Insufficient sagittal endplate-bone graft contact is a risk factor for high-grade cage subsidence occurring after lateral lumbar interbody fusion supplemented with lateral plate: An analysis of 122 cases

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Abstract

Background

Lateral lumbar interbody fusion (LLIF) is a minimally invasive fusion technique that can be performed with lateral plate. Insufficient contact between the endplate and bone graft in the fusion segment may result in instability and subsequent cage subsidence. This study aimed to investigate the potential correlation between endplate-bone graft contact and high-grade cage subsidence (HCS) occurring after LLIF supplemented with lateral plate.

Method

Between June 2017 and February 2023, 122 patients (47 males, 75 females; mean age 62.7 years; minimum follow-up period 12 months) undergoing LLIF supplemented with lateral plate were retrospectively reviewed. The incidence of HCS was assessed, and patients were categorized into HCS group or non-HCS group based on the occurrence of HCS. Comparative analyses were performed on demographic characteristics, surgical variables, and parameters related to endplate-bone graft contact between the two groups. Multivariable logistic regression analysis was employed to identify the potential risk factors associated with HCS.

Results

The HCS group comprised 13 patients, while the non-HCS group included 109 patients. The incidence of HCS occurring after LLIF supplemented with lateral plate was 10.7%. The sagittal contact rate of endplate-bone graft (OR, 0.844; 95% CI, 0.766–0.931; $P < 0.001$) and inferior cage-endplate angle (OR, 1.869, 95% CI, 1.215–2.873, $P = 0.004$) were determined to be significantly correlated with HCS occurring after LLIF supplemented with lateral plate. Compared to non-HCS group, the patients in HCS group had a lower sagittal contact rate of endplate-bone graft and a larger inferior cage-endplate angle.

Conclusion

The incidence of HCS occurring after LLIF supplemented with lateral plate was 10.7%. HCS was significantly associated with insufficient sagittal endplate-bone graft contact. Further study aiming to optimize the sagittal endplate-cage contact in the procedure of LLIF supplemented with lateral plate are warranted to enhance clinical outcomes.

Introduction

Lumbar interbody fusion has become a standard procedure for patients with degenerative lumbar diseases when conservative treatments have proved to be ineffective. Minimally invasive lateral lumbar

interbody fusion (LLIF) circumvents the need for dissection of posterior anatomical structures, such as ligaments and paravertebral muscles, essential in posterior or transforaminal lumbar interbody fusion [1, 2]. Consequently, LLIF presents several advantages, including reduced operative time, diminished surgical trauma and blood loss, and reduced risk of direct neural injury when compared to posterior/transforaminal lumbar interbody fusion [3, 4].

Traditionally, LLIF can be performed mainly in two techniques: the “stand-alone” procedure (without supplemental fixation) and the technique supplemented with posterior pedicle screw fixation through a separate posterior approach [5, 6]. However, the stand-alone procedure is associated with insufficient immediate stability, resulting high-grade cage subsidence (HCS) and subsequent revision [7, 8]. Conversely, posterior pedicle screw fixation provides immediate biomechanical stability but requires repositioning the patient to a prone position and an additional incision, leading to extended operative time and increased surgical trauma.

Several prior studies have explored the application of lateral plate in LLIF and affirmed the biomechanical efficacy of this fixation methodology [8, 9]. The supplemental lateral plate is commonly employed to mitigate the risk of cage subsidence, pseudarthrosis, and reoperation. In a retrospective study of 52 patients with degenerative lumbar diseases, Li et al. [10] demonstrated that oblique lateral interbody fusion with supplemental lateral plate is a safe and effective surgical option, resulting in less blood loss and a shorter operation time, favorable clinical results, and a fusion rate of approximately 88% for at least 12 months follow-up.

However, two critical questions remain unanswered. Firstly, can the lateral plate effectively prevent the occurrence of HCS, which leads to nonunion and reoperation? Comprehensive investigations involving substantial sample sizes are necessitated to investigate the incidence of HCS occurring after LLIF supplemented with lateral plate. Secondly, certain factors, including demographic characteristics, surgical variables, and insufficient endplate-bone graft contact have been found to lead to cage subsidence occurring after stand-alone LLIF [11, 12]. Are these factors associated with HCS occurring after LLIF supplemented with lateral plate? The relationship between demographic characteristics, surgical variables, endplate-bone graft contact and HCS has not been addressed in the existing literature.

To address these two questions, we conducted a retrospective study on cases undergoing LLIF supplemented with lateral plate at our institution. Our objective was to determine the incidence and the potential risk factors of HCS, a rare but serious complication of LLIF. The hypothesis was that the incidence of HCS occurring after LLIF supplemented with lateral plate is within an acceptable range and HCS is associated with some of the potential risk factors.

Methods

Patients and groups

After the institutional review board's approval (R2018-119) of our hospital, a complete search of our spinal surgical database was conducted to compile a list of all patients who underwent LLIF supplemented with lateral plate between June 2017 and February 2023.

The inclusion criteria of this study were as follows: (1) patients with degenerative lumbar stenosis, spondylolisthesis (Meyerding grade I and II) and disc herniation; 2) those classified as grade B and C according to Schizas' central canal stenosis classification [13], or grade 1 and 2 according to Lee's foraminal stenosis classification [14]; 3) patients with a documented failure of to conservative treatment for more than 6 months; 4) single-level disease requiring surgical treatment; 5) availability of complete medical and radiological records; 6) a follow-up period of more than 12 months. Exclusion criteria encompassed: 1) spinal trauma, tumor, and infection; 2) osteoporosis (T score < 2.5); 3) severe lumbar spinal canal stenosis requiring direct decompression; 4) revision surgeries due to failure in indirect neurological decompression.

Finally, the study cohort included 122 patients (Fig. 1). The included patients were categorized into HCS and non-HCS groups based on the occurrence of HCS during the 12-month follow-up period.

Surgical technique

LLIF was performed at the levels of L1-L5, following the established surgical methods as we previously reported [15]. A large rectangular polyetheretherketone cage (45/50/55 mm length, 18 mm width, and 8° lordotic angle) from Shanghai Sanyou Medical Co., Ltd, China, was utilized. To avoid intraoperative bony endplate injury, expansion was proceeded until the cage mold adhered to the endplate on fluoroscopic images, with a perceptible light resistance. Intraoperative radiography facilitated the selection of an appropriate cage. Allograft demineralized bone matrix mixed with bone marrow aspirate was employed in all cage. Subsequent to the conventional LLIF procedure, a miniature lateral plate fixation system (23/25 mm length, 15.4/16 mm width) was fixed at the lateral aspect of the vertebrae using screws (4.5mm diameter, 30/35/40 length). The screws were usually inserted upward and downward along the endplate in order to spare the segmental vessels.

Follow-up method

Patients were permitted to ambulate with a lumbar belt one day after surgery, wearing it for three months postoperatively. The medical records and images of patients who underwent this surgery were analyzed. The anterior-posterior and lateral plain film were taken immediately pre-surgery, post-surgery, at 1, 6 months postoperatively and at the final follow-up. In non-HCS group, CT examination were taken before surgery, immediately after surgery and at the final follow-up. On the opposite, an extra CT examination was taken when HCS occurred.

Risk factors of HCS

The diagnosis of HCS was established when cage subsidence grading indicated more than 50% collapse of the level based on the report of Marchi et al. [16]. To investigate risk factors for the occurrence of HCS,

patients' characteristics, surgical variables, and parameters related to the endplate-bone graft contact were analyzed and compared between the patients in HCS and non-HCS group.

Demographic characteristics comprised age, gender, body mass index (BMI), bone mineral density (BMD, DXA scans performed at L1–S1, femoral necks, and total hips), diagnosis, and comorbidity.

Surgical variables included operated levels, cage height, cage length, cage position, bony endplate injury, surgery time, and blood loss. Bony endplate injury was defined as continuous interruption and displacement of the adjacent upper and lower endplate on the immediate postoperative radiographs.

Parameters associated with the endplate-bone graft contact included the endplate concavity depth, the preoperative range of motion of the surgical level, pre- and post-operative intervertebral disc height, disc height variation, cage-endplate angle, and contact rate between endplate and bone graft. Preoperatively, the endplate concavity depth was measured on the coronal computed tomography (CT) scan (Fig. 2) and was classified as fat (< 2mm), shallow (2-4mm), or deep (> 4mm) based on the report of Xie et al [17]. Range of motion of the surgical level was measured with preoperative dynamic lateral flexion-extension radiographs. The disc height was measured between the superior and inferior endplates on the sagittal plane of the CT scan. Disc height variation was obtained by subtracting preoperative disc height from the postoperative disc height. The cage-endplate angle represented the angle between the cage and endplate on the cranial and caudal sides on sagittal CT imagines. The contact rate of endplate-bone graft was measured in the cage's central sagittal and coronal planes on the postoperative CT imagines and defined as the length of contiguous bone contact divided by the twice of the cage length.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows, version 19.0 (IBM Corp., Armonk, New York, USA). The normality of data distribution was assessed using Kolmogorov-Smirnov test. Continuous variables were expressed as mean ± standard deviation or median (25th-75th percentiles). The categorical variables were measured as frequency or percentages. Student's independent t- or Mann-Whitney tests were employed, as appropriate, to compare continuous variable differences. Chi-square test was applied to examine differences among categorical variables. Variables with P values < 0.05 were included in multivariable logistic regression analysis. A P-value < 0.05 was considered statistical significance.

Results

The study cohort included 122 patients, with a mean age of 62.7 ± 8.6 years. Thirteen cases, comprising 4 men and 9 women (mean age, 66.0 ± 6.1 years) constituted the HCS group. While the remaining 109 patients, comprising 44 men and 55 women (mean age, 61.1 ± 8.7 years) were categorized into the non-HCS group (Table 1). The incidence of HCS occurring after LLIF supplemented with lateral plate was 10.7% (13/122). There was no significant difference in patients' age, gender, body mass index, smoke, duration of symptoms, diagnosis and comorbidity between the two groups. Although the T score of BMD

in HCS group (-1.7 ± 0.7) was slightly lower than that in the non-HCS group (-1.4 ± 0.4), the difference did not reach statistical significance (*P* = 0.161).

Table 1
Demographic characteristics of the included patients

Demographics	**HCS**	**non-HCS**	***P* value**
No. of patients	13	109	
Age (year)	66.0 ± 6.1	61.1 ± 8.7	0.795
Gender(M/F)	3/10	44/65	0.231
BMI (kg/m2)	25.1 ± 3.3	26.5 ± 3.4	0.503
BMD (T score)	-1.7 ± 0.7	-1.4 ± 0.4	0.161
Smoke (Y/N)	2/11	27/82	0.452
Duration of symptoms (moth)	72.0 ± 53.1	69.8 ± 32.8	0.226
Principal diagnosis (No.[%])			0.783
Lumbar spinal stenosis	5 (38.4%)	42(38.5%)	
Lumbar spondylolisthesis	7 (53.8%)	63 (57.8%)	
Recurrent disc herniation	1 (7.8%)	4 (3.7%)	
Comorbidity (No.)			0.488
Hypertension	4	27	
Lacunar Infarction	0	2	
Diabetes	2	16	
Cardiovascular Disease	2	7	
Hyperlipidemia	1	12	
Hyperuricemia	1	3	
Chronic obstructive pulmonary disease	0	4	
Gastric disease	1	6	
Kidney disease	0	5	
Osteoarthritis	1	3	
Rheumatoid arthritis	1	0	
Gastrointestinal stromal tumors	0	1	

HCS, high-grade cage subsidence; BMI, body mass index, BMD, bone mineral density; Y/N, yes/no

Table 2 illustrated that HCS occurring after LLIF supplemented with lateral plate was found at L3-4 level in 23.1% (3/13) patients and at L4-5 in 76.9% (10/13) patients. While, no significant difference was observed in the distribution of the surgical levels between the HCS and non-HCS group. The incidence of bony endplate injury was comparable between the two group, with 23.1% (3/13) in the HCS group and 13.9% (17/122) in non-HCS group. Furthermore, no significant differences were noted in other surgical variables, including cage height, cage length, cage position, surgery time, and blood loss.

Table 2
Potential surgical parameters related to HCS

	HSC (No. of level = 13)	**Non-HCS (No. of level = 109)**	***P* value**
Surgical levels			0.807
L3-4	3	22	
L4-5	10	87	
Cage height			0.703
10 mm	2	9	
12 mm	10	90	
14 mm	1	7	
Cage length			0.222
45 mm	3	11	
50 mm	9	95	
55 mm	1	3	
Position of cage			
anterior	9	69	0.674
posterior	4	40	
Bony endplate injury	3	17	0.491
Surgery time (min)	67.9 ± 8.5	57.2 ± 6.2	0.250
Blood loss (ml)	30(20, 40)*	40(20, 50)*	0.563
HCS, lateral cage migration; *: median (25th-75th percentiles)			

Regarding the parameters associated with endplate-bone graft contact (Table 3), there was a notable difference in inferior endplate concavity depth between the HCS and non-HCS groups, with more patients

exhibiting shallow and deep endplate concavity depth in the HCS group ($P = 0.024$). However, no significant difference was observed in superior endplate concavity depth. Both inferior and superior cage-endplate angle were significantly different between the two groups, with patients in the HCS group exhibiting relative larger cage-endplate angles (both $P < 0.001$) (Fig. 3 and Fig. 4). Additionally, both sagittal and coronal contact rates between endplate and bone graft in HCS group were lower than those in non-HCS group (both $P < 0.001$). Meanwhile, preoperative range of motion, pre- and post-operative disc heights, and disc variation showed no significant differences between the two groups.

Table 3
Potential radiographic parameters related to HCS

	HCS (No.=13)	Non-HCS (No.=109)	*P* value
Endplate concavity depth			
Inferior endplate			**0.024**
Fat (< 2mm)	3	49	
Shallow (2-4mm),	7	49	
Deep (> 4mm)	5	11	
Superior endplate			0.732
Fat (< 2mm)	9	84	
Shallow (2-4mm)	3	16	
Deep (> 4mm)	1	9	
Preoperative range of motion (°)	5.7 ± 2.9	6.7 ± 2.3	0.111
Disc height (mm)			
Pre-operation			
Anterior height	11.2 ± 2.5	10.3 ± 2.4	0.150
Posterior height	14.0 ± 1.6	13.0 ± 2.2	0.095
Post-operation			
Anterior height	5.8 ± 1.5	5.6 ± 1.8	0.792
Posterior height	8.9 ± 1.5	8.2 ± 1.4	0.103
Disc variation (mm)			
Anterior height	2.6 ± 1.7	2.7 ± 1.8	0.929
Posterior height	2.8 ± 1.0	2.5 ± 1.7	0.289
Cage-endplate angle (°)			
Inferior	9.1 ± 3.8	2.9 ± 1.7	**< 0.001**
Superior	7.9 ± 3.3	3.7 ± 1.8	**< 0.001**
Contact rate of bone graft (%)			
Coronal	43.6 ± 14.6	74.9 ± 10.4	**< 0.001**

HCS, high-grade cage subsidence

	HCS (No.=13)	Non-HCS (No.=109)	*P* value
Sagittal	51.1 ± 11.9	80.0 ± 9.9	**< 0.001**
HCS, high-grade cage subsidence			

Table 4
Clinical data of 13 patients with HCS

No.	Gender	Age	Diagnosis	Level of HCS	Time interval (day)	Symptoms after HCS	Treatment
1	M	71	Lumbar spondylolisthesis	L4-5	34	Intolerable back pain	PPF
2	F	69	Lumbar spondylolisthesis	L3-4	27	Intolerable back pain	PPF
3	F	56	Lumbar spondylolisthesis	L4-5	14	Intolerable back pain	PPF
4	M	69	Lumbar spinal stenosis	L4-5	19	Intolerable back pain with left leg radiation pain	PPF and laminectomy
5	M	72	Recurrent disc herniation	L4-5	14	Intolerable back pain	PPF
6	F	60	Lumbar spinal stenosis	L4-5	12	Left leg radiation pain	PPF
7	F	56	Lumbar spinal stenosis	L4-5	17	Intolerable back pain	PPF
8	F	69	Lumbar spinal stenosis	L3-4	18	Back pain, numbness of left leg and claudication	PPF and laminectomy
9	F	60	Lumbar spinal stenosis	L3-4	28	Intolerable back pain	PPF
10	F	74	Lumbar spondylolisthesis	L4-5	25	Intolerable back pain	PPF
11	F	60	Lumbar spinal stenosis	L4-5	37	Intolerable back pain	PPF
12	F	73	Lumbar spinal stenosis	L4-5	15	Back pain with intolerable right leg radiation pain	PPF
13	M	78	Lumbar spondylolisthesis	L4-5	-	Mild back pain	non-operative treatment

HCS, lateral cage migration; M, male; F, female; LSS, lumbar spinal stenosis; LS, lumbar spondylolisthesis; PPF, posterior pedicle screw fixation.

Multivariable logistic regression analysis revealed that the sagittal contact rate of endplate and bone graft (OR, 0.844; 95% CI, 0.766–0.931; $P < 0.001$) and inferior cage-endplate angle (OR, 1.869, 95% CI, 1.215–2.873, $P = 0.004$) were significantly associated with HCS occurring after LLIF supplemented with lateral plate. Compared to non-HCS group, the patients in HCS group exhibited a lower sagittal contact rate of the endplate-bone graft and a larger inferior cage-endplate angle. (Table 3). Based on these results, a insufficient sagittal endplate-bone graft contact was a risk factor for HCS occurring after LLIF supplemented with lateral plate.

During the follow-up period, HCS predominantly occurred within the first month postoperatively (Table 4). The mean time interval between the initial surgery and the occurrence of HCS was 21.7 ± 2.4 days. Of the patients with HCS, 92.3% (12/13) patients reported intolerable low back pain or radicular pain and underwent revision surgery (Fig. 3). One patients with HCS was incidentally identified through routine postoperative radiographical examination. This patient experienced mild back pain, while declined revision surgery, opted for conservative treatment, and underwent a rigorous follow-up.

Discussion

LLIF is a minimally invasive technique developed in order to circumvent the complications associated with traditional anterior or posterior approaches for lumbar interbody fusion [1, 2]. Despite the cages used in the LLIF procedure are large and generally span the apophyseal ring, the reported incidence of cage subsidence range from 7.2–42.0% [16, 18–20]. In patients with HCS, the restorative effects on disc height and indirect decompression may be compromised, often necessitating revision surgery. In order to mitigate the occurrence of cage subsidence, lateral plate fixation is employed to enhance the biomechanically stability of the interbody fusion construct [21]. However, the incidence of HCS occurring after LLIF supplemented with lateral plate and the potential risk factors have been underexplored. This study revealed that the incidence of HCS occurring after LLIF supplemented with lateral plate was 10.7%. In addition, there was a significant association between HCS and insufficient sagittal endplate-bone graft contact.

The significance of cage subsidence grade in predicting the need for revision surgery after stand-alone LLIF has been well-established. Tempel et al.[22], identified HCS as a significant predictor of revision surgery. Therefore, assessing the efficacy of lateral plate in LLIF is imperative. Laboratory experiments by Fogel et al. [21] indicated that lateral plate fixation, compared to the stand-alone technique, significantly reduced the range of motion in lateral bending and axial rotation; in addition, the range of motion of lateral plate fixation was similar to bilateral pedicle screws fixation in lateral bending. While, the incidence of HCS in patients undergoing LLIF supplemented with lateral plate is still unknown. To answer this question, we conducted this retrospective study and found the incidence of HCS of present study was 10.7% during the follow-up of at least 12 months, which was consistent with the previous study of Chen et al [8]. During more than 1 year follow-up, Xi et al. found the the incidence of HCS was 19.1% (higher than current study) in 68 patients who underwent LLIF with bilateral pedicle screw fixation [23]. Based on

these results, we inferred that the incidence of HCS occurring after LLIF supplemented with lateral plate is within an acceptable range and lateral plate is an effective supplement fixation for LLIF.

Divergent opinions exist regarding the role of lateral plate fixation in the stability of cage in the procedure of LLIF. Li et al. demonstrated that oblique lateral interbody fusion with supplemental lateral plate is safe and effective in 52 patients with degenerative lumbar diseases [10]. Meanwhile, in a retrospective comparative study of 20 patients undergoing stand-alone oblique lumbar interbody fusion and 21 patients undergoing oblique lumbar interbody fusion fixated with lateral plate, Ge et al. found that lateral plate fixation had no effect in preventing cage subsidence in oblique lumbar interbody fusion [24]. In another investigation, Tender et al. [25] considered the lateral plate fixation as a risk factor for cage subsidence and vertebral fracture. They proposed that the screws of the plate altered the support effect of subchondral trabecular, leading to cage subsidence during flexion. However, caution is warranted in interpreting these findings. Ge et al. included patients with osteoporosis, and the mean follow-up duration was only 6.3 ± 2.4 months, which potentially influence the results. In Tender et al.'s study, the authors only reported one case of LLIF supplemented with lateral plate and experienced vertebral fracture. Based on this rare case, the author speculated that lateral plate as a risk factor for cage subsidence. However, they did not provide any biomechanical or finite element evidences, which rendered their conclusion speculative.

LLIF aims to provide segmental stability by insertions of large cage, neural decompression by intervertebral height elevation, and deformity correction by intervertebral release. The manipulation of vertebral endplates and the placement of intervertebral grafts are crucial for achieving these goals. Following LLIF, compression force is applied to the endplate-graft interface to establish initial stability and promote the formation of bone bridge. Complications such as cage subsidence may arise if the endplate-graft interface fails to withstand compressive loads. Mechanically, the pressure exerted by the cage on the endplate directly depends on the surface area of contact between the endplate and bone graft. Insufficient contact of endplate-bone graft significantly diminishes the resistance to subsidence.

We then analyzed the relationship between endplate-bone graft contact and HCS occurring after LLIF supplemented with lateral plate. The multivariable logistic regression analysis revealed that the sagittal contact rate of endplate-bone graft and the inferior cage-endplate angle were significantly associated with HCS occurring after LLIF supplemented with lateral plate. Incorporating the result that patients in HCS group exhibited a lower sagittal contact rate of endplate-bone graft and a larger inferior cage-endplate angle, we concluded that insufficient sagittal endplate-bone graft contact is a risk factor for HCS occurring after LLIF supplemented with lateral plate. This finding emphasizes the importance of maximizing sagittal endplate-bone graft contact in patients undergoing LLIF supplemented with lateral plate to mitigate the risk of HCS. This observation also has the potential to contribute significant insights to the surgeries of LLIF.

While, our finding that insufficient sagittal endplate-bone graft contact is a risk factor for HCS occurring after LLIF supplemented with lateral plate diverges from the result reported by Agarwal et al., wherein they

examined the association between endplate-cage area mismatch and the grade of cage subsidence following stand-alone LLIF [12]. Agarwal et al. demonstrated that there was no discernible correlation between endplate-implant area mismatch and cage subsidence. However, it is noteworthy that Agarwal et al. characterized the three-dimensional surfaces of endplate and cage as simplistic planes, and such oversimplification and approximation might lead to the formulation of an unfavorable result.

Furthermore, our study elucidated that HCS predominantly occurring in the first month postoperatively, underscoring the need for rigorous follow-up during this critical period for patients who underwent LLIF supplemented with lateral plate. We also found that active revision surgery was required for the patients complained with intolerable low back pain or radicular pain. Comparable to stand-alone LLIF, HCS emerged as a noteworthy predictor for revision surgery.

This present study had several important limitations. Firstly, the sample size of HCS group was small because of the low incidence. Secondly, in this study, single-level LLIF was performed in the levels at L3-4 orL4-5, so we did not know the incidence of HCS in other levels and the potential risk factors. Thirdly, the follow-up period was also relatively short. However, Marchi et al. identified that progression of cage subsidence was not observed after the 6-week postoperatively [16]. So 12 months follow-up maybe adequate to include all cases of HCS. Finally, the study was conducted retrospectively and was not randomized and controlled. Future investigations, ideally through randomized controlled or multi-center studies, are warranted to comprehensively elucidate the risk factors for HCS following LLIF supplemented with lateral plate.

Conclusion

In summary, the incidence of HCS occurring after LLIF supplemented with lateral plate was 10.7%. In addition, there was a significant association between HCS and insufficient sagittal endplate-bone graft contact. This finding underscores the necessity for further investigations aimed at maximizing sagittal endplate-bone graft contact in the procedure of LLIF supplemented with lateral plate.

Abbreviations

LLIF lateral lumbar interbody fusion

HCS high-grade cage subsidence

BMI body mass index

BMD bone mineral density

CT computed tomography

Declarations

Author contributions

All authors contributed to the study conception and design. Material preparation were performed by Ruijie Chen and Hao Li, data collection and analysis were performed by Zhengkuan Xu, Oujie Lai, and Ruijie Chen. The first draft of the manuscript was written by Ruijie Chen. Hao Li and Qixin Chen critically reviewed the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analysed during the current study are not publicly available due to the sake of patient privacy but are available from the corresponding author on reasonable request.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the Second Affiliated Hospital, School of Medicine, Zhejiang University.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

Informed consent to publish the relevant data was obtained from each included patient.

Competing interests

The authors declare no competing interests.

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Figures

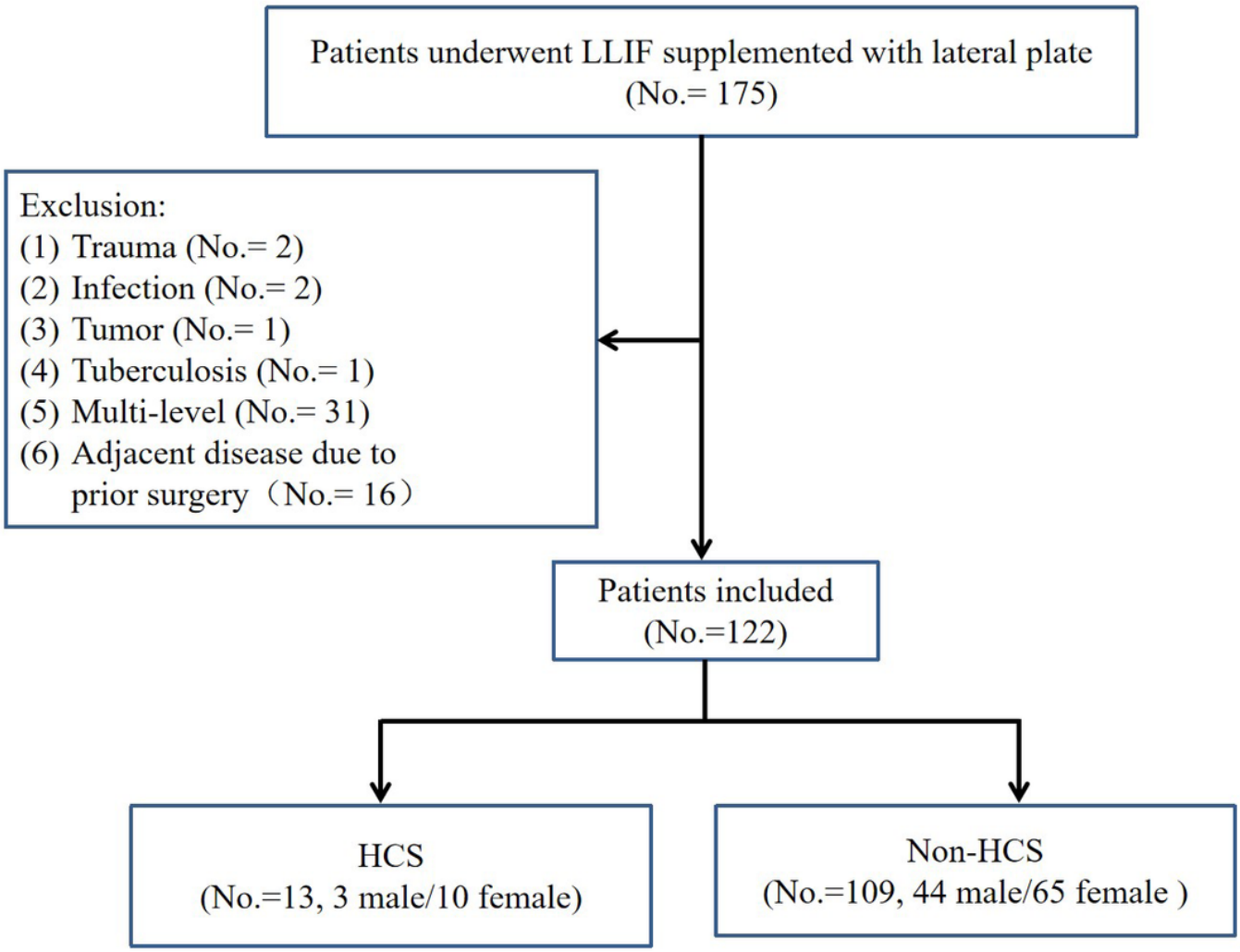

Figure 1

Flow diagram of this study. HCS, high-grade cage subsidence.

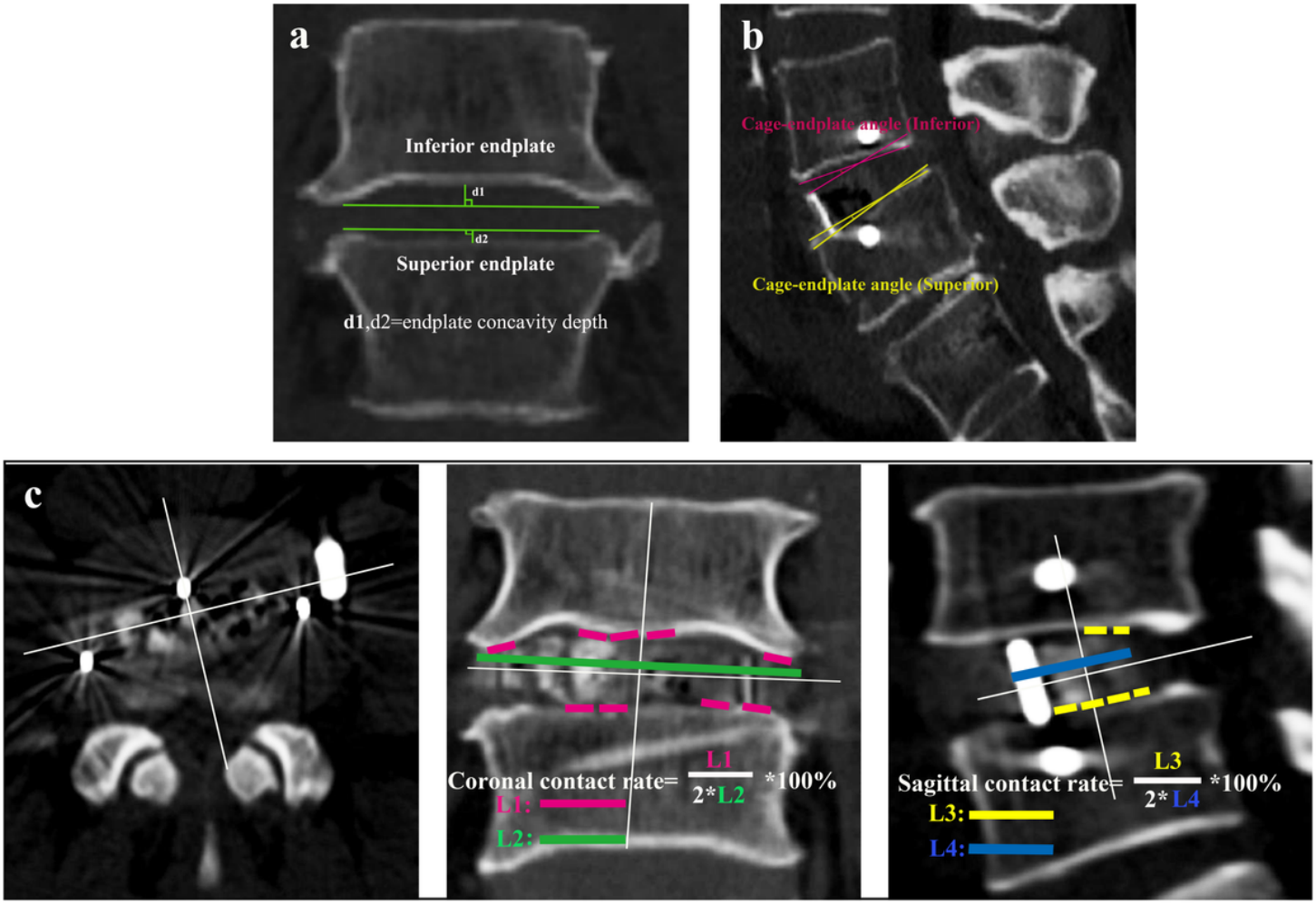

Figure 2

The measuring method of endplate concavity depth (A), cage-endplate angle (B) and contact rates (C).

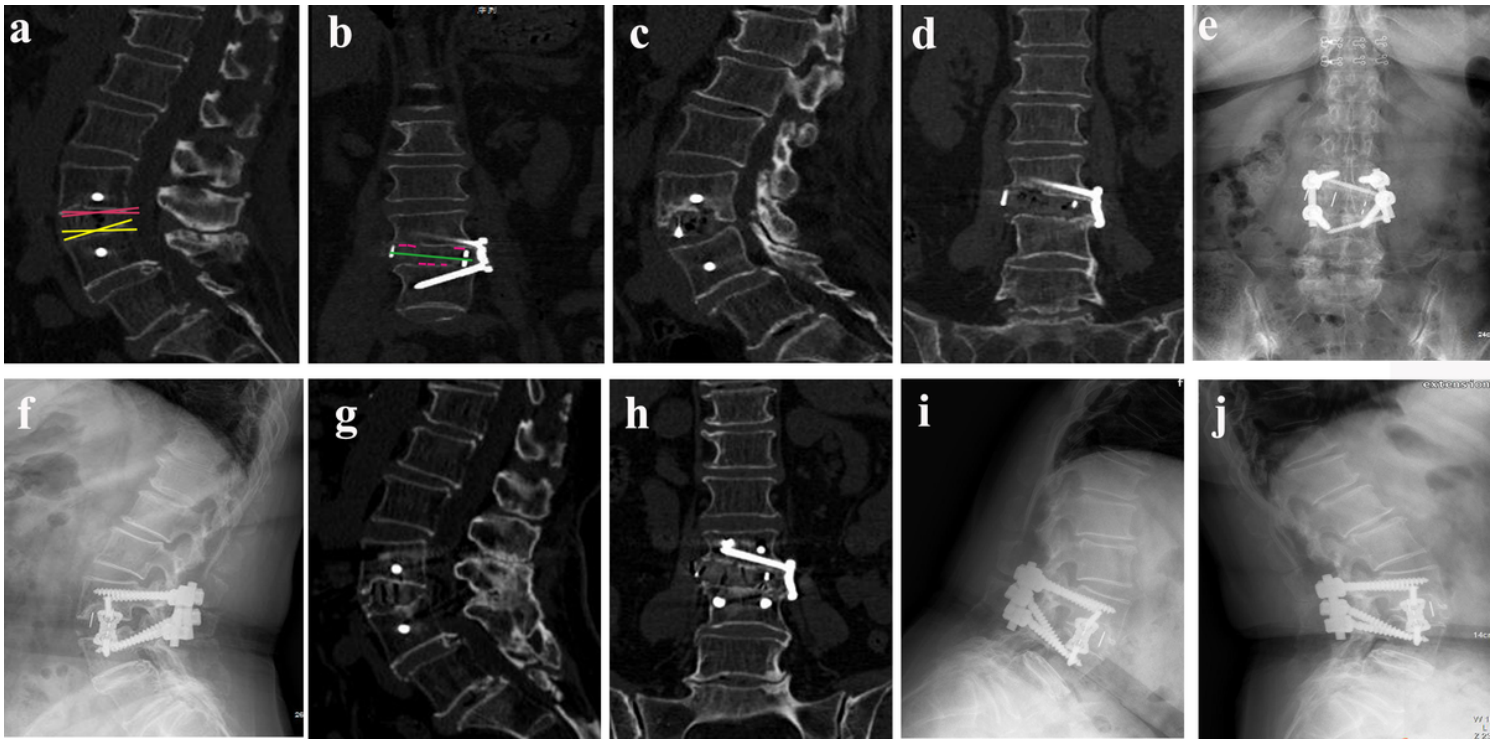

Figure 3

A typical case in the HCS group and underwent revision. (a, b) Sagittal and coronal CT scans showed LLIF performed at L3-4 with a large cage-endplate angle and a low sagittal contact rate of endplate-bone graft. (c, d) CT scan demonstrated HCS (arrow) occurred 37 days postoperatively. (e, f) X-ray showed posterior pedicle screw fixation being performed in the revision. (g, h) CT scan revealed solid fusion of L3-4 14 months after the revision. (i, j) Dynamic lateral flexion-extension radiograph confirmed the solid fusion.

LLIF, lateral lumbar interbody fusion; HCS, high-grade cage subsidence; CT, computed tomography.

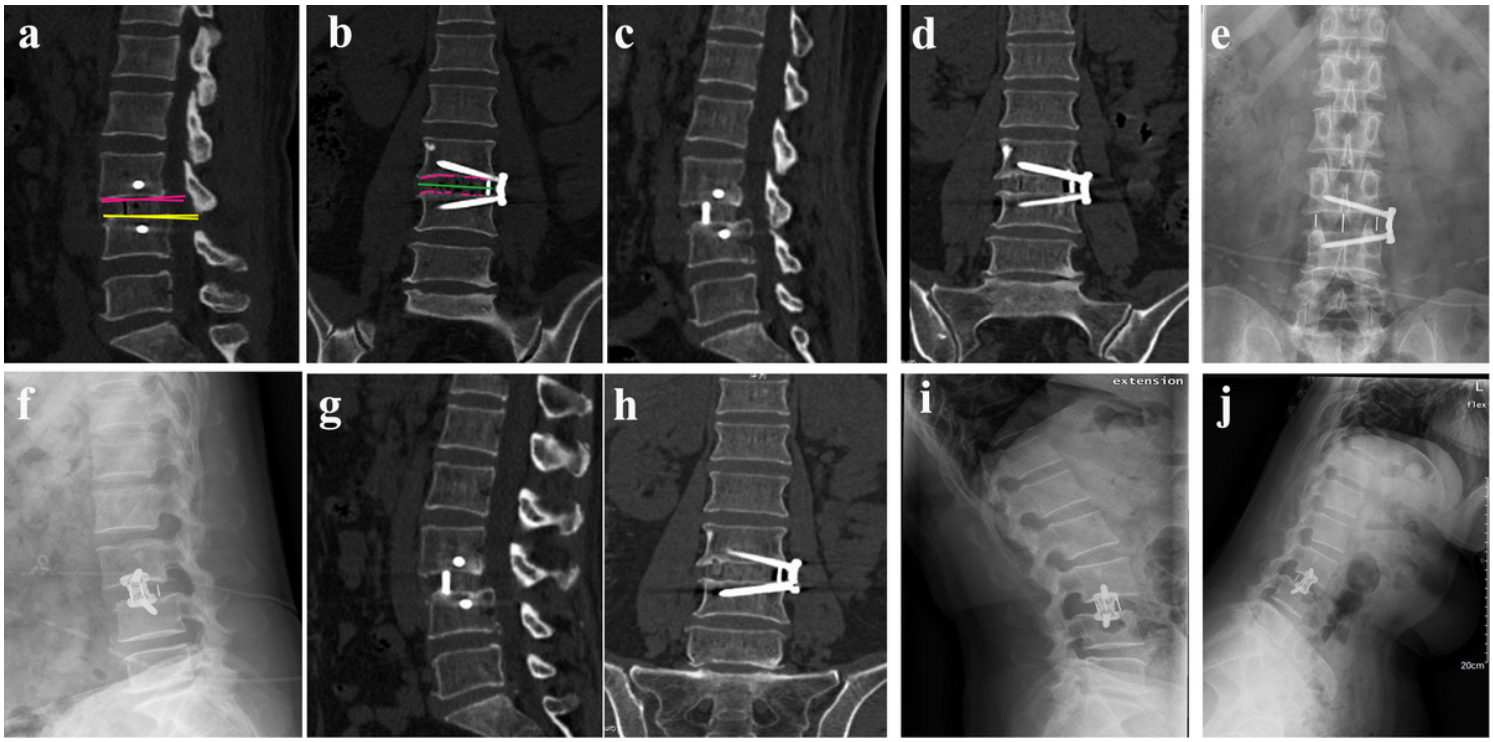

Figure 4

A typical case in the non-HCS group. (a, b) Sagittal and coronal scans showed LLIF performed at L3-4 with small cage-endplate angle and a high sagittal contact rate of endplate-bone graft. (c, d) CT scan demonstrated the normal height of the intervertebral disc without cage subsidence half year postoperatively. (e,f) X-ray showed normal position of cage and the lateral plate. (g, h) CT scan revealed solid fusion of L3-4 12 months postoperatively. (i, j) Dynamic lateral flexion-extension radiograph confirmed the solid fusion.

LLIF, lateral lumbar interbody fusion; CT, computed tomography.