Original Article
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Predictors of Vertebral Endplate Fractures after Oblique Lumbar Interbody Fusion

Wook Tae Park, MD, In Ha Woo, MD, Sung Jin Park, MD, Gun Woo Lee, MD

Department of Orthopedic Surgery, Yeungnam University Medical Center, Yeungnam University College of Medicine, Daegu, Korea

Background: Cage subsidence after oblique lumbar interbody fusion (OLIF) induces restenosis and adversely affects patient outcomes. Many studies have investigated the causes of subsidence, one of which is endplate fracture (EF). This study aimed to identify predictors of EF after OLIF.

Methods: This retrospective study reviewed consecutive patients who underwent OLIF at a single institute between August 2019 and February 2022. A total of 104 patients were enrolled. The patients' demographic data and surgical details were collected through chart reviews. Radiographic variables were measured. Related variables were also analyzed using binomial logistic regression, dividing each group into those with versus without EF.

Results: EF occurred at 30 of 164 levels (18.3%), and the binary logistic analysis revealed that sex (odds ratio [OR], 11.07), inferior endplate concave depth (OR, 1.95), disc wedge angle (OR, 1.22), lumbar lordosis (OR, 1.09), pelvic incidence (OR, 1.07), sagittal vertical axis (OR, 1.02), sacral slope (OR, 0.9), L3–4 level (OR, 0.005), and L4–5 level (OR, 0.004) were significantly related to EF.

Conclusions: OLIF in older Asian patients should be performed carefully after recognizing the high possibility of EF and confirming the factors that should be considered preoperatively.

Keywords: *Lumbar, Oblique lumbar interbody fusion, Endplate fracture, Risk factors, Subsidence*

Oblique lumbar interbody fusion (OLIF) has been applied to treat various degenerative spinal diseases.[1-3] The technique uses the retroperitoneal corridor between the major vessels (aorta and inferior vena cava) and psoas muscle to approach the disc.[4,5] Similar to other interbody fusion techniques with an anterior approach (anterior lumbar interbody fusion [ALIF]), OLIF can restore disc height via a large cage, thereby enabling indirect decompression.[6] However, unlike traditional ALIF, OLIF requires a small incision and no additional personnel during surgery. Moreover, the risk of bleeding is low; therefore, recovery occurs more quickly.[3]

Although OLIF has many advantages, it also features several complications with a 3.7%–66.7% overall complication rate.[7] The most common complications are transient psoas muscle weakness and thigh numbness, while other complications include vascular injury, hematoma, and cage subsidence.[6,8] Lateral lumbar interbody fusion (LLIF) depends on indirect decompression as a method of restoring the neural canal height using a large cage. Thus, cage subsidence is a significant complication of clinical outcomes. Tohmeh et al.[9] reported that the group with intraoperative endplate injury showed progressive subsidence of a larger magnitude than the group without intraoperative injury after LLIF. Satake et al.[10] subsequently reported that the risk factors for intraoperative endplate fractures (EFs) in LLIF surgery were significantly associated with bone mineral density (BMD). It has been argued that EFs are limited to only one side in cases of degenerative scoliosis indicative of the surgeon's technical failure. Hu et al.[11] argued that the morphology of the endplate was

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Correspondence to: Gun Woo Lee, MD
Department of Orthopedic Surgery, Yeungnam University Medical Center, Yeungnam University College of Medicine, 170 Hyeonchung-ro, Nam-gu, Daegu 42415, Korea
Tel: +82-53-640-3642, Fax: +82-53-628-4020
E-mail: gwlee1871@gmail.com

related to the subsidence of the cage and that the flatter endplate shape was associated with lower cage subsidence. Therefore, it is necessary to design the cage according to the endplate shape. Ohiorhenuan et al.[12] reported that in patients who underwent LLIF, the lower implant area/inferior endplate area ratio was associated with the greater occurrence of cage subsistence.

Previous studies demonstrated that intraoperative endplate injuries are associated with cage subsidence, but no risk factors associated with these injuries have been clearly identified. Therefore, here we reviewed a case series of consecutive patients who underwent OLIF and examined the association between radiographic intraoperative EFs and age, sex, bone density, cage size, and pelvic parameters. Moreover, we aimed to identify several radiological parameters that may influence EF occurrence after OLIF.

METHODS

Patient Population

This study was approved by the Institutional Review Board of Yeungnam University Medical Center (No. YUMC 2022-05-005), and patient consent was waived. We retrospectively reviewed consecutive patients who underwent OLIF at a single institute between August 2019 and February 2022. A total of 104 patients (mean age, 71.2 ± 8.1 years; 51 men; 164 total segments) who underwent OLIF (Medtronic Inc., Minneapolis, MN, USA) with an anterior approach to the psoas in a minimally invasive fashion were enrolled in this study. The inclusion criteria were as follows: (1) having undergone OLIF surgery for diseases such as spondylolisthesis, adjacent segment disease, adult degenerative scoliosis, and degenerative disc disease and (2) absence of concomitant spinal disease. The exclusion criteria were as follows: (1) absence of preoperative whole-spine radiographs (we also included patients whose variables could not be measured despite radiographs), (2) lacking BMD data, (3) concomitant neoplastic, metabolic, or severe infectious disease, and (4) a history of osteoporotic fracture.

Surgical Technique

All the surgeries were performed by a single surgeon (GWL). The patients were placed in a lateral decubitus position on their right side, and the target intervertebral disc space was marked on the skin under fluoroscopic guidance. A 4–5 cm skin incision was made 3 fingerbreadths anterior to the anterior margin of the target disc. The surgeon approached the retroperitoneal space through blunt dissection and exposed the oblique lateral window. Under fluoroscopy, we first marked to confirm the level of surgery and then used a knife to perform annulotomy. We then used pituitary forceps to remove enough disc material to the contralateral annulus. The disc material was removed from the endplate with a box curette while confirming with fluoroscopy to avoid endplate invasion. Finally, to perform contralateral annulotomy, Cobb's elevator was used to position the curved tip at the end of the endplate and a hammer was used to perform the annulotomy. During endplate preparation, we always checked the fluoroscope to make sure there were no injuries. After sufficient discectomy, the endplate was prepared, and the cage was vertically inserted under fluoroscopic guidance. In the case of the L5–S1 level, a modified approach different from the L2–5 approach was used because of anatomical problems of the vessels and bones. It uses a corridor that is similar to the approach of traditional ALIF, but the incision approaches the retroperitoneal space using a 3–7 cm incision between the line connecting the anterior superior iliac spine and disc space and the line parallel to the disc space, and then accesses the iliac vessel bifurcation sites. For sufficient decompression, the patient was placed in the prone position and posterior decompression was performed on the same day. In the case of more than 3 segments, posterior decompression and fixation were performed 3–7 days after the first operation.

The cage size was determined by selecting the Ideal cage position on the preoperative computed tomography (CT) scan, considering the width and height. After finding the anterior 1/3 of the body on the sagittal CT image, the lateral width of the body was measured on the coronal image to determine cage width. The cage height was selected to be relatively close to normal among the adjacent levels above or below the surgical site. A Clydesdale cage (Medtronic Sofamor Danek, Memphis, TN, USA) was used, and the determination of cage angulation was based on 6° at the L2–5 level. For the L5–S1 level, a Perimeter cage (Medtronic Sofamor Danek, Memphis, TN, USA) was used, and by default, we used a 12° cage.

DATA Collection

We collected patients' demographic data and surgical details through a chart review. Age, sex, body mass index, T-score for BMD measured at the spine and femur neck (the lower number of the two areas was selected), cage height, and operative level were recorded.

Radiologic Examination

EF was defined as endplate disruption identified in immediate postoperative lumbar radiography (Fig. 1). The radiographic assessment was performed using standing whole-spine anteroposterior, lateral, and lumbar (L) spine series. The lumbar disc gap, adjacent segment disc height, and endplate morphology were measured on an L-spine lateral radiograph. To determine endplate morphology, the vertebral endplate concave depth was measured with reference to a study published by Hu et al.[11] In standing whole-spine lateral radiographs, pelvic parameters (pelvic tilt, sacral slope [SS], and pelvic incidence [PI]), lumbar lordosis (LL), sagittal vertical axis (SVA), and lumbar disc coronal wedge angle were measured. The disc wedge angle was measured in the anteroposterior view (Fig. 2).

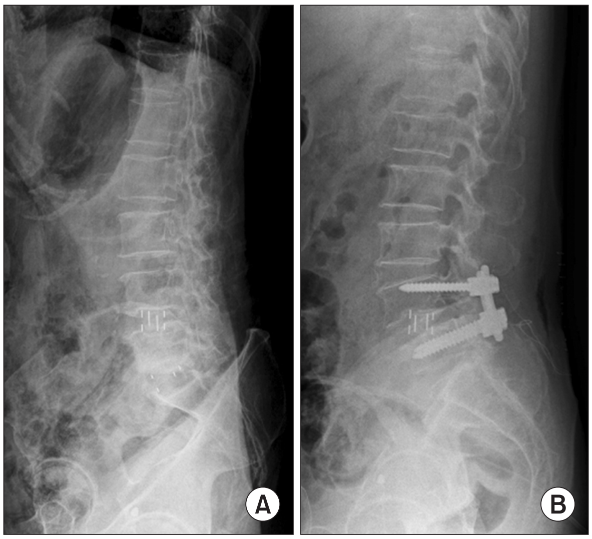

Fig. 1. A case of endplate fracture with cortical disruption after oblique lumbar interbody fusion (OLIF). (A) Immediately postoperative radiograph showing the upper endplate with cortical disruption. (B) Improper insertion of the cage with a fracture of the upper endplate could be observed immediately after OLIF at the L4–5 level.

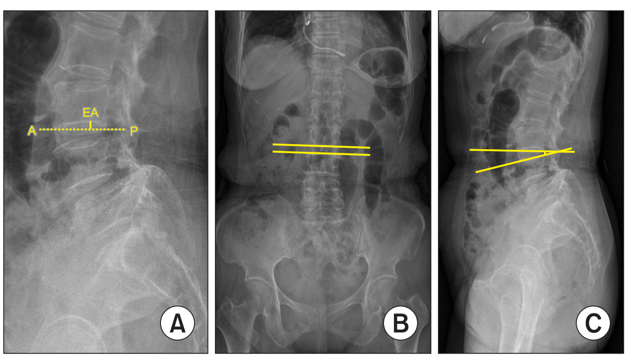

Fig. 2. (A) Measurement of the endplate concave depth from the endplate concavity apex (EA) to the line connecting the anterior (A) and posterior (P) margins of the endplate. (B) Coronal disc wedge angle: the angle between the lines connecting the margins of each of the upper and lower endplates in the coronal plane. (C) Sagittal disc wedge angle: the angle between the lines connecting the margins of the upper and lower endplates in the sagittal plane.

We defined and measured a new angle, the sacral endplate angle (SEA), considering that an EF would occur when the cage is inserted inappropriately without considering the lordosis and kyphosis angles formed by the segment being operated on. SEA was defined as the angle between the S1 endplate and the endplate of the segment to be operated on, and the endplate line drawn for angle measurement was the line connecting the margins of the anterior and posterior ends of the endplate. Data were collected by measuring the superior and inferior endplates at the surgical level. The creation of a lordotic angle was defined as a positive value. Similar to SEA, the horizontal endplate (HE) angle was defined as the angle between the horizontal line and the endplate at the surgical level. The superior and inferior endplate angles were measured at the surgical level (Fig. 3). The evaluation was performed by two independent orthopedic surgeons who were blinded to the study information (JJP and HGS), and each value was used as an average.

Statistical Analyses

Patients were classified into group F (endplate disruption)

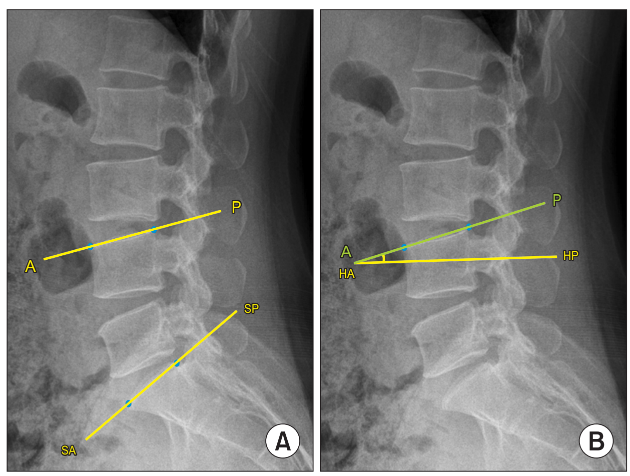

Fig. 3. Measurement of sacral endplate angle (SEA) and horizontal endplate (HE) angle. SEA is the angle between the endplate of S1 (SA–SP, solid line) and the endplate (anteroposterior, solid line). (A) Each solid line is a line connecting the margin of the endplate (blue dot) on the lateral radiograph. (B) HE angle is the angle between the horizontal line (solid line) and the endplate (anteroposterior, solid line). The dots show anterior and posterior endplate margins. A: anterior, P: posterior, SA: sacral anterior, SP: sacral posterior, HA: horizontal anterior, HP: horizontal posterior.

and group N (no endplate disruption). The patients' demographics, surgical details, and radiographic parameters were compared between groups. For the general demographic data, an independent sample *t*-test and two-way analysis of variance were performed for continuous variables, and the chi-square test and Fisher's exact test were used to examine categorical variables.

A multivariate analysis, including all variables, was performed using binomial logistic regression and the backward elimination (likelihood ratio) method. All variables were analyzed for each level at which the surgery was performed, and the level with missing values was removed. All analyses were performed using SPSS ver. 26 software (IBM Corp., Armonk, NY, USA).

Table 1. General Patient Characteristics Data

Characteristic	Group F	Group N	*p*-value
No. of patients treated	28 (25.2)	76 (68.5)	-
Age (yr)	70.87 ± 9.16	71.25 ± 7.87	0.82
Sex			0.02*
Male	8 (7.7)	43 (41.3)	
Female	20 (31.7)	33 (19.2)	
Previous operation			0.56
Yes	12 (11.5)	37 (35.6)	
No	16 (15.4)	39 (37.5)	
Body mass index (kg/m^2)	25.53 ± 3.95	26.18 ± 19.79	0.86
Bone mineral density (T-score)	–2.05 ± 1.1	–1.72 ± 1.29	0.20
Female	–2.3 ± 0.94	–2.3 ± 0.96	0.70
Male	–1.3 ± 1.25	–1.16 ± 1.32	

Values are presented as number (%) or mean ± standard deviation. To investigate the effect of patient's demographic data, each group was analyzed.
Group F: endplate fracture after oblique lumbar interbody fusion, Group N: no endplate fracture.
*$p < 0.05$.

Table 2. Patient Surgical Record Data

Variable	Group F	Group N	*p*-value
Levels treated	30 (18.3)	134 (81.7)	-
Previous operation			0.55
Yes	13 (7.9)	67 (40.9)	
No	17 (10.4)	67 (40.9)	
Cage height	12.67 ± 1.69	12.28 ± 1.74	0.27
Operated level			0.08
L2–3	7 (23.3)	17 (12.7)	
L3–4	7 (23.3)	41 (30.6)	
L4–5	15 (50.0)	52 (38.8)	
L5–S1	1 (3.3)	24 (17.9)	

Values are presented as number (%) or mean ± standard deviation. Surgical data analyzed by operation level.

RESULTS

A total of 106 patients who underwent surgery at 164 levels were included. There were no differences in most of the demographic data between groups F and N; however, there was a difference in sex (Table 1). EFs were observed in 30 of the 164 levels (18.3%) at which surgery was performed.

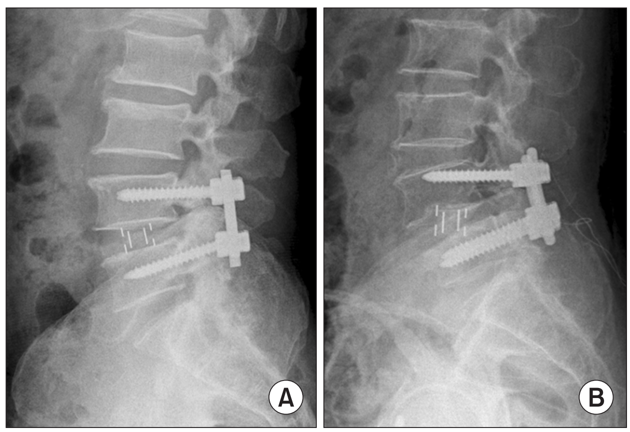

Fig. 4. A simple radiograph taken immediately after oblique lumbar interbody fusion surgery at the L4–5 level. (A) Appropriate cage insertion without endplate disruption. (B) The upper endplate is disrupted for the L4–5 disc, and the cage is tilted on the sagittal plane.

Table 3. Variables Used in the Analysis

	Variable
Demographic data	Age, sex, previous operation, operation level, body mass index, bone mineral density (T-score, categorical classification), cage size
Pelvic parameter	Pelvic tilt, sacral slope, pelvic incidence
Sagittal radiograph	Lumbar lordosis, sagittal vertical axis, sacral endplate angle, horizontal endplate angle, endplate concave depth, cage location, adjacent disc gap, disc wedge angle
Coronal radiograph	Disc wedge coronal angle

Variables used in binary logistic regression.

Table 4. Risk Factor Analysis of Intraoperative Endplate Fracture

Variable	B	SE	Wald	df	Sig.	Exp (B)	95% CI	
							Lower	Upper
Lumbar lordosis	0.081	0.035	5.262	1	0.022*	1.085	1.012	1.162
Sacral slope	–0.108	0.052	4.315	1	0.038*	0.897	0.810	0.994
Pelvic incidence	0.063	0.031	4.180	1	0.041*	1.065	1.003	1.131
Sex (female)	2.404	0.857	7.869	1	0.005*	11.071	2.064	59.391
Level (L5–S1)			7.677	3	0.053			
Level (L2–3)	–3.971	2.616	2.305	1	0.129	0.019	0	3.176
Level (L3–4)	–5.362	2.586	4.297	1	0.038*	0.005	0	0.747
Level (L4–5)	–5.506	2.618	4.422	1	0.035*	0.004	0	0.688
Sagittal vertical axis	0.015	0.007	5.137	1	0.023*	1.015	1.002	1.028
Inferior endplate concave depth	0.669	0.216	9.562	1	0.002*	1.952	1.278	2.983
Cage size	0.102	0.066	2.435	1	0.119	1.108	0.974	1.260
Disc wedge angle	0.195	0.099	3.872	1	0.049*	1.216	1.001	1.477
Constant	–10.083	3.601	7.842	1	0.005	0		
Full model likelihood ratio χ^2_{12} (df), sig.					31.50 (11), 0.001			

Binomial logistic regression analysis was performed for a total of 36 variables. Variables were analyzed using the backward elimination (likelihood ratio) method.
SE: standard error, df: degree of freedom, Sig: significance, CI: confidence interval.
*$p < 0.05$.

The L4–5 level showed the highest frequency of EFs in the operated segment in both groups (Table 2, Fig. 4). None of the enrolled patients underwent revision surgery because of EFs and/or symptoms worsening during the follow-up period.

A binary logistic regression analysis was conducted to assess whether the risk model with 34 predictors varied significantly depending on whether the patients developed EF (Table 3). A total of 12 variables were included in the predictive model (Table 4). Among these variables, 9 were statistically significant and sex had the highest odds ratio (OR). These 9 factors were sex (OR, 11.07; 95% confidence interval [CI], 2.06–59.39), inferior endplate concave depth (OR, 1.95; 95% CI, 1.28–2.98), disc wedge angle (OR, 1.22; 95% CI, 1.01–1.47), LL (OR, 1.09; 95% CI, 1.01–1.16), PI (OR, 1.07; 95% CI, 1.003–1.13), SVA (OR, 1.02; 95% CI, 1.002–1.03), SS (OR, 0.9; 95% CI, 0.81–0.99), L3–4 level (OR, 0.005; 95% CI, 0–0.75), and L4–5 level (OR, 0.004; 95% CI, 0–0.69).

DISCUSSION

The present study retrospectively reviewed 104 patients who underwent OLIF at 164 levels performed by a single surgeon at a single institution. The overall prevalence of intraoperative EFs was 18.3% at all treatment levels. In addition, the study results showed that the proportion of patients with revision status reached 50%. The authors performed disectomy, decompression, and fusion according to the revision status criteria. The revision status rate was high because the study was conducted according to these standards and the spine center of the hospital where the surgery was performed was a tertiary medical institution. According to our study, EFs can be predicted by 9 preoperatively measured factors. In particular, 3 factors (sex, inferior endplate concave depth, and disc wedge angle) were highly related to the OR, implying that a preoperative evaluation could prevent EF.

In a study by Ohiorhenuan et al.,[12] the incidence of EFs was approximately 5.4%, whereas that in the study by Satake et al.[13] was 16.8%. In a study published by Inoue et al.,[14] the incidence rate was 85.3%, while in a meta-analysis, it was 5.26%.[12,14-16] In comparison, the incidence in our study was 18.3%, lower than that reported by Inoue et al.[14] but higher than that of the previous 2 studies and meta-analysis. In the study by Inoue et al.,[14] the incidence of total fractures was high because EFs were evaluated using postoperative CT, and a direct comparison with this study is difficult. When comparing the results of this study with those of other studies, the difference in the incidence of EF has several implications. Given that the subjects of this study were Asians of old age, EFs are more likely to occur than in other races, such as Caucasians, and are more vulnerable. According to a study published by Shin et al.,[17] Koreans and Chinese had lower spinal BMD than other races. In addition, in a study by Nam et al.,[18] the BMD of the hip joint was similar between Caucasian American males and Hispanic males, while Korean males had a 3%–14% lower BMD in all regions except the femoral neck. From this point of view, the high incidence of EF can be attributed to the fact that Asian elderly patients were targeted.

The vertebral endplate is the cortical bone that consists of the upper and lower surfaces of the body. Several studies have shown that endplate removal reduces vertebral body stiffness and failure load.[8,19,20] In addition, Tohmeh et al.[9] argued that endplate injury leads to subsidence in their study. However, many previous studies have stressed the importance of the endplate, while few have elucidated the cause of endplate injury. Binary logistic regression analysis showed that the variable with the highest odds ratio was sex (OR, 11.07; 95% CI, 2.06–59.39). According to a biomechanical study conducted by Hou et al.,[19] BMD and lumbar endplate were related. Oh et al.[21] argued that severe osteoporosis was a risk factor for subsidence (OR, 8.44) in a study of the relationship between subsidence and BMD after PLIF. In addition, Park et al.[22] argued that osteoporosis was a risk factor for endplate injury during transforaminal lumbar interbody fusion. Although BMD was removed as an irrelevant variable in the overall result, the reason for this result is probably because the BMD value of women was lower than that of men as observed in the demographic data (Table 1). Because BMD shows only trabecular bone quality, EF occurring in the cortical bone may not be affected.[23] Although it was not possible to separate and analyze only women in this study, based on the results of previous studies and the results of this study, it seems that surgeons should pay attention not to make an endplate violation in female patients with low BMD.

Hu et al.[11] studied the effect of endplate morphology on cage subsidence in patients who underwent OLIF stand-alone surgery and reported that a higher frequency of cage subsidence occurred in the concave endplate. They further claimed that patients with concave endplates were more vulnerable to cage subsidence. Here, we measured the cage concave depth (OR, 1.95; 95% CI, 1.28–2.98) similarly. It was noted that as the depth of the inferior endplate of the surgical segment increased, the occurrence of EF increased accordingly. Previous studies have reported that cage subsidence is associated with EFs. In addition, the endplate superior (cranial) to the intervertebral disc is thicker and denser than the inferior (caudal) one.[24,25] Therefore, the inferior plate is thin and only slightly rigid, which may easily cause deformation. This can be expressed as endplate concave depth. In practice, the morphology of an endplate may be related to its stiffness. Although these studies do not fully explain this phenomenon, endplate morphology appears to influence EFs. This is thought to occur because the cage is inserted unevenly owing to the concavity of the inferior endplate when inserting the cage or because the concave endplate is vulnerable. The risk factors for intraoperative EFs suggested in the literature thus far include carelessness during endplate preparation, the instrument used for distraction, and cage position. There is also room for technical errors due to the incidence of nonparallel endplates in degenerative scoliosis.[10] We measured the disc wedge angles in the coronal and sagittal planes (Fig. 2) considering the uneven endplates in the sagittal and coronal planes. The occurrence of EFs increased as the disc wedge angle increased in the sagittal plane (OR, 1.22; 95% CI, 1.01–1.47), probably owing to the technical error of the surgeon as described above. Inoue et al.[14] argued that the occurrence of EFs after OLIF was due to the cantilever technique used for LL restoration. If EFs were confirmed on the intraoperative image before the posterior procedure, our claim could be further strengthened. However, not all images stored during the operation remained, and they were difficult to confirm. However, this aspect requires clarification in future studies.

Approximately three variables could be meaningfully selected in this study. However, we would like to briefly explain other variables as well. A chain of significant correlations was observed between the pelvic and spinal parameters. Since the sacrum forms the base of the spine, the SS determines the lumbar curve shape and size, thereby controlling the sagittal curve of the entire spine.[26] As the LL and PI increased, the occurrence of EFs increased. When the PI is large, SS also tends to be large, and LL tends to increase under the influence of SS.[27] Ultimately, the spinopelvic parameter is thought to increase the occurrence of EFs by causing discrepancies with the information the surgeon considered before surgery. In the current study, we selected SVA as a variable to investigate the effect of total spinal alignment on EFs. As SVA, which represents spinal balance, increased, the incidence of EFs also increased. This is ultimately thought to increase the incidence of EFs by causing a surgeon's technical error in the same context as the disc wedge angle, PI, and LL described above. In general, the segments contributing the most to LL are L4–5 and L5–S1.[28] In our study, a total of 164 levels were operated upon, and the largest number of procedures was performed at L4–5 (n = 67). Among them, 15 EFs occurred, followed by L3–4, which resulted in seven of 48 fractures. Therefore, the angle that contributes to lordosis may be misunderstood by the surgeon similar to the pelvic parameters, leading to EFs.

Minimally invasive OLIF was performed via a small incision using a tubular retractor. For this reason, the alignment of the entire spine and confirmation of LL during surgery depend on intraoperative fluoroscopic images. During surgery, the visible area was limited to the front of the psoas muscle and portions of the upper and lower endplates. When inserting a cage to prepare the endplate, surgeons normally rely on an intraoperative image intensifier and tactile stimuli to prevent EF. We hypothesized that the occurrence of EFs is related to these problems, and spinopelvic parameters were used to analyze the causal relationship. To reduce the inter-surgeon variable factors related to intraoperative EFs, we devised a new variable. SEA is the angle between the plateau of the sacrum and the endplate. If this angle is too large or too small, it may confuse the insertion angle predicted by the surgeon before surgery. Similar confounding factors can occur during endplate preparation, and these factors can cause EFs. The HE angle was devised using a concept similar to SEA and was defined as the angle between the horizontal line and the endplate. This also showed results that were not related to EFs. In contrast to the spinopelvic parameters, the reason for these results appears to be that LL, SS, and PI are relatively static factors. In other words, the SEA and HE devised by the authors are the same as those measured on a standing whole-spine radiograph before surgery, but are variables that are easy to change in the operating position. Therefore, we believe that this result is not related to the occurrence of EFs.

Looking at the previous research literature, most studies reported only the incidence of intraoperative EFs, which was discovered during a study on the subsidence of

Table 5. Summary of Studies That Reported Intraoperative Endplate Injury

Study	Study population (M : F)	Study design	Study target	Endplate injury incidence (%)	Race	Risk of endplate fracture
Malham et al.[29]	128 Patients (41 : 87) underwent LLIF	Prospective	Intraoperative endplate fracture and cage subsidence	3	Caucasian	None reported
Satake et al.[10]	102 Patients (41 : 61) underwent LLIF	Retrospective	Intraoperative endplate fracture	10.4	East Asian	Female sex, low BMD, cage material
Satake et al.[13]	93 Patients (34 : 59) underwent LLIF	Prospective	Intraoperative endplate fracture and cage subsidence	16.8	East Asian	Low BMD
Kim et al.[30]	125 Patients (50 : 75) with narrow cage and 38 patients (12 : 26) with wide cage underwent LLIF	Retrospective	Intraoperative endplate fracture and cage subsidence	24.8 (Narrow cage) 42.1 (Wide cage)	East Asian	Cage height (cage profile)
Tohmeh et al.[9]	140 Patients (78 : 62) underwent LLIF	Prospective	Intraoperative endplate fracture and cage subsidence	20 (1 mm or more) 4.5 (4 mm or more)	Caucasian	None reported
Wewel et al.[31]	77 Patients (39 : 38) underwent LLIF	Retrospective	Intraoperative endplate fracture and cage subsidence	4	Unknown	Endplate preparation
Kim et al.[32]	186 Patients (38 : 148) underwent LLIF	Retrospective	Intraoperative endplate fracture and	20.4	East Asian	Disc angle (sagittal, extension position), female sex, endplate sclerosis
This study	104 Patients (28 : 76) underwent OLIF	Retrospective	Intraoperative endplate fracture	18.4	East Asian	Female sex, osteoporosis, endplate morphology

LLIF: lateral lumbar interbody fusion, BMD: bone mineral density, OLIF: oblique lumbar interbody fusion.

patients who underwent LLIF surgery (Table 5). Therefore, the risk factors for intraoperative EFs are often not mentioned. Approximately 2 papers have studied intraoperative EFs alone, and all of them have been conducted in Asians. In a study by Satake et al.,[13] it was suggested that the occurrence of intraoperative EFs was caused by sex, low BMD, and cage material. In a study by Kim et al.,[23] sex, disc angle, and endplate sclerosis were considered risk factors. We believe that subsidence is affected by intraoperative EFs but do not think that EFs and subsidence have the same risk factors. Our study limited the cage material to the PEEK cage in OLIF but not LLIF. Therefore, the previously mentioned effect of the cage material can be eliminated, and indicators representing osteoporosis, including sex, are commonly associated with OLIF and LLIF.

This study has some limitations. First, because EFs were evaluated only with intraoperative C-arm images and simple postoperative radiographs, the actual rate of EFs related to the OLIF procedure may differ from the outcomes of the current study. However, to mitigate this limitation, we attempted to confirm EFs in detail by examining various radiographic and intraoperative imaging directions. Second, owing to the retrospective nature of this study, we did not consider the clinical and radiological outcomes of EF occurrence after OLIF surgery. The occurrence of EFs after OLIF is important; however, the follow-up results of EFs are of paramount importance. Thus, further studies with long-term follow-up of EFs are necessary to determine their impact on surgical outcomes. Third, other minor factors that influence EF development following OLIF, including preoperative motion and osteoarthritis severity, were not considered. Fourth, our study included heterogeneous factors that may have influenced the study outcomes, such as surgical level, sex, and age distribution. Finally, the number of patients enrolled in the current study was relatively small, and further investigation is required.

In this study, the EF following OLIF surgery was significantly related to various factors, including sex, inferior endplate concave depth, and disc wedge angle. It is necessary to reduce the risk of intraoperative EFs by analyzing and considering the factors that can be evaluated before surgery. In addition, when OLIF is performed in elderly Asians, the surgeons should be aware of the high possibility of EFs and be cautious.

CONFLICT OF INTEREST

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

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ORCID

Wook Tae Park https://orcid.org/0000-0002-2871-3198
In Ha Woo https://orcid.org/0000-0001-7510-1955
Sung Jin Park https://orcid.org/0000-0001-8835-9525
Gun Woo Lee https://orcid.org/0000-0002-8441-0802

REFERENCES

1. Yingsakmongkol W, Jitpakdee K, Varakornpipat P, et al. Clinical and radiographic comparisons among minimally invasive lumbar interbody fusion: a comparison with three-way matching. Asian Spine J. 2022;16(5):712-22.
2. Kim WJ, Shin HM, Song DG, et al. Comparison of clinical outcomes and complications of primary and revision surgery using a combined anterior and posterior approach in patients with adult spinal deformity and sagittal imbalance. Clin Orthop Surg. 2021;13(2):196-206.
3. Silvestre C, Mac-Thiong JM, Hilmi R, Roussouly P. Complications and morbidities of mini-open anterior retroperitoneal lumbar interbody fusion: oblique lumbar interbody fusion in 179 patients. Asian Spine J. 2012;6(2):89-97.
4. Kim YH, Ha KY, Rhyu KW, et al. Lumbar interbody fusion: techniques, pearls and pitfalls. Asian Spine J. 2020;14(5):730-41.
5. Li R, Li X, Zhou H, Jiang W. Development and application of oblique lumbar interbody fusion. Orthop Surg. 2020;12(2):355-65.
6. Xu DS, Walker CT, Godzik J, Turner JD, Smith W, Uribe JS. Minimally invasive anterior, lateral, and oblique lumbar interbody fusion: a literature review. Ann Transl Med. 2018;6(6):104.
7. Oh BK, Son DW, Lee SH, et al. Learning curve and complications experience of oblique lateral interbody fusion: a single-center 143 consecutive cases. J Korean Neurosurg

Soc. 2021;64(3):447-59.

8. Oxland TR, Grant JP, Dvorak MF, Fisher CG. Effects of endplate removal on the structural properties of the lower lumbar vertebral bodies. Spine (Phila Pa 1976). 2003;28(8):771-7.

9. Tohmeh AG, Khorsand D, Watson B, Zielinski X. Radiographical and clinical evaluation of extreme lateral interbody fusion: effects of cage size and instrumentation type with a minimum of 1-year follow-up. Spine (Phila Pa 1976). 2014;39(26):E1582-91.

10. Satake K, Kanemura T, Nakashima H, Yamaguchi H, Segi N, Ouchida J. Cage subsidence in lateral interbody fusion with transpsoas approach: intraoperative endplate injury or late-onset settling. Spine Surg Relat Res. 2017;1(4):203-10.

11. Hu Z, He D, Gao J, et al. The influence of endplate morphology on cage subsidence in patients with stand-alone oblique lateral lumbar interbody fusion (OLIF). Global Spine J. 2023;13(1):97-103.

12. Ohiorhenuan IE, Walker CT, Zhou JJ, et al. Predictors of subsidence after lateral lumbar interbody fusion. J Neurosurg Spine. 2022:37(2):183-7.

13. Satake K, Kanemura T, Yamaguchi H, Segi N, Ouchida J. Predisposing factors for intraoperative endplate injury of extreme lateral interbody fusion. Asian Spine J. 2016;10(5):907-14.

14. Inoue G, Saito W, Miyagi M, et al. Prevalence and location of endplate fracture and subsidence after oblique lumbar interbody fusion for adult spinal deformity. BMC Musculoskelet Disord. 2021;22(1):880.

15. DiGiorgio AM, Edwards CS, Virk MS, Mummaneni PV, Chou D. Stereotactic navigation for the prepsoas oblique lateral lumbar interbody fusion: technical note and case series. Neurosurg Focus. 2017;43(2):E14.

16. Li HM, Zhang RJ, Shen CL. Differences in radiographic and clinical outcomes of oblique lateral interbody fusion and lateral lumbar interbody fusion for degenerative lumbar disease: a meta-analysis. BMC Musculoskelet Disord. 2019;20(1):582.

17. Shin MH, Zmuda JM, Barrett-Connor E, et al. Race/ethnic differences in associations between bone mineral density and fracture history in older men. Osteoporos Int. 2014;25(3):837-45.

18. Nam HS, Shin MH, Zmuda JM, et al. Race/ethnic differences in bone mineral densities in older men. Osteoporos Int. 2010;21(12):2115-23.

19. Hou Y, Yuan W, Kang J, Liu Y. Influences of endplate removal and bone mineral density on the biomechanical properties of lumbar spine. PLoS One. 2013;8(11):e76843.

20. Polikeit A, Ferguson SJ, Nolte LP, Orr TE. The importance of the endplate for interbody cages in the lumbar spine. Eur Spine J. 2003;12(6):556-61.

21. Oh KW, Lee JH, Lee JH, Lee DY, Shim HJ. The correlation between cage subsidence, bone mineral density, and clinical results in posterior lumbar interbody fusion. Clin Spine Surg. 2017;30(6):E683-9.

22. Park MK, Kim KT, Bang WS, et al. Risk factors for cage migration and cage retropulsion following transforaminal lumbar interbody fusion. Spine J. 2019;19(3):437-47.

23. Kim YH, Ha KY, Kim KT, et al. Risk factors for intraoperative endplate injury during minimally-invasive lateral lumbar interbody fusion. Sci Rep. 2021;11(1):20149.

24. Wang Y, Battie MC, Boyd SK, Videman T. The osseous endplates in lumbar vertebrae: thickness, bone mineral density and their associations with age and disk degeneration. Bone. 2011;48(4):804-9.

25. Zhao FD, Pollintine P, Hole BD, Adams MA, Dolan P. Vertebral fractures usually affect the cranial endplate because it is thinner and supported by less-dense trabecular bone. Bone. 2009;44(2):372-9.

26. Stagnara P, De Mauroy JC, Dran G, et al. Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for the evaluation of kyphosis and lordosis. Spine (Phila Pa 1976). 1982;7(4):335-42.

27. Lee JK, Hyun SJ, Kim KJ. Reciprocal changes in the whole-body following realignment surgery in adult spinal deformity. Asian Spine J. 2022;16(6):958-67.

28. Celestre PC, Dimar JR 2nd, Glassman SD. Spinopelvic parameters: lumbar lordosis, pelvic incidence, pelvic tilt, and sacral slope: what does a spine surgeon need to know to plan a lumbar deformity correction? Neurosurg Clin N Am. 2018;29(3):323-9.

29. Malham GM, Parker RM, Blecher CM, Seex KA. Assessment and classification of subsidence after lateral interbody fusion using serial computed tomography. J Neurosurg Spine. 2015;23(5):589-97.

30. Kim SJ, Lee YS, Kim YB, Park SW, Hung VT. Clinical and radiological outcomes of a new cage for direct lateral lumbar interbody fusion. Korean J Spine. 2014;11(3):145-51.

31. Wewel JT, Hartman C, Uribe JS. Timing of lateral lumbar interbody subsidence: review of exclusive intraoperative subsidence. World Neurosurg. 2020;137:e208-12.

32. Kim YH, Ha KY, Kim KT, et al. Risk factors for intraoperative endplate injury during minimally-invasive lateral lumbar interbody fusion. Sci Rep. 2021;11(1):20149.