlu S, Cheng WK (2011) Vertebral body fractures after transpsoas interbody fusion procedures. Spine J 11:1068–1072
5. Chang SY, Kang DH, Cho SK (2023) Innovative developments in lumbar interbody cage materials and design: A comprehensive narrative review. Asian Spine J. https://doi.org/10.31616/asj.2023.0407
6. Cummock MD, Vanni S, Levi AD, Yu Y, Wang MY (2011) An analysis of postoperative thigh symptoms after minimally invasive transpsoas lumbar interbody fusion. J Neurosurg Spine 15:11–18
7. Dua K, Kepler CK, Huang RC, Marchenko A (2010) Vertebral body fracture after anterolateral instrumentation and interbody fusion in two osteoporotic patients. Spine J 10:e11-15
8. Flamme CH, von der Heide N, Heymann C, Hurschler C (2006) Primary stability of anterior lumbar stabilization: interdependence of implant type and endplate retention or removal. Eur Spine J 15:807–818
9. Grimm BD, Leas DP, Poletti SC, Johnson DR 2nd (2016) Postoperative Complications Within the First Year After Extreme Lateral Interbody Fusion: Experience of the First 108 Patients. Clin Spine Surg 29:E151-156
10 Hou Y, Luo Z (2009) A study on the structural properties of the lumbar endplate: histological structure, the effect of bone density, and spinal level. Spine 34:E427-433 (Phila Pa 1976)
11. Kim WJ, Lee JW, Park KY, Chang SH, Song DG, Choy WS (2019) Treatment of Adult Spinal Deformity with Sagittal Imbalance Using Oblique Lumbar Interbody Fusion: Can We Predict How Much Lordosis Correction Is Possible? Asian Spine J 13:1017–1027
12. Kim YH, Ha KY, Kim KT, Chang DG, Park HY, Yoon EJ, Kim SI (2021) Risk factors for intraoperative endplate injury during minimally-invasive lateral lumbar interbody fusion. Sci Rep 11:20149
13. Kim YH, Ha KY, Kim YS, Kim KW, Rhyu KW, Park JB, Shin JH, Kim YY, Lee JS, Park HY, Ko J, Kim SI (2022) Lumbar Interbody Fusion and Osteobiologics for Lumbar Fusion. Asian Spine J 16:1022–1033
14. Kim YH, Ha KY, Rhyu KW, Park HY, Cho CH, Kim HC, Lee HJ, Kim SI (2020) Lumbar Interbody Fusion: Techniques, Pearls and Pitfalls. Asian Spine J 14:730–741
15. Le TV, Smith DA, Greenberg MS, Dakwar E, Baaj AA, Uribe JS (2012) Complications of lateral plating in the minimally invasive lateral transpsoas approach. J Neurosurg Spine 16:302–307
16 Oxland TR, Grant JP, Dvorak MF, Fisher CG (2003) Effects of endplate removal on the structural properties of the lower lumbar vertebral bodies. Spine 28:771–777 (Phila Pa 1976)
17 Park HY, Ha KY, Kim YH, Chang DG, Kim SI, Lee JW, Ahn JH, Kim JB (2018) Minimally Invasive Lateral Lumbar Interbody Fusion for Adult Spinal Deformity: Clinical and Radiological Efficacy With Minimum Two Years Follow-up. Spine 43:E813-e821 (Phila Pa 1976)
18. Park HY, Kim YH, Ha KY, Kim SI, Min HK, Oh IS, Seo JY, Chang DG, Park JT (2019) Minimally Invasive Lateral Lumbar Interbody Fusion for Clinical Adjacent Segment Pathology: A Comparative Study With Conventional Posterior Lumbar Interbody Fusion. Clin Spine Surg 32:E426-e433
19. Park J, Ham DW, Kwon BT, Park SM, Kim HJ, Yeom JS (2020) Minimally Invasive Spine Surgery: Techniques, Technologies, and Indications. Asian Spine J 14:694–701
20. Polikeit A, Ferguson SJ, Nolte LP, Orr TE (2003) The importance of the endplate for interbody cages in the lumbar spine. Eur Spine J 12:556–561
21 Rodgers WB, Gerber EJ, Patterson J (2011) Intraoperative and early postoperative complications in extreme lateral interbody fusion: an analysis of 600 cases. Spine 36:26–32 (Phila Pa 1976)
22. Satake K, Kanemura T, Yamaguchi H, Segi N, Ouchida J (2016) Predisposing Factors for Intraoperative Endplate Injury of Extreme Lateral Interbody Fusion. Asian Spine J 10:907–914
23. Tempel ZJ, Gandhoke GS, Bolinger BD, Okonkwo DO, Kanter AS (2015) Vertebral body fracture following stand-alone lateral lumbar interbody fusion (LLIF): report of two events out of 712 levels. Eur Spine J 24(Suppl 3):409–413
24. Tender GC (2014) Caudal vertebral body fractures following lateral interbody fusion in nonosteoporotic patients. Ochsner J 14:123–130
25. Walker CT, Farber SH, Cole TS, Xu DS, Godzik J, Whiting AC, Hartman C, Porter RW, Turner JD, Uribe J (2019) Complications for minimally invasive lateral interbody arthrodesis: a systematic review and meta-analysis comparing prepsoas and transpsoas approaches. J Neurosurg Spine 30:446–460
26. Weishaupt D, Zanetti M, Boos N, Hodler J (1999) MR imaging and CT in osteoarthritis of the lumbar facet joints. Skeletal Radiol 28:215–219
27. Zeng ZY, Xu ZW, He DW, Zhao X, Ma WH, Ni WF, Song YX, Zhang JQ, Yu W, Fang XQ, Zhou ZJ, Xu NJ, Huang WJ, Hu ZC, Wu AL, Ji JF, Han JF, Fan SW, Zhao FD, Jin H, Pei F, Fan SY, Sui DX (2018) Complications and Prevention Strategies of Oblique Lateral Interbody Fusion Technique. Orthop Surg 10:98–106