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Clinical Study

Risk factors for cage migration and cage retropulsion following transforaminal lumbar interbody fusion

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ABSTRACT

BACKGROUND CONTEXT: Transforaminal lumbar interbody fusion (TLIF) is a widely accepted surgical procedure, but cage migration (CM) and cage retropulsion (CR) are associated with poor outcomes.

PURPOSE: This study seeks to identify risk factors associated with these serious events.

STUDY DESIGN: A prospective observational longitudinal study.

PATIENT SAMPLE: Over a 5-year period, 881 lumbar levels in 784 patients were treated using TLIF at three spinal surgery centers.

OUTCOME MEASURES: We evaluated the odds ratio of the risk factors for CM with and without subsidence and CR in multivariate analysis.

METHODS: Our study classified CM into two subgroups: CM without subsidence and CM with subsidence. Cases of spinal canal and/or foramen intrusion of the cage was defined separately as CR. Patient records, operative notes, and radiographs were analyzed for factors potentially related to CM with subsidence, CM without subsidence, and CR.

RESULTS: Of 881 lumbar levels treated with TLIFs, CM without subsidence was observed in 20 (2.3%) and CM with subsidence was observed in 36 (4.1%) patients. Among the CM cases, CR was observed in 17 (17/56, 30.4%). The risk factors of CM without subsidence were osteoporosis (OR 8.73, $p < .001$) and use of a unilateral single cage (OR 3.57, $p < .001$). Osteoporosis (OR 5.77, $p <$

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.001) and endplate injury (OR 26.87, p < .001) were found to be significant risk factors for CM with subsidence. Risk factors of CR were osteoporosis (OR 7.86, p < .001), pear-shaped disc (OR 8.28, p = .001), endplate injury (OR 18.70, p < .001), unilateral single cage use (OR 4.40, p = .03), and posterior cage position (OR 6.45, p = .04). A difference in overall fusion rates was identified, with a rate of 97.1% (801 of 825) for no CM, 55.0% (11 of 20) for CM without subsidence, 41.7% (15 of 36) for CM with subsidence, and 17.6% (3 of 17) for CR at 1.5 years postoperatively.

CONCLUSIONS: Our results suggest that osteoporosis is a significant risk factor for both CM and CR. In addition, a pear-shaped disc, posterior positioning of the cage, the presence of endplate injury and the use of a single cage were correlated with the CM with and without subsidence and CR.

Keywords: Cage migration; Cage retropulsion; Interbody cage; Osteoporosis; Risk factors; Subsidence; Transforaminal lumbar interbody fusion

Introduction

Transforaminal lumbar interbody fusion (TLIF) using an interbody cage is an effective treatment for patients with degenerative lumbar spine diseases [1]. However, perioperative and postoperative complications can occur after TLIF. A recognized complication of TLIF is anteriorposterior migration of the cage within the disc space [2]. Cage migration (CM) may lead to progressive spinal deformity and narrowing of the disc space, thus preventing successful fusion. In its most severe form, CM may result in retropulsion of the cage back into the spinal canal or foramen. Such "cage retropulsion" (CR) can exacerbate neurological deficits through direct compression of the neural tissue [3]. As CM and CR are associated with poor outcomes [3], it is important to identify related risk factors so that these complications can be prevented.

Previous studies have suggested risk factors for CM and CR after TLIF [3–6]. However, most previously identified risk factors did not reach statistical significance in these reports, perhaps because of an insufficient sample size. In addition, previous studies have not fully reflected the current trends regarding aging patients who undergo spine surgery. As the population ages, the number of patients with osteoporosis and other comorbidities, for which TLIF is being considered, increases. In particular, any correlation with osteoporosis is significant, because it potentially affects mechanical cage support. There have been too few analyses of surgical risk factors related to the incidence of CM and CR. Our study divided the CM into CM without subsidence and CM with subsidence for a more detailed study and obtained the respective risk factors, also those for CR. In particular, we focused on osteoporosis and surgical risk factors, which have not been adequately analyzed in previous studies.

Materials and methods

Patient population

Between January 2011 and December 2015, 802 patients were treated with TLIF. Eighteen patients were excluded (four patients died, 11 patients were lost to follow-up, and three patients rejected enrollment in this study). All patients had failed conservative treatment and were experiencing pain, sensory disturbances, or motor weakness. Bone mineral density (BMD) was measured with dual-energy X-ray absorptiometry (DEXA) at the fusion level. Osteoporosis was defined as a BMD of 2.5 standard deviations below that of a young adult [7]. We performed a DEXA scan on patients aged 60 years or older. We considered those younger than 60 years old as having a normal BMD. Even if a patient was younger than 60 years, a DEXA scan was performed if the patient had a disease or took a medication that could cause osteoporosis. A DEXA scan was performed in 661 (84.3%) out of 784 patients. In all, 598 patients were over 60 years old and 63 patients had a disease or took a medication that could cause osteoporosis. Multiple clinical factors were reviewed for each patient, including patient sex, age, diagnosis, comorbidities, such as hypertension and diabetes mellitus, and fusion level. This study protocol was approved by our institutional review board, and all patients provided informed consent

Radiographic analysis

Our study classified CM into two subgroups: CM with subsidence and without subsidence. The CM with subsidence was defined as a measured diagonal (vertical+horizontal) or vertical (pure subsidence) migration of more than 2 mm on follow-up radiographs compared with immediate postoperative radiographs (Fig. 1). The CM without subsidence was defined as a measured horizontal migration of more than 2 mm on follow-up radiographs compared with immediate postoperative radiographs (Fig. 2). The CR was defined as movement of the posterior margin of the cage into the spinal canal or foramen (Fig. 3).

The medical records and radiographic images of patients who underwent TLIF at three spinal centers were analyzed. Postoperative X-ray was done immediately (operative day) and at 1, 3, 6, 9, 12, and 18 months, respectively, and flexion-extension radiographs were performed at 1.5 years after surgery. The radiographs were interpreted as showing incomplete union if at least one of the following three conditions was demonstrated: mobility of more than 3°, a remaining clear zone, or no definite bone connection [8,9]. The presence of a

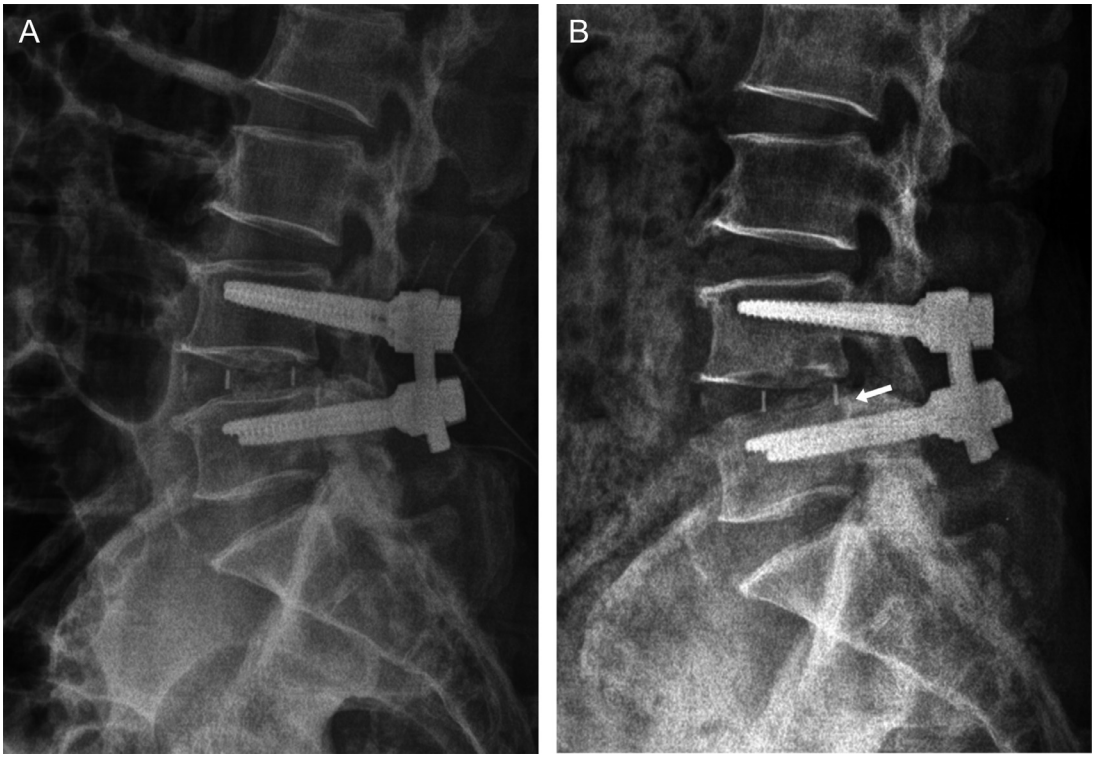

Fig. 1. A case showing cage migration with subsidence following TLIF. (A) Immediately postoperative radiograph showing the size and location of both cages is appropriate. (B) Three months after surgery, the cage migrated with subsidence.

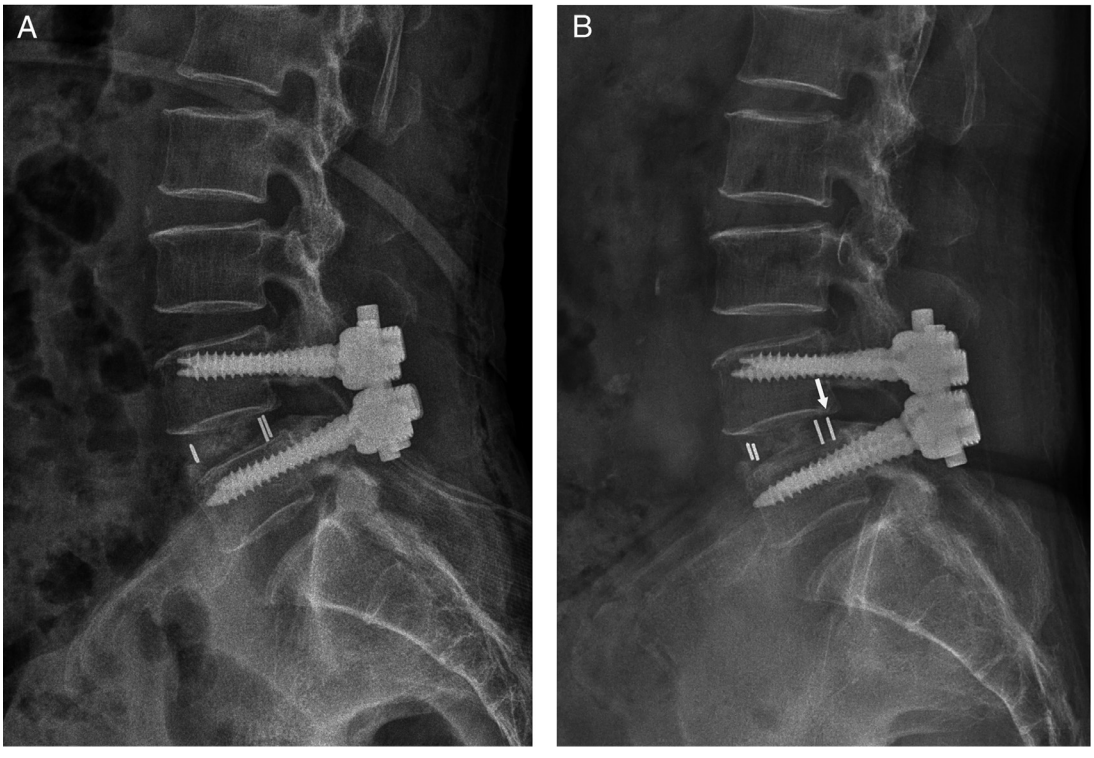

Fig. 2. A case showing cage migration without subsidence following TLIF. (A) Immediate postoperative radiograph showing the size and location of both cages is appropriate. (B) Three months after surgery, the cage migrated without subsidence.

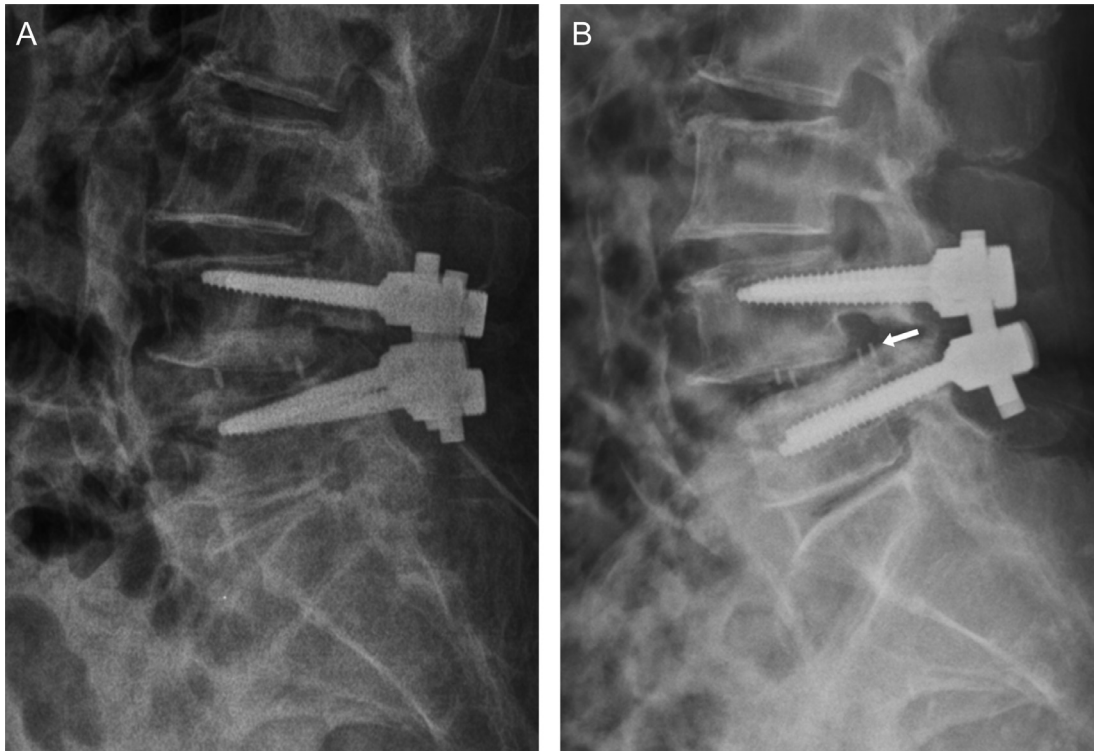

Fig. 3. A case showing cage retropulsion following TLIF. (A) Immediate postoperative radiograph showing the size and location of both cages is appropriate. (B) Six months after surgery, the cage migrated into the spinal canal.

radiolucent area was defined as screw loosening at 1.5 years postoperatively by postoperative X-ray [10,11]. A patient whose fusion was not confirmed by radiography nor had screw loosening, were examined by CT. All patients with CM had CT performed 1.5 years postoperatively. In total, 578 patients did not undergo CT and the remaining patients (206 of 784 patients, 26.3%) underwent CT. Fusion was defined by using the fusion grade system of Bridwell et al. [12].

Surgical procedures

All patients underwent a TLIF with a bilateral pedicle screw. A midline skin incision exposed the posterior elements and lateral aspect of the facet joint. Following bilateral laminectomy, facetectomy at the level of pathology was performed to expose the intervertebral disc. Material was removed from the central disc and foraminal areas until the dural sac and nerve root were thoroughly decompressed. After discectomy and endplate preparation, autologous bone graft material harvested from posterior spinal elements was packed into the disc space and cage, and the cage was inserted into the disc space. Endplates were prepared with curette only, and we did not use a drill or osteotomy. Following cage insertion, bilateral pedicle screw and rod fixation with axial compression were performed using a C-arm.

Types of fusion cages

In our study, several cage types were used: box type cages [INNESIS PEEK cages (BK MEDITECH, Seoul, South Korea)], rotation type cages [PLIVIOS PEEK cages (Depuy Synthes, Raynham, MA, USA)], and bullet-shaped cages [Capstone PEEK cages (Medtronic Sofamor Danek, Memphis, TN, USA)].

Radiological and surgical factor assessment

Spinal range of motion was measured with preoperative dynamic lateral flexion-extension radiographs. The disc height was measured between the midpoints of the superior and inferior endplates on the sagittal plane of the CT scan. Using lateral radiographs, we defined a pear-shaped disc as one that had a convex surface on the posterior halves of the superior and inferior endplates, and a concave surface on the anterior halves of the endplates (Fig. 4) [3]. We evaluated the positioning of the cage, the cage number, and the pedicle screw depth on postoperative radiography. We examined surgical records to determine the type of cage and the cage angle. We defined an endplate injury as the cage breaching into the cortical endplate on the immediate postoperative X-ray (Fig. 5). Cage position was classified as either anterior or posterior based on the relationship between the midpoint of the vertebral body and the midpoint of the cage in the immediate postoperative sagittal X-ray. To analyze pedicle screw depth, we divided the vertebral body into four parts on lateral radiographs. Where the pedicle screw tip was located, the depth was evaluated (Fig. 6). A parameter, obtained by subtracting preoperative disc height from cage height, was defined as “cage height minus disc height.” By comparing

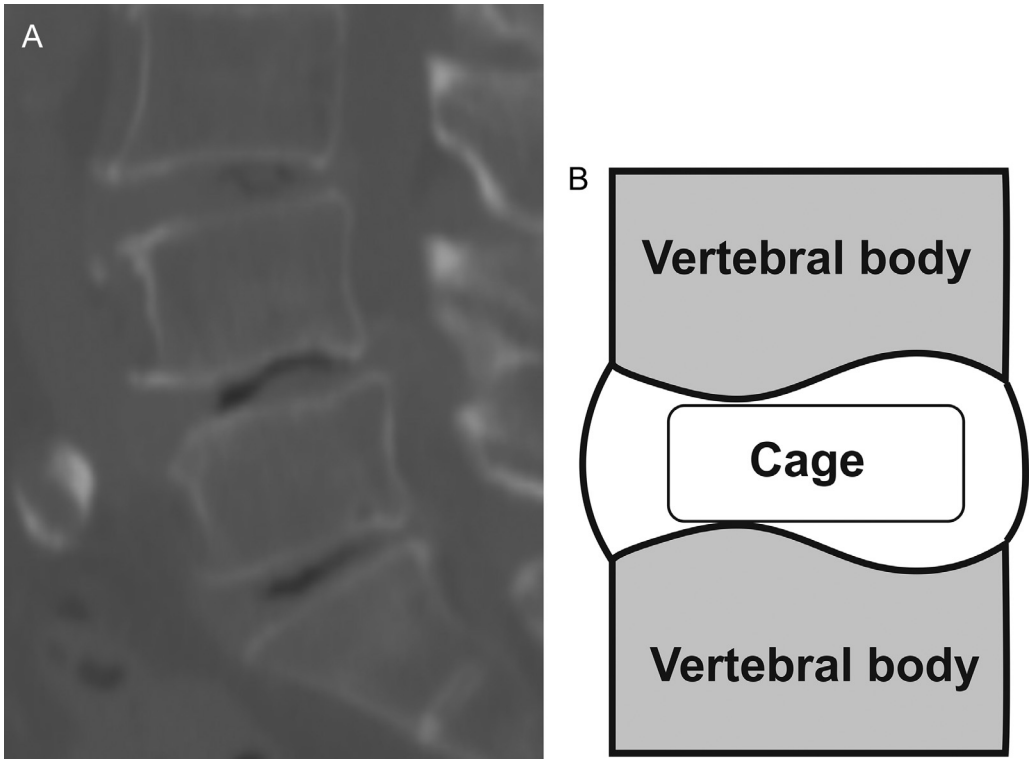

Fig. 4. The computed tomographic scan and schematic representation of the pear-shaped disc. A pear-shaped disc was defined as a disc that had a convex surface in the posterior halves of the superior and inferior end plates and a concave surface in the anterior halves (A). The cage contacts the end plates at only two points (B), which creates instability between the end plates and the cage.

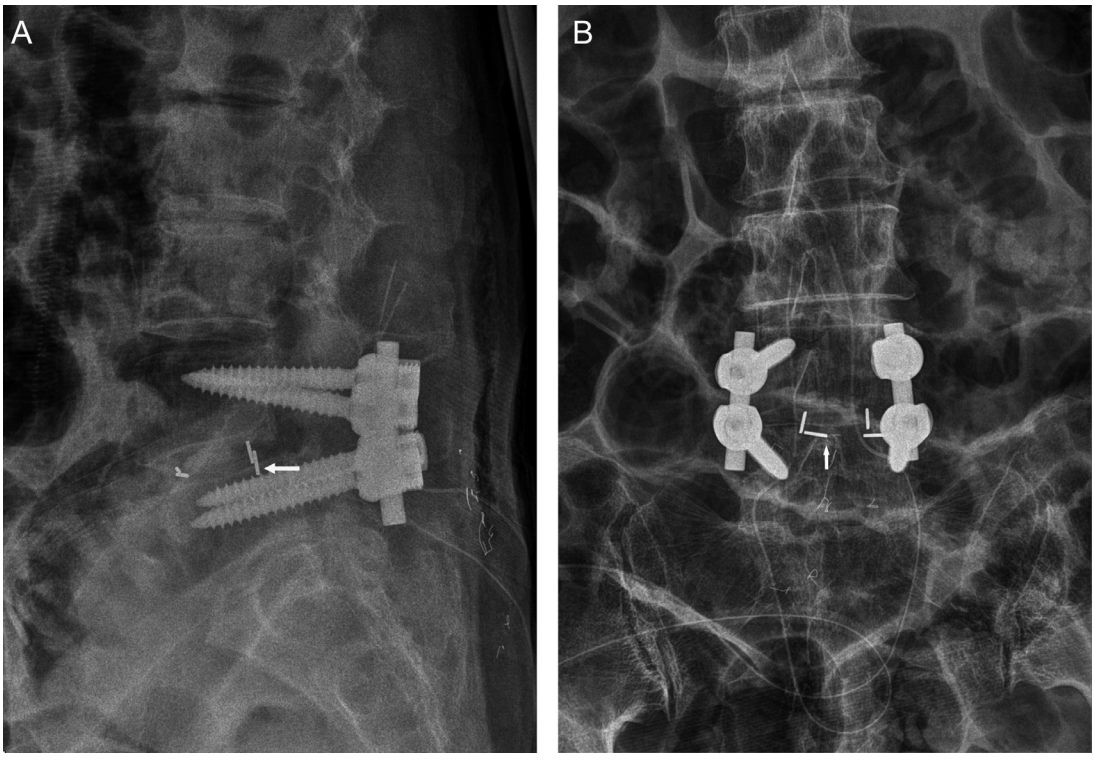

Fig. 5. Endplate injury at immediate postoperative X-ray. We defined an endplate injury as the cage breaching into the cortical endplate on the immediate postoperative X-ray (A: Lateral view, B: anteriorposterior view).

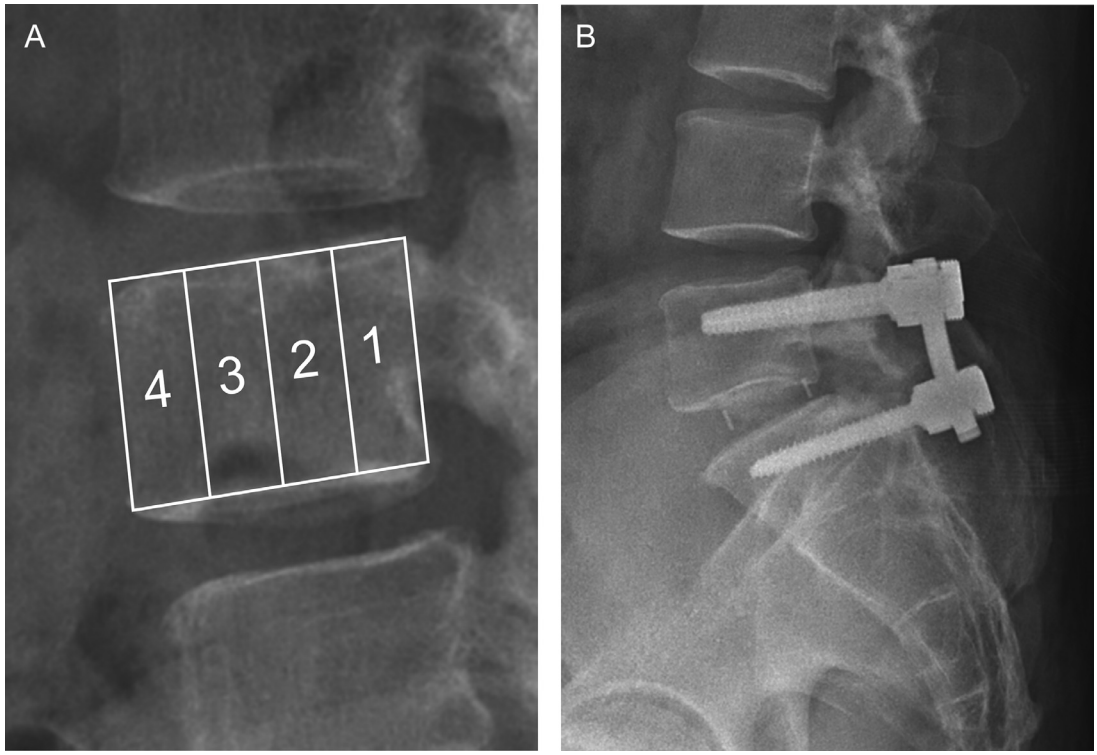

Fig. 6. Measurement of pedicle screw depth. The vertebral body was divided into four parts from the body's posterior margin in the lateral plain (A) and where the screw-end tip was located in the vertebral body, the pedicle screw depth was evaluated (B).

preoperative and postoperative lateral radiographs, we measured a "listhesis correction degree," which was obtained by subtracting the postoperative listhesis degree from the preoperative listhesis degree.

Statistical analysis

Univariate analyses of clinical, radiologic, and surgical parameters were performed using the chi-square test. Multivariable logistic regression analysis was then used to identify independent risk factors for CM and CR using significant variables identified by univariate analysis. All statistical calculations were performed by SAS version 9.4 (SAS Institute Inc, Cary, NC, USA)

Results

Patient factors

The enrolled 784 patients had a total of 881 levels treated with TLIF at three spinal surgery centers. There were 301 men and 483 women, with a mean age of 63.3 years and an age range of 20–85 years. Patients were divided into two groups according to whether or not they experienced CM. In our study of 784 patients, out of the 881 levels treated with TLIF, there were 56 instances of CM (6.4 %). Of the 881 levels, 20 levels (2.3%) were designated as CM without subsidence and 36 levels (4.1%) were designated as CM with subsidence. Of the 56 levels experiencing CM, 17 levels (30.4 %) were designated as CR.

A total of 22 patients (22/784 patients, 2.8%) underwent revision surgery within 18 months after surgery (four patients: recurrent symptoms caused by CR; four patients: ASD; three patients: screw malposition; two patients: hematoma; three patients: deep infection; two patients: delayed CSF leakage; two patients: exploration surgery caused by unknown origin neurological deficits after surgery; one patient: adjacent fracture caused by trauma; one patient: radicular pain caused by screw loosening). Of the 17 patients with CR, 10 patients (58.8%, 10 of 17) complained of radicular pain postoperatively. Four patients (23.5%, 4 of 17) required further revision surgery, but the remaining six patients improved after conservative treatment. Patient sex, age, diagnosis, the presence of hypertension or diabetes mellitus, fusion level, and cage insertion level were not statistically significant risk factors for CM or CR (Table 1). However, the incidence of CM and CR was significantly more frequent in levels with osteoporosis, compared with levels with normal BMD. For the CM without subsidence group, seven of 20 levels showed osteoporosis (35.0%, $p < .001$), and for the CM with subsidence group, 13 of 36 levels had osteoporosis (36.1%, $p < .001$). In the CR group, nine out of 17 patients had osteoporosis (52.9%, $p < .001$). Only 52 of 825 levels without CM showed osteoporosis (6.3%) (Table 2). In multivariate analysis, osteoporosis showed statistical significance as a risk factor for CM without subsidence ($p < .001$), CM with subsidence ($p < .001$), and CR ($p < .001$). The odds of developing CM without subsidence, CM with subsidence, and

Table 1
Baseline characteristics of patients with cage migration with and/or without subsidence, cage retropulsion and no cage migration

	No cage migration	Cage migration without subsidence	p value*	Cage migration with subsidence	p value*	Cage retropulsion	p value*
Number of patients	728 (92.9%)	20 (2.6%)		36 (4.6%)		17 (2.2%)	
Age, years (mean ± SD)	63.3 ± 9.7	62.1 ± 9.5	.59	65.5 ± 12.0	.28	62.5 ± 13.5	.83
Sex			.85		.43		.10
Male	278 (38.2%)	8 (40.0%)		16 (44.4%)		3 (17.6%)	
Female	450 (61.8%)	12 (60.0%)		20 (55.6%)		14 (82.4%)	
Diagnosis			.82		.33		.02
Spinal stenosis	219 (30.1%)	5 (25.0%)		14 (38.9%)		6 (35.3%)	
DS	415 (57.0%)	11 (55.0%)		17 (47.2%)		7 (41.2%)	
IS	46 (6.3%)	2 (10.0%)		4 (11.1%)		4 (23.5%)	
HNP	48 (6.6%)	2 (10.0%)		1 (2.8%)		0 (0.0%)	
HTN	256 (35.2%)	7 (35.0%)	.99	9 (25.0%)	.21	4 (23.5%)	.60
DM	152 (20.9%)	3 (15.0%)	.52	8 (22.2%)	.85	4 (23.5%)	.84
Fusion level			.06		.74		.37
1	638 (87.6%)	20 (100.0%)		30 (83.3%)		14 (82.4%)	
≥ 2	90 (12.4%)	0 (0%)		6 (16.7%)		3 (17.6%)	

To investigate the effect of patient's general factors on cage migration, Table 1 was analyzed for each patient.
DS, degenerative spondylolisthesis; IS, isthmic spondylolisthesis; HNP, herniated nucleous pulposus; HTN, hypertension; DM, diabetes mellitus.
* Compared with No cage migration.

CR in patients with osteoporosis are 8.73, 5.77, and 7.86 times higher than that in patients without osteoporosis, respectively (Table 3).

Radiological factors

Univariate analysis showed that a pear-shaped disc was significantly associated with both CM with subsidence, occurring in eight of 36 levels (22.2%, p < .001), and CR, seen in seven of 17 levels (41.2%, p < .001), compared with only 51 of 825 levels without CM (6.2%) (Table 2). In multivariate analysis, a pear-shaped disc was only associated with CR (OR 8.28, p = .001) (Table 3).

Surgical factors

Of the 881 levels, there were 90 levels (10.2%) with endplate injury. Endplate injury occurred frequently in conjunction with CM with subsidence, where it was seen in 26 of 36 levels (72.2%, p < .001), and CR, where it was seen in 12 of 17 levels (70.6%, p < .001), compared with levels with no CM (7.4%). Endplate injury was a significant risk factor for CM with subsidence (OR 26.87, p < .001) and CR (OR 18.70, p < .001) in multivariate analysis (Table 3).

Anterior cage position occurred in 17.9% of patients with CM and in 0% of patients with CR, but the posterior position occurred in 82.1% of patients with CM and in 100% of patients with CR. The posterior cage position was a significant factor for CR (OR 6.45, p = .04).

Univariate cage number analysis showed that a unilateral single cage was present more frequently in levels with CM without subsidence, occurring in seven of 20 levels (35.0%), compared with levels without CM, where it was seen in 113 of 825 levels (13.7%, p = .01). No statistical significance for the unilateral single cage was seen with CR, where it was noted in four of 17 levels (23.5%), compared with levels without CM (13.7%, p = .20). However, in multivariate analysis, the presence of a unilateral single cage was a significant risk factor for CR (OR 4.40, p = .03) and CM without subsidence (OR 3.57, p < .001) (Table 3). Type of cage, cage angle, pedicle screw depth, and listhesis correction degree were not statistically significant risk factors for CM or CR.

Fusion and screw loosening rate at 1.5 years after surgery

A difference in overall fusion rates was identified, with a rate of 97.1% (801 of 825) for no CM, 55.0 % (11 of 20) for a CM without subsidence, 41.7% (15 of 36) for CM with subsidence, and 17.6% (3 of 17) for a CR at 1.5 years postoperatively. In paired analysis, there was a statistically significant difference between no CM and CM with or without subsidence. Also, comparison of no CM and CR revealed a significant difference (p < .001). Compared with a screw loosening rate for cases of no CM (4.7%, 39 of 825), rates for CM with subsidence (61.1%, 22 of 36) and CR (70.6%, 12 of 17) were high and statically significant (Table 4; Fig. 7).

Discussion

The CM can occur horizontally, vertically, or in a combination of both directions (diagonally). In the case of vertical or diagonal migration, it can be regarded that a subsidence occurs. The biomechanical impact of CM with subsidence, which can decrease the intervertebral height and influence the anterior support of the spine, can be different from horizontal migration without subsidence. Therefore, we analyzed risk factors and radiologic outcomes after dividing CM into groups with subsidence and without subsidence.

Although we generally know that CM and CR have an adverse effect on fusion, no previous study has provided

Table 2
Patient, radiologic, surgical factors in patient with cage migration with /without subsidence and cage retropulsion

	No cage migration	Cage migration without subsidence	p value*	Cage migration with subsidence	p value*	Cage retropulsion	p value*
Number of cage inserted	825 (93.7%)	20 (2.3%)		36 (4.1%)		17 (1.9%)	
BMD			<.001		<.001		<.001
> - 2.5	773 (93.7%)	13 (65.0%)		23 (63.9%)		8 (47.1%)	
≤ - 2.5	52 (6.3%)	7 (35.0%)		13 (36.1%)		9 (52.9%)	
Cage inserted location			.52		.91		.86
L1-2	8	0		0		0	
L2-3	25	0		0		0	
L3-4	171	0		7		3	
L4-5	508	18		23		11	
L5-S1	113	2		6		3	
ROM (°)	7.68 ± 5.23	9.55 ± 6.03	.41	8.14 ± 4.43	.60	7.47 ± 3.90	.98
Pear-shaped disc			.47		<.001		<.001
No	774 (93.8%)	18 (90.0%)		28 (77.8%)		10 (58.8%)	
Yes	51 (6.2%)	2 (10.0%)		8 (22.2%)		7 (41.2%)	
Cage-disc height (mm)	1.67 ± 2.06	0.36 ± 0.50	.45	1.28 ± 1.75	.97	2.06 ± 1.79	.25
Endplate injury			.22		<.001		<.001
No	764 (92.6%)	17 (85.0%)		10 (27.8%)		5 (29.4%)	
Yes	61 (7.4%)	3 (15.0%)		26 (72.2%)		12 (70.6%)	
Cage position			.62		.34		.03
Anterior	169 (20.5%)	5 (25.0%)		5 (13.9%)		0 (0.0%)	
Posterior	656 (79.5%)	15 (75.0%)		31 (86.1%)		17 (100.0%)	
Type of cage							
Box	513 (62.2%)	9 (45.0%)		19 (52.8)		9 (52.9%)	1
Rotation	132 (16.0%)	3 (15.0%)	.70	9 (25.0%)	.67	3 (17.7%)	.97
Bullet	180 (21.8%)	8 (40.0%)	.06	8 (22.2%)	.14	5 (29.4%)	.49
Cage number			.01		.61		.20
Unilateral single	113 (13.7%)	7 (35.0%)		6 (16.7%)		4 (23.5%)	
Bilateral double	712 (86.3%)	13 (65.0%)		30 (83.3%)		13 (76.5%)	
Cage angle (°)							
0	475 (57.6%)	9 (45.0%)	1	18 (50.0%)	1	10 (58.8%)	1
4 + 5 + 6	213 (25.8%)	7 (35.0%)	.29	13 (36.1%)	.21	6 (35.3%)	.70
8	137 (16.6%)	4 (20.0%)	.48	5 (13.9%)	.94	1 (5.9%)	.21
Pedicle screw depth							
1 + 2	31 (3.8%)	0	1	2 (5.6%)	1	1 (5.9%)	1
3	634 (76.8%)	15 (75.0%)	1	31 (86.1%)	.67	15 (88.2%)	.92
4	160 (19.4%)	5 (25.0%)	.58	3 (8.3%)	.27	1 (5.9%)	.37
Listhesis correction degree (mm)	3.23 ± 3.17	2.70 ± 2.77	.41		.60	0.80 ± 1.30	.17

To investigate the exact effect of each level on CM and CR, osteoporosis, radiologic and surgical factors were analyzed by cage inserted levels.
BMD, bone mineral density; ROM, range of motion.
* Compared with No cage migration.

detailed analysis about the fusion rate and screw loosening rate of CM and CR. With regard to the relationship between the fusion rate and CM (with or without subsidence) and CR, fusion levels with no CM had significantly higher rates of successful fusion compared with levels with CM or CR in our study. The screw loosening rate was significantly higher in the CM with subsidence and CR groups compared with the no CM and CM without subsidence groups. When subsidence or CR occurs, the intervertebral height will be lower, and sufficient axial compression could not be

Table 3
Multivariate analysis of risk factors of cage migration with/without subsidence and cage retropulsion

	Cage migration without subsidence		Cage migration with subsidence		Cage retropulsion	
	OR (95% Cl)	p value	OR (95% Cl)	p value	OR (95% Cl)	p value
Osteoporosis	8.73 (3.28–23.25)	<.001	5.77 (2.30–14.48)	<.001	7.86 (2.58–23.96)	<.001
Pear-shaped disc			1.62 (0.55–4.78)	.38	8.28 (2.34–29.39)	.001
Endplate injury			26.87 (12.00–-60.17)	<.001	18.70 (6.20–56.42)	<.001
Unilateral single cage	3.57 (1.40–9.30)	<.001			4.40 (1.13–13.20)	.03
Cage position (posterior)					6.45 (1.84–21.51)	.04

OR, odds ratio; Cl, confidence interval.

Table 4
Radiologic fusion and screw loosening rate at 1.5 year postoperatively

	No cage migration	Cage migration without subsidence	p value*	Cage migration with subsidence	p value*	Cage retropulsion	p value*
Number of cage inserted	825 (93.7%)	20 (2.6%)		36 (4.6%)		17(1.9%)	
Fusion rate in 1.5 year follow-up after surgery			<.001		<.001		<.001
Yes	801 (97.1%)	11 (55.0%)		15 (41.7%)		3 (17.6%)	
No	24 (2.9%)	9 (45.0%)		21 (58.3%)		14 (82.4%)	
Screw loosening in 1.5 year follow-up after surgery			.25		<.001		<.001
Yes	39 (4.7%)	2 (10.0%)		22 (61.1%)		12 (70.6%)	
No	786 (95.3%)	18 (90.0%)		14 (38.9%)		5 (29.4%)	

* Compared with no cage migration.

provided [10–12]. Furthermore, screw loosening is associated with other complications, such as screw breakage, nonunion, pseudoarthrosis, and progressive kyphosis [13].

Risk factors for CM and CR have been discussed in several other studies [3–6]. Aoki et al. [4] suggested that the use of a bullet-shaped cage, a higher posterior disc height, the presence of scoliotic curvature, and undersized cages were possible risk factors. Kimura et al. [3] reported that the risk factors for CR after TLIF were multilevel fusion, involvement of L5/S1, greater range of motion of the disc space, taller discs, and a pear-shaped disc space. Zhao et al. [6] reported that the use of rectangular-shaped cages, small cages, conducting double segment fusion, and adjacent endplates of linear type might be risk factors for CM. Finally, Pan et al. [5] suggested that either the use of a bullet-shaped cage or the involvement of L5/S1 were associated with a higher rate of CR.

In our study, patients with osteoporosis had a significantly higher rate of CM, with or without subsidence, and CR in comparison to those with a normal BMD. Some cadaveric studies have reported that BMD was a significant factor relating to cage stabilization [14–16]. Furthermore, the fixation strength of pedicle screws depends on the mechanical properties of the trabecular bone at the bone-screw interface [17]. Consequently, osteoporosis could lead to loosening of the pedicle screws, which are then unable to provide sufficient axial compressive strength. It is important to measure the BMD of each patient before surgery and to administer antiosteoporosis drugs to patients. To our knowledge, this study is the first and only clinical report to demonstrate that osteoporosis can be a significant risk factor for CR and CM with or without subsidence.

Prior studies have shown that disc shape is related to the incidence of CM and CR [3,6]. Our study confirmed previous reports that CR occurs more frequently with a pear-shaped disc. Generally, the endplate exhibits a flat or concave surface opposing the disc space. Ideally, perfectly matching the cage with the underlying endplate could result in a more uniform pressure distribution. A pear-shaped disc space does not make uniform contact with all four corners of the cage in the sagittal plane [3]. This results in reduced contact area between the cage and the vertebral surface, providing a possible explanation for the higher incidence of CR (Fig. 4). For this reason, surgeons need to carefully evaluate the shape of the disc space when considering TLIF.

Endplate injury was found to be a significant risk factor for CR and CM with subsidence in our study. The importance of preserving the bony endplate to prevent CM has been reported in other studies [18,19]. Before cage insertion, endplate preparation is a vital step in creating a successful fusion. However, if the vertebral body has endplate injury, the interface between the cage and the vertebral body may not have sufficient strength to support cage's stabilization. Based on our experience, we recommend the cages should be carefully inserted into the disc space to avoid endplate injury.

In the current study, there were significantly higher rates of CR and CM without subsidence in procedures employing a unilateral single cage, compared with bilateral double cages. Biomechanical and anatomical studies indicate that the center of an endplate is the weakest part and that the posterolateral region is the strongest part [20]. Labrom et al. [21] showed that two smaller titanium mesh cages placed posterolaterally in a cadaver spine provided superior construct rigidity compared with centrally placed interbody cages. A single cage tends to be located more in the center of an endplate than double cages. For that reason, double cages placed in the posterolateral regions of an endplate seem to have the advantage of minimizing CM and CR. However, we need to consider that the single cages were all traditional posterior lumbar interbody cages and the facet joints were removed in the present study. Some studies demonstrate a large single cage, like a banana-shaped cage or a TLIF cage, could provide biomechanical stability comparable to traditional double cages [22–24]. Also the posterior oblique lumbar interbody fusion technique requires partial facetectomy, which preserves the posterior elements and could provide increased stabilization [24]. Therefore, we should pay attention to the cage design or surgical technique, if we want to use a single cage.

The posterior cage position appeared in 100% of patients with CR, which was a significant factor for CR (OR 6.45, p =

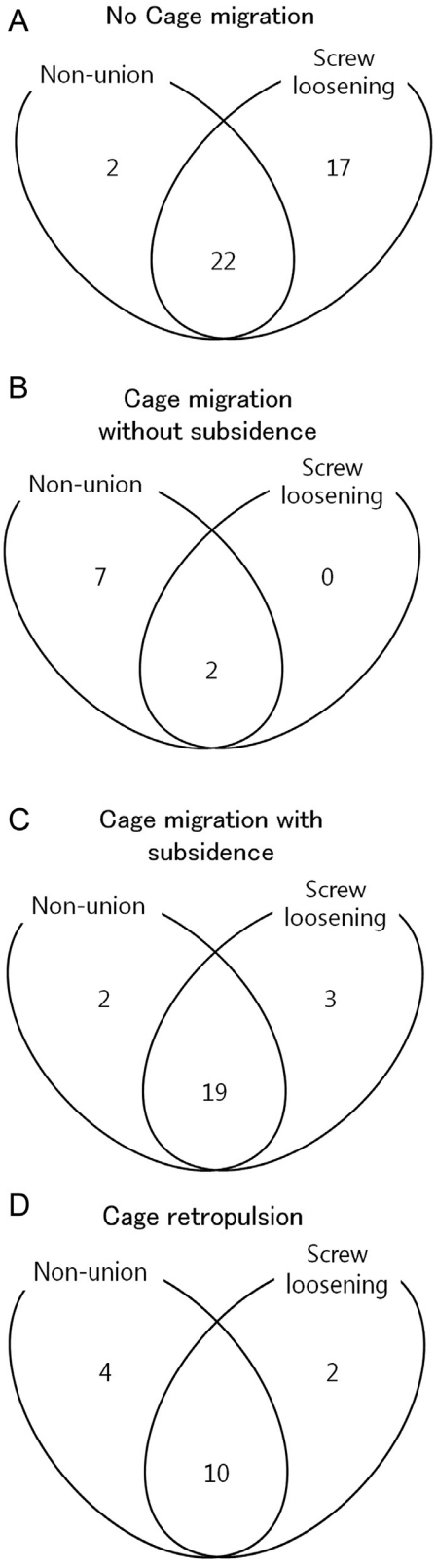

Fig. 7. Venn diagram of nonunion and screw loosening at 1.5 years postoperatively. (A) No cage migration. (B) Cage migration without subsidence. (C) Cage migration with subsidence. (D) Cage retropulsion.

.04), but not for CM with or without subsidence. Therefore, placing the cage forward might be a way to prevent CR.

One strength of this study, in contrast to other studies, is our use of multivariate analysis to identify risk factors for CR and CM with or without subsidence. Cage migration was classified with respect to patients with or without subsidence, and risk factors were calculated. By discussing all of the demonstrated risk factors in detail, we hope to aid in the prevention of these complications. Moreover, we wish to stress the significance of surgical risk factors, such as single cage insertion, posterior cage position, and endplate injury, which may be preventable. We recommend the following fundamental techniques to prevent CM and CR while performing TLIF: (1) surgeons need to check for BMD and the presence of a pear-shaped disc before TLIF, (2) the cage should be inserted in the anterior location without endplate injury, (3) the use of a double cage is preferable, especially in patients who have potential risk factors, such as osteoporosis and a pear-shaped disc and when both facets are being removed.

Limitations

The primary limitation of the present study is that we did not examine whether or not cage width had an influence on CM and CR. Previous studies have reported that both cage height and width are correlated with CM [2,4,18]. However, the contact area between the cage and the endplate is more important than cage width. The contact area could not be analyzed accurately because of the irregularity of endplates and the cage's curves. If we can measure contact area in the future, more accurate research will be possible. Second, there may have been differences in surgical technique, especially endplate preparation, as four different spine surgeons performed the surgeries. Although all four surgeons were proficient in endplate preparation, we did not compare individual endplate preparation techniques. Third, the choice of cage number was not specifically guided or indicated in our study, but was based on the preference of the surgeon. Thus, it is possible that selection bias could unintentionally occur. Fourth, we performed a DEXA scan for patients over 60 years in age and for some patients under 60 years of age with certain conditions (ovariectomized patients, steroid medicated patients, etc.). Therefore, it is possible that the incidence of osteoporosis was underestimated.

Conclusions

This study analyzed patient data, radiographic findings, and surgical parameters of patients who underwent cage-instrumented TLIF at three spinal surgery centers. Our results suggest that osteoporosis is a very significant risk factor for both CM and CR. Also, a pear-shaped disc, posterior cage position, presence of endplate injury, and single cage usage were correlated with CR and CM (with

and without subsidence). When considering TLIF, the surgeon should pay close attention to these risk factors.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spinee.2018.08.007.

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