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Morphological analysis of interbody fusion following posterior lumbar interbody fusion with cages using computed tomography

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Abstract

Posterior lumbar interbody fusion (PLIF) using cages in conjunction with pedicle screw fixation is considered the gold standard for surgical treatment of degenerative lumbar spine disorders due to its biomechanical stability and high fusion rate. However, research regarding patterns of fusion in the interbody space during the early postoperative period is lacking.

Sixty consecutive patients were recruited from May 2013 to June 2015. All patients underwent PLIF using 2 titanium cages filled with local bone chips from decompressed lamina and facet bone in conjunction with pedicle screw fixation. Computed tomography scans were obtained 3 to 6 months following surgery in order to evaluate the partial fusion state. Computed tomography (CT) classification of fusion morphology was divided into 8 groups and then into compartments according to fusion space, and the rate of fusion for each was calculated. Further follow-up was conducted to confirm fusion state and assess outcomes.

The most frequent pattern of interbody fusion was bilateral intra-cage fusion with unilateral lateral bridging of extra-cage areas (N = 36, 43.4%); the least frequent was interspace bridging of the 2 cages alone (N = 0, 0%). The fusion rate for the intra-cage area (Compartment 1) reached 100%. However, the fusion in the lateral space outside of cages (Compartment 2) was not satisfactory, though reasonable (72.3%). All patients were confirmed as achieving adequate fusion at the final follow-up, with improved clinical outcomes.

Widening of the contact area between the vertebral body and cages is recommended to promote increased interbody fusion during the early postoperative period.

Abbreviations: BMI = body mass index, CT = computed tomography, ODI = Oswestry Disability Index, PLIF = posterior lumbar interbody fusion, VAS = Visual Analogue Scale.

Keywords: classification, computed tomography, fusion status, lumbar spine, posterior lumbar interbody fusion

1. Introduction

Of the diverse techniques utilized in performing lumbar fusion, posterior lumbar interbody fusion (PLIF) in conjunction with pedicle screw fixation has been reported to be near biomechanically ideal, with high rates of successful fusion in patients with degenerative lumbar diseases.[1,2] In spite of successful fusion rates, however, this technique may also be associated with unfavorable outcomes such as pseudoarthrosis, posterior migration of the cage, and instrumentation failure after surgery.[3–5]

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Qualitative analysis has been performed using various methods and modalities to assess fusion status during postoperative periods.[6–8] Among them, modern computed tomography (CT) imaging, including fine-cut axial and multiplanar reconstruction views, appears to be the most effective noninvasive method of determining fusion status following lumbar fusion surgery, as CT imaging can detect pseudoarthrosis in some patients in whom fusion appeared to be successful based on standard radiographic criteria.[9–11] Moreover, research has also revealed CT to be useful for the assessment of fusion in the presence of spinal instrumentation.[6,7,12] Furthermore, radiologic follow-up with CT seems to be more critical and informative during the early postoperative period due to the increased potential for surgery-related active bone resorption. CT imaging may also detect even relatively subtle signs of adverse dynamic changes such as spacer subsidence, loss of correction, spacer dislodgment, and loosening of instrumentation. In such cases, early identification of these changes may allow for correction using more conservative methods such as prolonged bracing or restriction of activity. However, some studies have reported that evaluating fusion status in the early stages of post spinal surgery recovery (~6 months postoperation) did not lead to significantly different final outcomes.[8]

Thus, in the present study, we performed early postoperative CT imaging of patients who had undergone single- or two-level lumbar fusion surgery (i.e., PLIF with pedicle screw fixation) in order to evaluate the status of fusion and determine whether additional bracing would be required. We further classified the various fusion patterns observed on these early postoperative scans according to their morphological characteristics, with

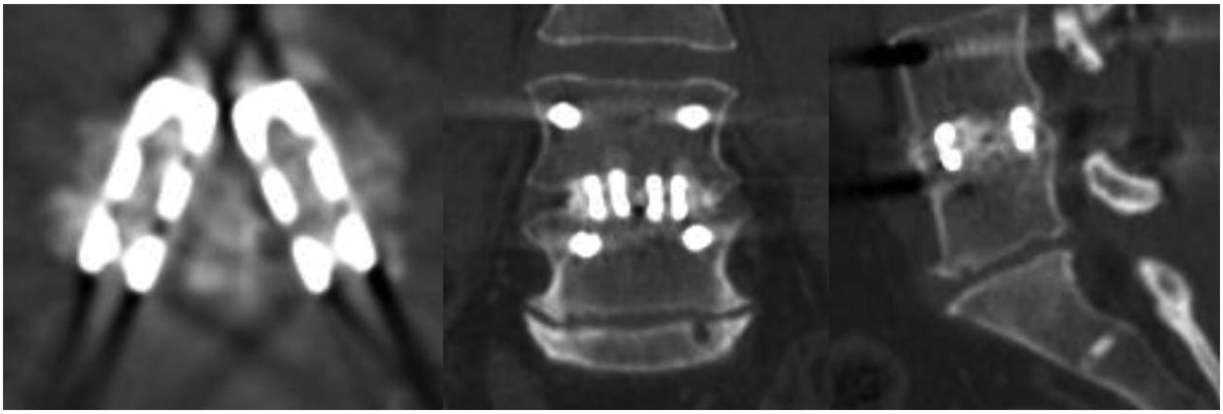

Figure 1. Three-dimensional CT scans (with axial, coronal, and sagittal reconstruction) were obtained in this study (1 mm slice thickness). CT=computed tomography.

emphasis on identifying surgical implications. The purposes of the present study are to propose a descriptive method for classifying the status of lumbar interbody fusion using CT findings and discuss surgical recommendations for achieving more complete fusion.

2. Materials and methods

Between May 2013 and June 2015, a total of 60 consecutive patients (83 spinal levels in total) who had undergone either single- or two-level lumbar interbody fusion surgery were prospectively selected for early CT follow-up in the present study. This study has been reviewed and approved by the Asan Medical Center Institutional Review Board (Approval Number 2016–0860). Patient diagnoses included lumbar spinal stenosis, degenerative lumbar spondylolisthesis, and isthmic lumbar spondylolisthesis. All patients had no history of lumbar surgery and had undergone a consistent method of surgery that involved decompression and PLIF with 2 titanium cages (NEO IC Square cage, U&I Corp, Uijeongbu, Korea) filled with excised lamina and facet joint bone (i.e., local bone), in conjunction with pedicle screw fixation (without additional posterolateral fusion), performed by a single senior neurosurgeon. Three-dimensional CT scans were then carried out 12 to 24 weeks postoperatively (Fig. 1). Patients with pregnancy, malignancy, and medical comorbidity (e.g., age over 80), severe pulmonary/liver/renal disease, and infection were excluded. The baseline characteristics of patients are presented in Table 1.

The early postoperative CT scans (12–24 weeks after surgery) were used to determine whether the patient would be required to continue wearing a brace. CT scans were usually obtained 3 months following single-level fusion surgery and 4 months following two-level fusion surgery. Patients were allowed to discontinue use of the brace only after some partial fusion had been confirmed using CT imaging. If the fusion status was deemed insufficient, patients were instructed to continue wearing the brace for 1 month. The brace was then removed following confirmation that no translation had occurred at the index level using dynamic lumbar radiographs. At the 1-year postoperative follow-up, flexion and extension lateral lumbar radiographs were obtained in order to confirm complete fusion and assess any instances of instrument failure, cage migration, or adverse changes. The clinical outcomes were assessed by comparing pre- and postoperative Visual Analogue Scale (VAS) and Oswestry Disability Index (ODI) scores and analyzing the correlation of these scores with the radiologic results.

2.1. Surgical techniques

Total laminectomy was performed for decompression, and the bilateral medial facets (the inferior articular processes in the cephalad vertebrae) were totally removed. The superior articular process was partially excised in the caudal vertebra to allow space for cage insertion. Harvested local bone was prepared by removing cartilage and fibrous soft tissue from the excised bone, which was then morselized. Prior to cage insertion, morselized local bone chips were inserted into the anterior and lateral

Table 1

Patient demographic characteristics.

Characteristic	Patient data (60 patients with 83 levels)
Age,* y	65.0±10.0 (27–78)
Sex (M:F)	30:30
BMI,* kg/m^2	25.0±3.48 (18.0–35.6)
Mean follow up using CT,* wk	16.1±3.75 (12–24)
Clinical follow up,* mo	15.6±4.32 (12–29)
Bone density* (T-score)†	−0.5±1.7 (−3.5 to 1.5)
Comorbidities	
Diabetes	10 (16.7%)
Smoker	19 (31.7%)
Primary diagnosis	
Spondylolisthesis	24
Stenosis	36
Levels per operation	
1 level	37
2 levels	23
Levels treated (N=83)	
L2–3	3 (3.6%)
L3–4	22 (26.5%)
L4–5	50 (60.3%)
L5–S1	8 (9.6%)
Cage size (N=83)	
12 mm	48
10 mm	24
8 mm	11

BMI=body mass index, CT=computed tomography.

* Values shown are mean±SD.

† Forty-seven of the patients underwent bone mineral density scanning.

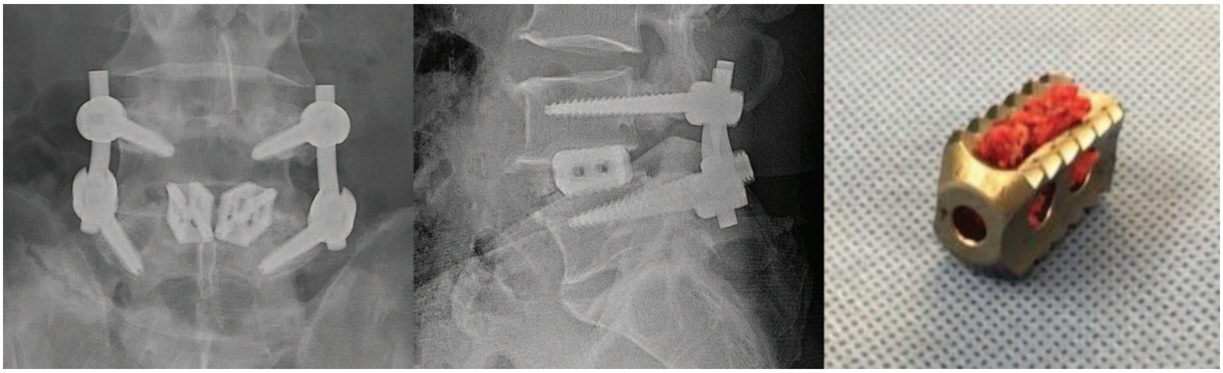

Figure 2. Plain lumbar radiograph following posterior lumbar interbody fusion using 2 metallic cages with pedicle screw fixation. The photograph shows the cage utilized in the present study, which is packed with morselized local bone chips.

portions of the interbody space and subsequently packed into 2 titanium cages, which were inserted bilaterally into the interbody space with distraction using pedicle screws (Fig. 2).

Additional local bone chips were inserted laterally outside the cages in the interbody space, following which the posterior ends of the cages were rotated laterally to close the lateral interbody space and avoid retropulsion of the laterally-placed bone chips (Fig. 3). In order to preserve the integrity of the paraspinal muscles, we refrained from extensive muscle exposure, which has been associated with failed back surgery syndrome (FBSS).[13] Therefore, the fused area was limited to the interbody space.

2.2. CT evaluation and classifications

CT images (SOMATOM Definition AS+, Siemens, Munich, Germany) were obtained using three-dimensional reconstruction (with 1 mm thin-sliced axial, sagittal, and coronal views) of scans performed during the early postoperative period (mean: 16.1 ± 3.75 weeks, range, 12–24 weeks), and the interbody fusion status was classified according to morphological CT findings into 8 types (Fig. 4, Table 2). In each reconstructed coronal and sagittal view, we verified the presence of trabecular bridging and continuity of bony structures in the intra-cage or extra-cage space. In the present study, we defined bone fusion as bony continuity without radiographic evidence of a cleft between the upper and lower vertebral bodies in each reconstructed CT view. Fusion types were classified according to areas fused relative to the cage on CT coronal and sagittal views. All CT images were evaluated by 3 independent neurosurgeons for morphologic classification of fusion types. Interobserver reliability was calculated using the Fleiss Kappa statistic, and the final classification of each case was confirmed by the agreement 2 of the 3 raters. Moreover, the frequency of each type was assessed using Pearson's chi-square test. Statistical analyses were performed using R 3.3.0 (R Foundation for Statistical Computing, Vienna, Austria) and SPSS 21.0.0 (SPSS Inc., Chicago, IL) for Windows. The level of statistical significance was set at $P < .05$.

Additionally, CT classifications were further divided into 4 levels in order to investigate the rates of bone fusion according to location within the interbody space (Fig. 5). Each compartment

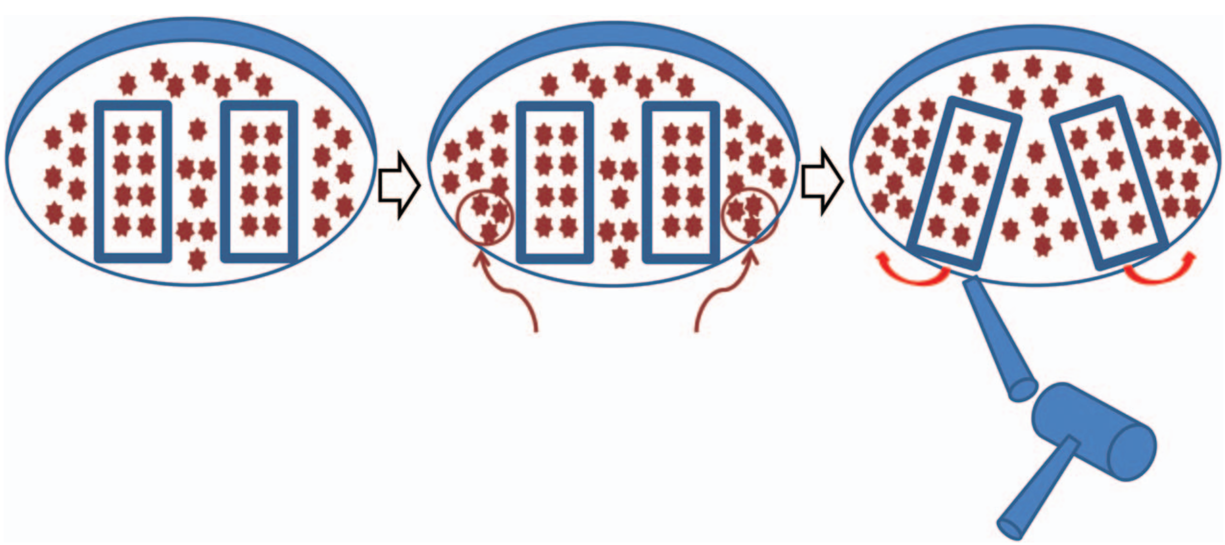

Figure 3. Schematic images illustrate the surgical method for interbody fusion. Two titanium cages packed with morselized local bone chips were inserted bilaterally into the anterior and lateral portions of the interbody space. Additional local bone chips were inserted in the lateral spaces outside the cages in the interbody space following cage insertion, and the posterior ends of the cages were then rotated laterally to close the lateral interbody space and avoid retropulsion of the lateral bone chips.

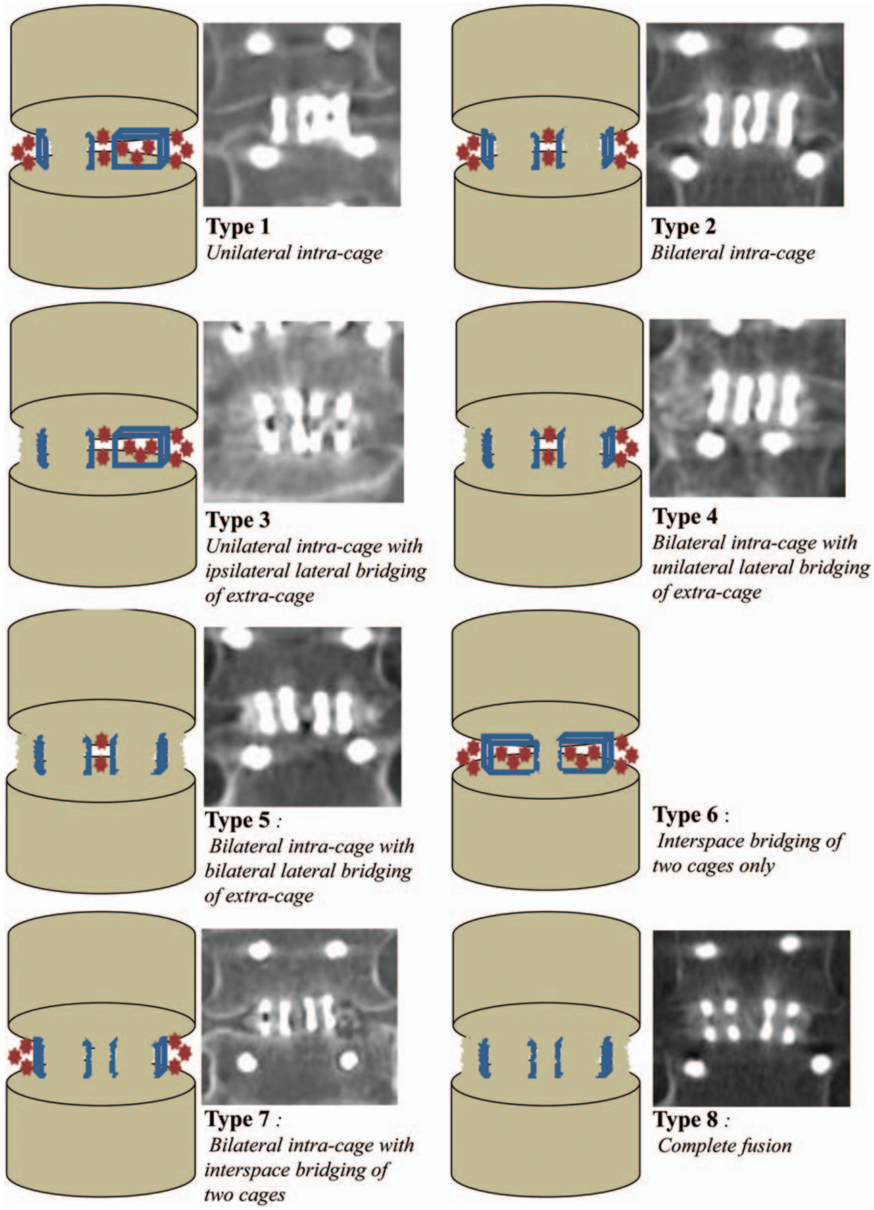

Figure 4. The 8 types of posterior lumbar interbody fusion according to morphological CT characteristics. Type 1: Unilateral intra-cage; trabecular bone bridging between 2 adjacent vertebral bodies is observed inside the unilateral cage on CT coronal view. Type 2: Bilateral intra-cage; bone bridging is observed inside both cages. Type 3: Unilateral intra-cage with ipsilateral lateral bridging of extra-cage; bone bridging is observed between the area inside the unilateral cage and the lateral space outside the cage. Type 4: Bilateral intra-cage with unilateral lateral bridging of extra-cage; bone bridging is observed between the bilateral areas inside the both cages and the lateral space outside the unilateral cage. Type 5: Bilateral intra-cage with bilateral lateral bridging of extra-cage; bone bridging is observed between the inside of both cages and each lateral space outside the cages. Type 6: interspace bridging of 2 cages only; bone bridging is observed only in the space between the 2 cages. Type 7: bilateral intra-cage with interspace bridging of 2 cages; bone bridging is observed between the areas inside both cages and the space between the 2 cages. Type 8: Complete fusion; bone bridging is observed in all spaces inside and outside of the 2 cages. CT=computed tomography.

achieving radiographic bridging at the individual level on CT images considered to have achieved fusion. The percentage of fusion for each compartment per total level was then calculated (Table 3).

3. Results

Morphological types of lumbar interbody fusion during the early postoperative period were divided into 8 groups. The interobserver reliability was calculated by determining Fleiss' kappa (0.8019, 95% CI: 0.7430–0.8608) for the 3 raters. The most frequent pattern observed was that of Type 4, classified as bilateral intra-cage fusion with unilateral lateral bridging of extra-cage areas (N=36, 43.4%), whole the least observed pattern was that of Type 6, classified as interspace bridging of the 2 cages only (N=0, 0%). The number and percentage of cases classified according to the remaining types are as follows: Type 1: 7 (8.4%); Type 2: 11 (13.3%); Type 3: 8 (9.6%); Type 5: 9 (10.9%); Type 7: 5 (6.0%); and Type 8: 7 (8.4%) (Table 2). The level of statistical significance was reached for Types 4 and 6 ($P<.05$) with regard to observed frequencies.

The CT classification was rearranged according to compartments that were then divided into 4 spaces in order to investigate the rates of bone fusion according to location within the

Table 2

CT classification and rates of lumbar interbody fusion.

Classification (type)	Visible trabecular bridging pattern on CT reconstruction	Frequency (N=83) (%)	*P*
1	Unilateral intra-cage	7 (8.4%)	.2629
2	Bilateral intra-cages	11 (13.3%)	.8357
3	Unilateral intra-cage with ipsilateral lateral bridging of extra-cage	8 (9.6%)	.4305
4	Bilateral intra-cage with unilateral lateral bridging of extra-cage	36 (43.4%)	<.001*
5	Bilateral intra-cage with bilateral lateral bridging of extra-cage	9 (10.9%)	.6481
6	Interspace bridging of 2 cages only	0 (0%)	.0005*
7	Bilateral intra-cage with interspace bridging of 2 cages	5 (6.0%)	.0744
8	Complete fusion	7 (8.4%)	.2627

CT = computed tomography.
* The statistical significance was set at $P<.05$.

interbody space (Fig. 5), the results of which are indicated in Table 3. Our analysis revealed that local bone areas located inside cages (i.e., intra-cage portion, Compartment 1) were always fused at adjacent endplates (100%), but that extra-cage local bone areas (Compartment 2, 3, 4), were less fused than those within cages. Among these extra-cage areas, the posterocentral portion (Compartment 4) exhibited the lowest rates of fusion (4.8%). These results indicate that each compartment is associated with different patterns of fusion in the interbody space.

Subsidence of cages was observed in 9 patients on early postoperative CT images, all of whom had achieved complete fusion and tolerable clinical outcomes at the final follow-up, as observed on lumbar radiographs with flexion/extension views as well as additional CT scans. Eventually, no cases exhibited signs of instrumentation failure or dynamic instability on final flexion/extension lumbar radiographs at final follow up.

Clinical outcomes such as postoperative VAS (back, leg) and ODI scores significantly improved compared with those obtained prior to spinal surgery. Preoperative VAS scores for back and leg pain were 4.3 ± 2.14 and 5.1 ± 1.28, which decreased to 1.8 ± 1.57 and 1.9 ± 1.65 by the final postoperative follow-up, respectively. Similarly, ODI scores had decreased from 25.5 ± 5.77 to 12.2 ± 7.28 by the 1-year postoperative follow-up (Table 4).

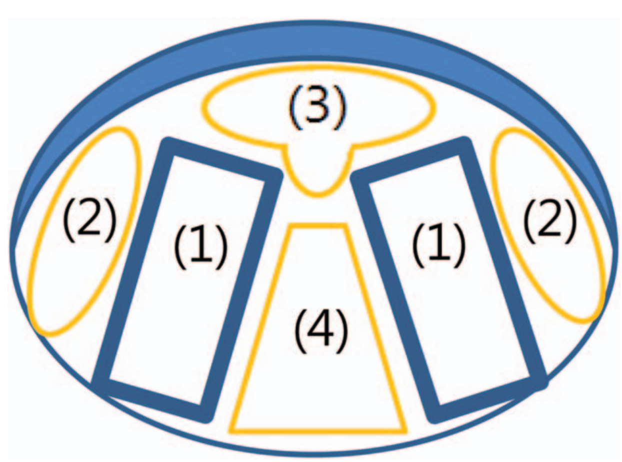

Figure 5. A schematic image illustrates compartments of the interbody space relative to the cages. Compartment 1 is defined as the space inside cages. Compartment 2 is defined as each lateral space outside the cages in the interbody space. Compartment 3 is defined as the anterior portion of the space between 2 cages, while Compartment 4 is defined as the posterocentral portion.

4. Discussion and conclusions

Lateral lumbar radiographs utilizing dynamic fusion criteria (i.e., flexion and extension) have been useful for evaluating fusion status and assessing potential instability after operation.[6,9–11] However, as these scans may lead to false positive results associated with pseudoarthrosis, we investigated fusion status using CT imaging during the early postoperative period. Some research has indicated that CT imaging may possess further advantages for early postoperative assessment.[8] Indeed, CT images may allow for the detection of perihardware radiolucencies, which suggest a loss of fixation and subsidence of the implant, which has a direct impact on ligamentotaxis and therefore reflects a partial loss of structural stability during the early postoperative period. Accordingly, CT scans obtained at this stage provide important information regarding the progression of patient activity levels, particularly regarding the decision to return to work or maintain restriction of activity and bracing. Furthermore, CT scans obtained 6 months postoperatively often indicate that bony arthrodesis may be nearing completion, with evidence of trabecular bridging, similar to findings obtained 12 months postoperatively, though the latter is associated with more mature levels of trabecularization characterized by obvious bridging between the vertebral bodies.[8,14] As previously described, many authors have evaluated the rate of lumbar interbody fusion using dynamic x-ray assessment, while some others have utilized quantitative CT analysis.[15,16] However, no report has detailed a method for categorizing the various morphological patterns of fusion according to CT features in patients who have undergone lumbar interbody fusion. In the present study, we conducted CT evaluation 3 to 6 months postoperatively, revealing the distinct advantages of this method with regard to clinical decision-making and morphological observation of fusion.

Interestingly, bony material in the intra-cage areas exhibited strong propensity for fusion (100%) in the present study, while that in extra-cage areas did not. This tendency may be explained in light of evidence regarding the biomechanical properties of bone fusion. Wolf law states that a bone remodels in response to the stresses and forces applied in order to become stronger in resisting that sort of loading.[17] Moreover, such a result may be explainable by the characteristics of the cage itself. Morselized local bone materials are compactly inserted into the cage, which provides a rigid barrier for preventing the effluence of bone materials. Therefore, the high density of bone materials in such a locally restricted area (i.e., cage) may have enhanced fusion in the intra-cage areas compared with the extra-cage areas. Meanwhile, among the extra-cage compartments in the interbody space, the

Table 3

Reclassification of compartments in the interbody space.

Compartment	Fusion achievement according to CT classification (type)	Number of each compartment (N=83, overlapped count)		Fusion rates
1 (intra-cage)	Unilateral—1, 3	7+8=15	83	100%
	Bilateral—2, 4, 5, 7, 8	11+36+9+5+7=68		
2 (extra-cage-lateral portion)	Unilateral—3, 4	8+36=44	60	72.3%
	Bilateral—5, 8	9+7=16		
3* (extra-cage-anterior portion of inter-cage space)	6, 7, 8		8	9.6%
4* (extra-cage-posterocentral portion of inter-cage space)	6, 7, 8		4	4.8%

CT=computed tomography.
*The compartments were sub-classified from type 6, 7, and 8 according to sagittal CT images.

lateral compartments (Compartment 2 in Fig. 5) were more likely to exhibit trabecular bone bridging than other compartments (3 or 4). The lowest fusion rates were observed in the extra-cage areas of the posterocentral compartment (Compartment 4). Both lateral spaces of each cage in the interbody space were compactly filled with local bone, and the subsequent lateral rotation of the cages may have provided a closed space in migration of bone chips could be avoided, potentially explaining the relatively high fusion rates.

Biomechanically speaking, bone density in the peripheral regions (either anterior or lateral) is higher than that in the central or posterior regions.[18–20] Therefore, some authors have suggested that cages should be designed such that they offer a larger graft volume and rely on the strong peripheral portion of endplates for support.[21] Similarly, our surgical technique of including additional bone chips as well as lateral rotation of the cages may be desirable when relying on the lateral spaces. The inserted bone chips may exert an osteoinductive effect, even though they did not result in bone fusion in the present study.

Furthermore, we refrained from performing any additional posterolateral fusion in order to prevent FBSS, which often occurs following extensive muscle dissection associated with exposure of the fusion bed and decortication of transverse processes and lateral surfaces of facets.[13,22,23] Avoiding posterolateral fusion in the present study was associated with reduced intraoperative bleeding, shorter operation times, and successful fusion rates without pseudoarthrosis or obvious instrumentation failure. Moreover, the clinical outcomes (VAS score for back pain) were reasonable, indicating that posterolateral fusion is not necessary for satisfactory fusion.

The present study possesses some limitations. As we obtained CT images during the early postoperative period, the status of fusion may not have been representative of the final fusion state. However, this early analysis is useful in revealing the tendency and extent of fusion as well as morphological characteristics associated with specific patterns of interbody fusion, which may aid in assessing which patients require further postoperative recovery time. Further studies are required in order to determine the value of CT analysis of long-term fusion progression in this patient population.

We classified patterns of lumbar interbody fusion according to morphological characteristics observed via CT analysis, revealing that local bone chips placed inside the cages during PLIF with pedicle screw fixation were more likely to achieve successful fusion at very high rates (100%). Therefore, widening of the contact area between the vertebral body and cages is recommended in order to maximize the interbody fusion rate during the early postoperative period. Based upon our date, techniques such as additional packing of bone chips after cage insertion and lateral rotation of cages may aid in the progression of lateral extra-cage fusion. Moreover, posterolateral fusion is not necessarily required for satisfactory fusion outcomes if interbody fusion and screw fixation are meticulously performed.

Table 4

Clinical outcomes of all patients (N=60).

	Preoperative	Last follow-up	P^*
VAS score (back)	4.3±2.14	1.8±1.57	<.001
VAS score (leg)	5.1±1.28	1.9±1.65	<.001
ODI score	25.5±5.77	12.2±7.28	<.001

Values are presented as the mean±SD.
ODI=Oswestry Disability Index, VAS=Visual Analogue Scale.
*The statistical significance was set at $P<.05$.

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