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ORIGINAL ARTICLE

Instrumented Posterior Lumbar Interbody Fusion in Adult Spondylolisthesis

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Abstract It is unclear whether using artificial cages increases fusion rates compared with use of bone chips alone in posterior lumbar interbody fusion for patients with lumbar spondylolisthesis. We hypothesized artificial cages for posterior lumbar interbody fusion would provide better clinical and radiographic outcomes than bone chips alone. We assumed solid fusion would provide good clinical outcomes. We clinically and radiographically followed 34 patients with spondylolisthesis having posterior lumbar interbody fusion with mixed autogenous and allogeneic bone chips alone and 42 patients having posterior lumbar interbody fusion with implantation of artificial cages packed with morselized bone graft. Patients with the artificial cage had better functional improvement in the Oswestry disability index than those with bone chips alone, whereas pain score, patient satisfaction, and fusion rate were similar in the two groups. Postoperative disc height ratio, slip ratio, and segmental lordosis all decreased at final followup in the patients with bone chips alone but remained unchanged in the artificial cage group. The functional outcome correlated with radiographic fusion status. We conclude artificial cages provide better functional outcomes and radiographic improvement than bone chips alone in posterior lumbar interbody fusion for lumbar spondylolisthesis, although both techniques achieved comparable fusion rates.
Level of Evidence: Level III, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

During the last decade, posterior lumbar interbody fusion (PLIF) has been widely used in arthrodesis for segmental instability of the lumbar spine [9, 14, 30]. With additional instrumentation and posterolateral fusion, the overall fusion rate has been high, ranging from 96% to 100%, and the clinical success has been satisfactory as reported in the literature [1, 14, 44, 45].

In practice, several kinds of bone grafts have been used for interbody fusion. Autologous iliac bone graft is a suitable choice with good biological healing ability but may cause considerable donor-site morbidity, such as local pain, increased operation time and blood loss, and infection [16, 24]. Local lamina bone and facet joint autograft obtained from the decompression procedure are also good sources of bone grafts in PLIF and have the advantage of not increasing morbidity [21, 33]. Allografts alone may have less potential for bony union and carry a higher risk of disease transmission if not properly screened [38, 47]. The literature supports use of local autograft from the posterior elements in PLIF, with a 90% fusion rate [10] and 79%

good results [42]. Accordingly, we have performed PLIF with mixed bone chips from allograft and local host bone since 1998.

To minimize the complications from graft harvesting and provide better mechanical strength, interbody cages were developed [35]. In 2003, we began to use interbody cages in PLIF, presuming they would provide better biomechanical advantages, including restoration of disc space height, better sagittal alignment, and good initial anterior column weightbearing [6, 36]. However, whether interbody cages provide better functional outcomes than bone chips alone in PLIF and whether functional outcomes relate to fusion status remain unclear.

We asked if using interbody cages could provide better clinical outcome scores and better radiographic outcomes at followup (fusion status, disc height ratio, slip ratio, and segmental lordosis) than bone chips alone in PLIF for patients with lumbar spondylolisthesis with unstable segments. We also questioned if solid fusion could correlate with better clinical scores.

Materials and Methods

We retrospectively reviewed 116 selected patients operated on for adult lumbar spondylolisthesis (including isthmic and degenerative types) from January 2000 to February 2006. The operative indications included persistent incapacitating claudication, radicular pain, or mechanical back pain related to posture and activities of daily life with functional compromise for degenerative spondylolisthesis, persistence of back pain and progression of slip for isthmic spondylolisthesis, and failed nonoperative treatment for more than 3 months. The indications for PLIF were gross instability defined radiographically by the criteria of Posner et al. [34] (comparing affected motion of discs before surgery or after bilateral wide bony decompression of the stenotic canal with that of the adjacent nondegenerated disc). We excluded 35 patients with Grade 3 or 4 slippage (Meyerding classification) [32] and revision spine surgery at the same level. We also excluded five of the remaining 81 patients because of incomplete medical data. Thus, 76 of the 116 patients (66%) (29 men, 47 women) were enrolled for data analysis. Patients were divided in two groups, depending on the surgeon's choice of bone graft: the bone chip (BC) group (n = 34; 19 men, 15 women) and the artificial cage (AC) group (n = 42; 10 men, 32 women). For patients in the BC group, we used mixed allograft and local host bone chips only for PLIF. For patients in the AC group, we used interbody cages packed with morselized autograft bone chips for PLIF. For further analysis, the AC group was divided in two groups, according to the material of the cages: the titanium cage (TC) group (31 patients) and the polyetheretherketone (PEEK) cage (PC) group (11 patients). In sample size power analysis, given a common within-group standard deviation of 15 (in the Oswestry disability index [ODI]), the total sample of 76 patients achieves 82% power to detect differences among the means versus the alternative of equal means using an F test with a 0.05 significance level [18].

Table 1. Patient demographics

Data	Bone chips	Artificial cages
Patient numbers	34	42
Male:female	19:15	10:32
Age (years)*	58.7 (23–79)	59.4 (23–80)
Classification (degenerative:isthmic)	18:16	29:13
Slip level (L3/L4:L4/L5:L5/S1)	2:20:11	7:32:3
Slip grade (1:2)	19:15	32:10
Followup (months)*	58.7 (22–80)	28.6 (18–42)
Cage type (titanium:polyetheretherketone)		31:11

* Data are expressed as mean, with range in parentheses; there were no significant differences between the two groups except in mean followup.

The patient demographics in the BC and AC groups were similar (Table 1). Their mean age was 59 years (range, 23–80 years). The spinal conditions included degenerative spondylolisthesis with spinal stenosis in 47 patients (62%) and isthmic spondylolisthesis in 29 patients (38%). Of the 34 patients in the BC group, 18 had degenerative spondylolisthesis and 16 had isthmic spondylolisthesis, and of the 42 patients in the AC group, 29 had degenerative spondylolisthesis and 13 had isthmic spondylolisthesis (Table 1). The disease distribution between the BC and AC groups was similar ($p = 0.151$, chi square test). The minimum followup was 18 months (mean, 42 months; range, 18–80 months). No patients were lost to followup. Patient data were obtained from the medical records. We (CHY, PQC) determined grade of slip (Meyerding classification) [32] from preoperative radiographs.

Two surgeons (CHY, PQC) performed the PLIF. Through a midline posterior approach, the patients underwent wide decompression with removal of the posterior elements, including the spinous process, interspinous ligament, lamina, hypertrophic ligamentum flavum, and medial facet joints. We routinely checked the tension of bilateral nerve roots and performed foraminal decompression if there was tightness of the roots. After insertion of pedicle screws, the disc space was gently distracted between the adjacent pedicle screws by a lamina spreader. The disc space was entered through a posterolateral

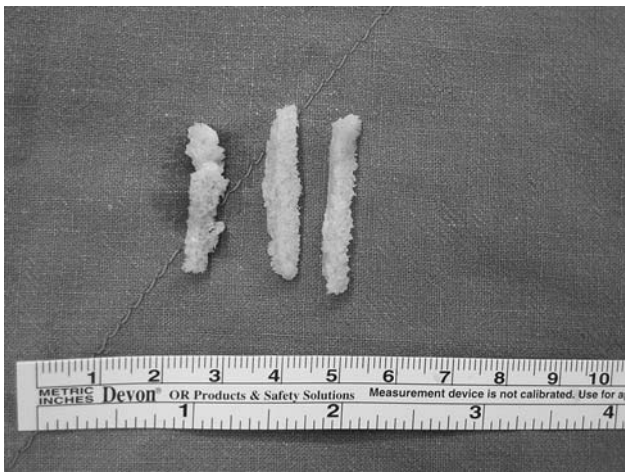

Fig. 1 A photograph shows allogeneic bone chips harvested from the cancellous part of the allograft in the bone bank. They were shaped manually into a rectangle and were approximately 3 × 2 × 5 mm each.

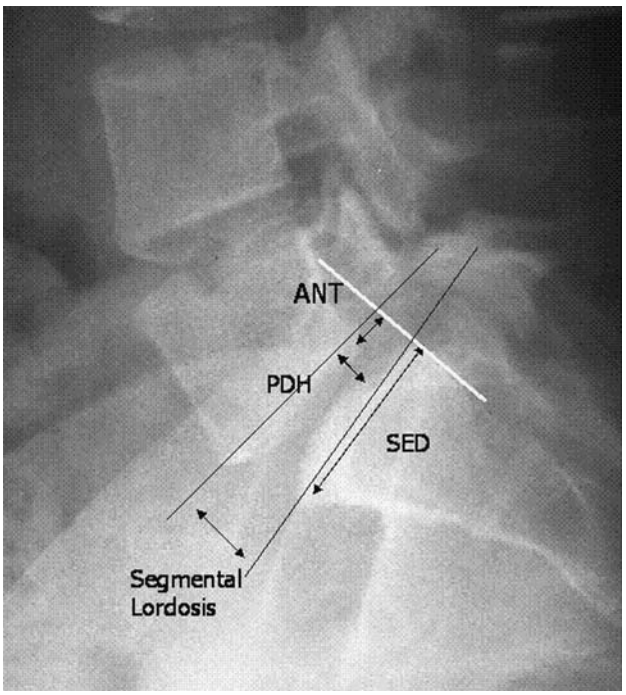

Fig. 2 Radiographic measurement of posterior disc height (PDH), anterolisthesis (ANT), and segmental lordosis is illustrated. Posterior disc height was measured at the maximal point along the posterior disc space. Anterolisthesis was measured from the posterior border of the slipped vertebral body to that of the caudal segment. Both values are expressed as a percentage of the superior end-plate diameter (SED) to normalize the variations between patients. Subsequently, two parameters were obtained: disc height ratio = (PDH/SED)% and slip ratio = (ANT/SED)%. Segmental lordosis was measured from the angle between the upper and lower end plates at the spondylolisthetic level.

approach using nerve retractors to displace the theca sac and nerve root medially and inferiorly. After radical discectomy with end-plate preparation by pituitary rongeurs and curettes, graft materials were placed and impacted into the anterior disc space for the interbody fusion.

In the BC group, cancellous allograft taken from a bone bank (femoral head or knee condyle) was shaped into chips approximately 3 × 2 × 5 mm (Fig. 1). We inserted the allogeneic bone chips closely mixed with local morselized bone to fill the disc space followed by firm impaction to avoid retropulsion. In the AC group, two kinds of interbody cages were used. One was a titanium cage (Aaxter Corp, Taipei, Taiwan) and the other was a PEEK cage (Stryker Corp, Kalamazoo, MI), both having anterior tilting angles of 0°, 4°, and 8°. We placed morselized host bone in the anterior aspect of the disc space followed by insertion of artificial cages, which also were packed with morselized local bone graft in the empty space. The cage position was at least 5 mm from the posterior cortical margin and was routinely confirmed by portable radiograph or C-arm fluoroscopy. After the proper position was obtained, gentle compression force was applied over the adjacent screws to achieve firm contact between end plates and grafted materials. Bilateral posterolateral fusion was performed routinely using morselized bone grafts to achieve circumferential arthrodesis. The postoperative care and rehabilitation protocols were the same for both groups. Patients could walk on the first postoperative day with a light corset that was worn for 3 months.

We (CHY, PQC) assessed sagittal contour of the lumbar spine by a standard standing lumbosacral lateral view according to the modified method of Kwon and Albert [25]. Three radiographic characteristics were evaluated in this study on the preoperative, initial postoperative, and final postoperative plain films: posterior disc height (PDH), anterolisthesis (ANT) of the rostral vertebral body, and segmental lordosis of the spondylolisthetic segment (Fig. 2). To normalize the variations between patients' spines, both absolute measurements (ANT and PDH) were represented as a percentage of the anteroposterior diameter of the superior end plate (SED) of the caudal vertebral body. In this way, we obtained two ratios: (1) disc height ratio = (PDH/SED)% and (2) slip ratio = (ANT/SED)%.

Fusion status also was assessed by two independent surgeons (TSZ, HLH) not involved with either surgery or postoperative patient care. The operative segment was considered radiographically fused if there was bridging bone formation over the involved disc space and no radiolucency around the cages by plain film or intimate contact between the cage and the end plates (Fig. 3) [12]. Posterolateral fusion also was assessed and the arthrodesis was deemed successful if continuity in the fusion mass between the cephalad and caudal transverse process was present [17]. For interobserver agreement, the kappa value

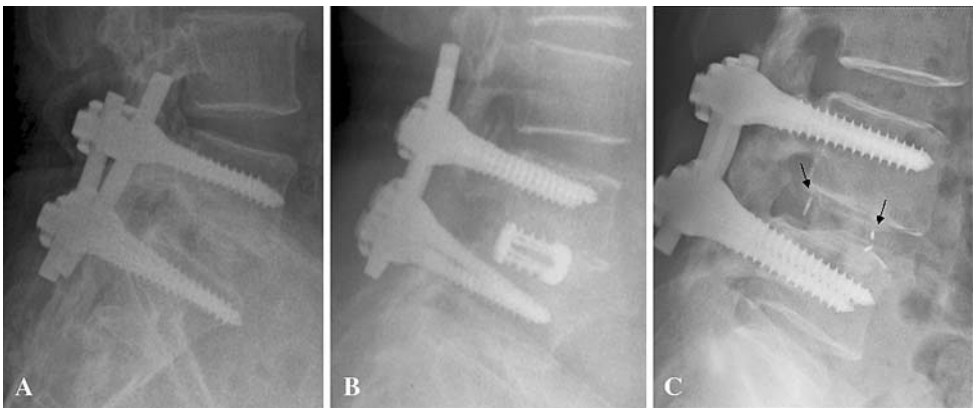

Fig. 3A–C Radiographic assessment of the fusion status after PLIF using (**A**) bone chips only, (**B**) a titanium cage, and (**C**) a PEEK cage is illustrated. The PLIF site was considered fused if there was bridging bone formation over the involved disc space and no radiolucency around the implants (titanium or PEEK cage) on plain radiographs. White marks (arrows) denote the anterior and posterior borders of the radiolucent PEEK cages.

was 0.623 and the proportion of agreement was 92%. In some patients, dynamic flexion-extension lateral views were taken when the two surgeons could not determine or reach consensus regarding the fusion status on the standing view radiograph.

We evaluated clinical outcomes preoperatively and postoperatively with the Oswestry disability low back pain questionnaire (ODI; 0%–100%), considered an accepted validated tool of low back pain functional outcome [15], and a visual analog scale for back pain (VAS; 0–10 points). The evaluation was performed at 3-, 6-, and 12-month intervals after surgery and then at 1-year intervals thereafter. We determined absence of radiculopathy of the lower leg by the absence of pain or numbness after surgery and at the outpatient visits. Patient satisfaction was rated with a four-point Likert scale [48] (1 = very satisfactory; 2 = satisfactory; 3 = unsatisfactory; 4 = very unsatisfactory). This was obtained from the patient's statement in the presence of an evaluator who was not involved with the surgery.

We compared preoperative and postoperative ODI and VAS scores with a paired t test and multivariate robust regression analysis (MVRRA) with preoperative function score and dummy variables for groups as covariates. Preoperative and postoperative disc height ratios, slip ratios, and segmental lordosis were assessed using a paired t test. Fusion, patient satisfaction, and radiculopathy improvement rates were evaluated using the chi square test. Clinical and radiographic outcomes also were assessed by MVRRA, with age, gender, fusion status, spondylolisthesis level, spondylolisthesis type, final correction of disc height ratio, final correction of vertebral slip ratio, final correction of regional lordosis angle, and dummy variables for groups as covariates. We used the Stata® program (StataCorp LP, College Station, TX) for analysis.

Results

Although the BC and AC groups (including the TC and PC groups) showed functional improvement in ODI and VAS scores after PLIF (Table 2), the TC and PC groups had greater ODI improvement than the BC group (p = 0.008

Table 2. Clinical outcomes (pain and function)

End points evaluated	BC group (n = 34)		AC group (n = 42)				p Value*		
	Preoperative	Postoperative	TC group (n = 31)		PC group (n = 11)		BC vs TC	BC vs PC	TC vs PC
			Preoperative	Postoperative	Preoperative	Postoperative			
ODI	49.0 ± 12.1	28.0 ± 16.0 ($p < 0.0001$)†	55.5 ± 14.5	22.2 ± 13.0 ($p < 0.0001$)†	43.8 ± 14.0	14.9 ± 9.8 ($p = 0.0002$)†	0.008	0.013	0.654
VAS (pain)	7.6 ± 1.3	2.0 ± 1.8 ($p < 0.0001$)†	8.1 ± 1.5	1.6 ± 1.5 ($p < 0.0001$)†	7.8 ± 1.0	1.2 ± 1.3 ($p < 0.0001$)†	0.160	0.063	0.477

Data are expressed as mean ± standard deviation; *p value in analysis of group differences between preoperative and postoperative function scores using multivariate robust regression analysis with preoperative function score and dummy variables for groups as covariates; †p value in analysis of difference between preoperative and postoperative function scores using paired t test; BC = bone chips only; AC = artificial cage; TC = titanium cage; PC = polyetheretherketone cage; ODI = Oswestry disability index (0%–100%); VAS = visual analog scale (0–10 points).

Table 3. Clinical outcomes

End points evaluated	BC group (n = 34)	AC group (n = 42)		p Value*
		TC group (n = 31)	PC group (n = 11)	
Fusion rate	88.24% (30/34)	93.55% (29/31)	100% (11/11)	0.421
Patient satisfaction	79.4% (27/34)	90.3% (28/31)	90.9% (10/11)	0.394
Radiculopathy improvement	63.3% (19/30)	51.9% (14/27)	44.4% (4/9)	0.514

* p value in analysis of difference among three groups with chi square test; BC = bone chips only; AC = artificial cage; TC = titanium cage; PC = polyetheretherketone cage.

and p = 0.013, respectively) (Table 2). In contrast to the ODI, there was no difference in VAS score improvement among the BC, TC, and PC groups. The fusion rate, subjective satisfaction rate, and ratio of patients free of radiculopathy postoperatively were similar in the BC, TC, and PC groups (p = 0.421, p = 0.394, and p = 0.514, respectively) (Table 3).

Titanium and PEEK cages maintained the corrected sagittal alignment of the lumbar spine better than bone chips alone (Table 4). Compared with preoperative lateral films, on the immediately postoperative films, the disc height ratio, slip ratio, and segmental lordosis appeared corrected in the BC and AC groups. However, comparing the immediate postoperative with the last films, correction in disc height ratio (p < 0.0001), slip ratio (p = 0.04), and segmental lordosis (p < 0.0001) were not maintained in the BC group, whereas correction was maintained in the TC and PC groups (Table 4).

Functional improvement in ODI was better (p = 0.042) in the PC group than in the BC group (Table 5). Patient satisfaction was better (p = 0.002) in the TC group than in the BC group. In addition, the radiographic fusion status was associated with better (p < 0.001) ODI and better (p < 0.001) satisfaction.

Five (14.7 %) patients in the BC group had complications. These included three implant-related failures; we observed screw breakage at the S1 level in two patients during 6 to 12 months' followup (Fig. 4) and one patient had a one-sided rod broken. One had a dura tear during surgery, and one had a fungal infection at the perioperative stage (Candida albicans). The infection was controlled uneventfully after wound débridement and antifungal drug administration. The reason for the one rod breakage was not clarified because the patient was symptom-free and the implant was not removed for analysis. Five (11.9%) complications also occurred in the AC group, including two postoperative superficial wound infections, one each for dura tearing during surgery, epidural hematoma

Table 4. Radiographic outcomes

Time of assessment	Disc height ratio (%)			Slip ratio (%)			Segmental lordosis (°)		
	BC group (n = 34)	AC group (n = 42)		BC group (n = 34)	AC group (n = 42)		BC group (n = 34)	AC group (n = 42)	
		TC (n = 31)	PC (n = 11)		TC (n = 31)	PC (n = 11)		TC (n = 31)	PC (n = 11)
Preoperative	13.4 ± 6.7	15.4 ± 5.1	16.5 ± 4.1	24.5 ± 9.3	17.9 ± 6.7	22.1 ± 5.9	1.6 ± 4.3	1.0 ± 3.9	0.8 ± 4.8
Immediately postoperative	23.8 ± 7.0 (p < 0.0001)*	30.5 ± 4.7 (p < 0.0001)*	28.9 ± 5.4 (p < 0.0001)*	13.9 ± 7.2 (p < 0.0001)*	14.1 ± 5.7 (p = 0.001)*	15.3 ± 5.1 (p = 0.001)*	4.2 ± 3.2 (p < 0.0001)*	5.4 ± 2.0 (p < 0.0001)*	5.8 ± 3.3 (p = 0.001)*
Latest followup	17.7 ± 7.1 (p = 0.004)* (p < 0.0001)†	29.3 ± 5.6 (p < 0.0001)* (p = 0.091)	29.5 ± 5.6 (p < 0.0001)* (p = 0.532)	16.7 ± 8.9 (p < 0.0001)* (p = 0.04)†	15.1 ± 5.4 (p = 0.008)* (p = 0.101)	15.3 ± 6.9 (p = 0.010)* (p = 0.996)	2.5 ± 3.8 (p = 0.085) (p < 0.0001)†	4.9 ± 2.3 (p < 0.0001)* (p = 0.060)	5.1 ± 2.8 (p = 0.004)* (p = 0.181)

Disc height ratio is the percentage of the diameter of the superior end plate of the caudal vertebral body; slip ratio is the percentage of the diameter of the superior end plate of the caudal vertebral body; data are expressed as mean ± standard deviation; *significantly different from preoperative data (paired t test); †significantly different from immediately postoperative data (paired t test); BC = bone chips only; AC = artificial cage; TC = titanium cage; PC = polyetheretherketone cage.

Table 5. Result of multivariable robust regression analysis for clinical outcomes

End points evaluated	BC vs TC	BC vs PC	TC vs PC	Fusion status	Disc height correction	Slip ratio correction	Regional lordosis correction
ODI*	0.080 (−6.62)	0.042 (−9.75)	0.450 (−3.13)	< 0.001 (−21.26)	0.900 (−2.58)	0.054 (38.73)	0.880 (0.07)
VAS (pain)*	0.620 (−2.48)	0.160 (−0.85)	0.250 (−0.60)	0.120 (−1.06)	0.870 (−0.46)	0.002 (8.314)	0.760 (−0.02)
Radiculopathy improvement†	0.260 (0.34)	0.097 (0.13)	0.340 (0.37)		0.780 (3.63)	0.210 (243.10)	0.750 (1.03)
Patient satisfaction‡	0.002 (9.74)	0.560 (1.71)	0.067 (0.18)	< 0.001 (92.54)	0.580 (0.10)	0.560 (11.74)	0.430 (1.08)

* Data are p values, with coefficients in parentheses, calculated in multivariate robust regression analysis with age, gender, fusion status, spondylolisthesis type, final correction of disc height ratio, final correction of vertebral slip ratio, final difference of regional lordosis angle, preoperative functional score, and dummy variables for groups as covariates; †data are p values, with odds ratios in parentheses, calculated in multivariate robust logistic regression analysis with age, gender, fusion status, spondylolisthesis level, spondylolisthesis type, final correction of disc height ratio, final correction of vertebral slip ratio, final correction of regional lordosis angle, and dummy variables for groups as covariates; ‡data are p values, with odds ratios in parentheses, calculated in multivariate robust ordinal logistic regression analysis with age, gender, fusion status, spondylolisthesis level, spondylolisthesis type, final correction of disc height ratio, final correction of vertebral slip ratio, final correction of regional lordosis angle, and dummy variables for groups as covariates; BC = bone chips only; TC = titanium cage; PC = polyetheretherketone cage.

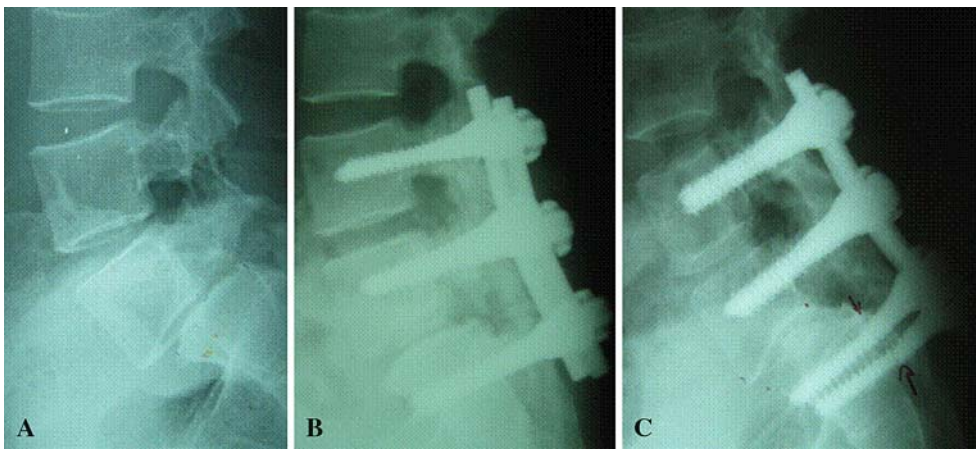

Fig. 4A–C Lateral radiographs of a 38-year-old woman show Grade 2, L5/S1 isthmic spondylolisthesis (**A**) before and (**B**) after treatment with instrumented PLIF with a bone chip graft. (**C**) Bilateral sacrum screw breakage (arrow) was observed at 10 months. She was pain-free and felt little discomfort from soft tissue irritation over the buttocks at 2 years' followup.

postoperatively, and urinary retention. Cage migration was not observed. There was no fatal morbidity in either group.

Discussion

Bone grafts traditionally have been used for interbody fusion but they may have some disadvantages including donor-site morbidities for autologous iliac bone graft [24], less healing ability for allograft alone [47], and graft collapse for amorphous bone chips [3]. Interbody cages have been used to minimize these complications and it is believed that interbody cages could provide better mechanical strength and fusion rates in PLIF [6, 36]. Thus we hypothesized PLIF using interbody cages, compared with bone chips, would result in higher clinical scores and fusion rates in patients with lumbar spondylolisthesis. We assumed solid fusion would correlate with good functional outcomes in patients with unstable lumbar segments.

Our study has limitations. First, it is not straightforward to objectively assess the radiographic fusion status, especially with implants in the grafted sites. Computed tomography and MRI are reportedly more reliable to assess the fusion status [23, 37], but we did not use these high-cost technologies in this study. Blumenthal and Gill [4] stated the only reliable method to determine fusion rate may be reexploration which is obviously impractical on a routine basis. To avoid bias estimation, however, the fusion status was assessed by two independent surgeons not involved in either surgery or postoperative care of the patients. The kappa statistic for interobserver agreement was 0.623, which represented substantial interobserver reliability [27]. Second, there was still concern regarding the heterogeneity between patients with isthmic and degenerative spondylolisthesis. Although these two disease

groups have a different pathogenesis and clinical manifestations, we believe both represent disease conditions with an unstable spine clinically and radiographically, and the treatment principles are the same. A good arthrodesis also is mandatory for good outcomes in lytic and degenerative spondylolisthesis [31, 41]. Thus, we thought it reasonable to put them together in the analysis. Additionally, the disease distribution between the BC and AC groups was not different. Numerous investigators have used the same study design we used [28, 43]. Furthermore, we performed multivariable analysis with spondylolisthesis type as one of the covariates to adjust the result statistically. Third, the followup was not equal in the BC and AC groups and this may have influenced the outcome assessment owing to possible adjacent disease seen with longer followup. Yet this problem was inherent in our study design and it was not possible to solve it in our study. Insertion of artificial cages incurs extra cost for the PLIF (approximately $1000 [USD] for the titanium cage and $2000 [USD] for the PEEK cage in Taiwan, depending on the manufacturer). However, we found cage insertion provided better clinical outcomes. Whether insertion of artificial cages is cost-effective needs additional study. The use of bone chips alone or artificial cages provided functional improvements after PLIF for lumbar spondylolisthesis. However, the artificial cages provided better functional improvement in ODI and better postoperative radiographic results, including maintaining the correction of disc height ratio, slip ratio, and segmental lordosis than bone chips alone. In contrast, VAS pain score improvement, patient satisfaction, and fusion rate were not different between the two groups. We also found functional outcome was correlated with radiographic fusion status.

Both fusion techniques reduced mechanical back pain as reflected by VAS assessment, and the AC groups achieved better functional outcomes than the BC group in terms of ODI score. In the literature, the clinical outcomes of instrumented PLIF in lumbar spondylolisthesis have varied, although interbody cages have provided better outcomes than autogenous bone chips and dorsal elements in some case series (Table 6). In fact, to date, there is no report to show cages are superior to bone chips alone in such situations. Although Arai et al. found no functional difference between an iliac bone chips group and a carbon cage group [3], our data suggest the use of cages in PLIF is superior to the use of bone chips alone for functional aspects. However, although we observed that cages provide better functional outcomes in ODI, the VAS improvement was not different between the AC and BC groups. This may indicate artificial cages have functional advantages, other than alleviating pain, over bone chips alone. The true reason for this functional advantage was not determined in our study, but we speculate that one of the reasons might be

Table 6. Fusion rates and clinical outcomes of instrumented posterior lumbar interbody fusion in lumbar spondylolisthesis*

Study	Year	Methodology	Number of patients	Spondylolisthesis type	Grafting materials	Followup	Fusion rate	Clinical outcome
Simmons [42]	1985	Retrospective	113	NR	Posterior element bone chips	NR	NR	79% good
Csecsei et al. [11]	2000	Prospective	46	Mixed types	Laminectomy bone chips	27.3 months	95.70%	87% good or excellent
La Rosa et al. [26]	2001	Retrospective	17	Isthmic	Titanium cage + AIC	24 months	100%	76.5 successful
Chen et al. [8]	2003	Retrospective	118	Mixed types	BAK cage + local grafts	33 months	95%	NR
Zhao et al. [49]	2003	Retrospective	27†	Degenerative and isthmic	BAK cage + AIC	> 24 months	100%	92.5% good or excellent
Kai et al. [21]	2004	Retrospective	42	Degenerative and isthmic	Local facet joint bone	8.5 years	92.90%	76% recovery rate (JOA)
Sears [39]	2005	Prospective	34	Degenerative	Interbody cages‡	21.2 months	NR	91% good or excellent
Sears [40]	2005	Prospective	18	Isthmic	Interbody cages‡	17.3 months	NR	83.3% good or excellent

* Correlations between fusion rates and clinical outcomes were not reported in any of the studies; †this study included seven patients with herniated disc; ‡these studies included the use of carbon, titanium, and polyetherketone cages; NR = not reported; BAK cage = Bagby and Kuslich™ cage (Sulzer Spine-Tech, Minneapolis, MN); AIC = autogenous iliac crest; JOA = Japanese Orthopaedic Association.

that the quality of the fused bone may be different between the bone chip group and the cage group, because the immediate stability that could be achieved by the two groups may not be the same after the operation. We need additional studies to explain this observation.

We found a comparable union rate in the BC and AC groups (BC group, 88.2%; TC group, 93.6%; PC group, 100.0%). Furthermore, the ODI score improvement and patient satisfaction correlated with fusion status in our MVRRA. A couple studies have addressed the correlation between fusion status and clinical outcomes, and this correlation has remained controversial [22, 29]. One study concluded a solid fusion improved long-term clinical results in patients undergoing decompression and posterolateral arthrodesis for degenerative spondylolisthesis [22]. On the contrary, another study reported no correlation between clinical and radiographic outcomes [28]. We believe the explanation for correlation between fusion and ODI score improvement in our study is straightforward: the mechanical back pain produced from a pars defect, degenerated intervertebral disc, or facet arthropathy could be reduced once the unstable segment was fused successfully, especially with circumferential arthrodesis. We also recommend fusion to prevent subsequent instability after wide laminectomy in patients with degenerative spondylolisthesis with severe spinal stenosis. Once the back pain and neuroclaudication improved, our patients had good functional outcomes. The average reported fusion rate ranges from 90% to 95.7% in patients with noncage PLIF [11, 21] and from 90% to 100% in patients with cage PLIF [1, 3, 5, 20, 25, 26, 39, 40, 49]. Our fusion result was comparable to those of other published studies (Table 6).

We found titanium or PEEK cages in PLIF were better in maintaining the corrected disc height, corrected slip ratio, and corrected segmental lordosis of the lumbar spine than bone chips alone in PLIF for lumbar spondylolisthesis. The failure to maintain corrected lumbar alignment in the BC groups may result from insufficient mechanical strength of the inserted bone chips, which could not provide the initial stability before union of the grafted sites. A graft collapse rate of 16.7% has been reported in using the strut and autograft from the facet joint for fusion in patients with spondylolisthesis [21]. Our finding of good ability in maintaining corrected lumbar alignment in the AC groups confirms the findings of other studies [5, 19]. It is known that lordosis of the operative segment in lumbar alignment influences the long-term clinical outcome and subsequent adjacent level disease [2, 46]. In addition, restoration of the disc height may decompress the narrowed neural foramen and thus improve the radiculopathy [7] resulting from pedicle kinking. For these reasons, it is reasonable for the AC groups in our study to have better functional outcomes than the BC group.

We found satisfaction rates higher than the rates of improvement in radiculopathy in all three groups. This probably is attributable to the fact that overall satisfaction represents many dimensions of functional recovery, whereas radiculopathy is only one of the dimensions.

Complication rates of cage PLIF reportedly are high during intraoperative and late postoperative periods [8, 13]. We observed implant breakage only in the BC group. This might have been the result of a weaker mechanical spinal construct using unstructured bone grafts without cages. For the two patients who had broken screws removed from the S1 region, the diameter of the screws was 6.5 mm, which might be too small to sustain the repeated lumbosacral motion. We changed to using the 7.5-mm-diameter screws for bony purchase in the S1 region thereafter. In addition to implant breakage, motion segments adjacent to fused ones may degenerate from high stresses [2, 46]. In our relatively short-term followup none of the patients underwent additional surgery for adjacent degenerative disease but longer followup is required to determine the rate of this complication.

We found artificial cages provide better functional and radiographic outcomes than only bone chips in PLIF for lumbar spondylolisthesis, whereas both techniques achieved comparable fusion rates. Our data also suggest clinical outcomes correlate with radiographic fusion. Additional research is needed to determine the cost-effectiveness of cage insertion in PLIF for lumbar spondylolisthesis.

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References

1. Agazzi S, Reverdin A, May D. Posterior lumbar interbody fusion with cages: an independent review of 71 cases. *J Neurosurg.* 1999;91:186–192.
2. Akamaru T, Kawahara N, Tim Yoon S, Minamide A, Su Kim K, Tomita K, Hutton WC. Adjacent segment motion after a simulated lumbar fusion in different sagittal alignments: a biomechanical analysis. *Spine.* 2003;28:1560–1566.
3. Arai Y, Takahashi M, Kurosawa H, Shitoto K. Comparative study of iliac bone graft and carbon cage with local bone graft in posterior lumbar interbody fusion. *J Orthop Surg (Hong Kong).* 2002;10:1–7.
4. Blumenthal SL, Gill K. Can lumbar spine radiographs accurately determine fusion in postoperative patients? Correlation of routine radiographs with a second surgical look at lumbar fusions. *Spine.* 1993;18:1186–1189.
5. Brantigan JW, Neidre A. Achievement of normal sagittal plane alignment using a wedged carbon fiber reinforced polymer fusion cage in treatment of spondylolisthesis. *Spine J.* 2003;3:186–196.
6. Brantigan JW, Steffee AD, Lewis ML, Quinn LM, Persenaire JM. Lumbar interbody fusion using the Brantigan I/F cage for posterior lumbar interbody fusion and the variable pedicle screw placement system: two-year results from a Food and Drug

Administration investigational device exemption clinical trial. *Spine.* 2000;25:1437–1446.
7. Chen D, Fay LA, Lok J, Yuan P, Edwards WT, Yuan HA. Increasing neuroforaminal volume by anterior interbody distraction in degenerative lumbar spine. *Spine.* 1995;20:74–79.
8. Chen L, Tang T, Yang H. Complications associated with posterior lumbar interbody fusion using Bagby and Kuslich method for treatment of spondylolisthesis. *Chin Med J (Engl).* 2003;116:99–103.
9. Cloward RB. Spondylolisthesis: treatment by laminectomy and posterior interbody fusion. *Clin Orthop Relat Res.* 1981;154:74–82.
10. Csecsei G, Klekner A, Sikula J. Posterior lumbar interbody fusion (PLIF) using the bony elements of the dorsal spinal segment. *Acta Chir Hung.* 1997;36:54–56.
11. Csecsei GI, Klekner AP, Dobai J, Lajgut A, Sikula J. Posterior interbody fusion using laminectomy bone and transpedicular screw fixation in the treatment of lumbar spondylolisthesis. *Surg Neurol.* 2000;53:2–6; discussion 6–7.
12. Diedrich O, Perlick L, Schmitt O, Kraft CN. Radiographic characteristics on conventional radiographs after posterior lumbar interbody fusion: comparative study between radiotranslucent and radiopaque cages. *J Spinal Disord.* 2001;14:522–532.
13. Elias WJ, Simmons NE, Kaptain GJ, Chadduck JB, Whitehill R. Complications of posterior lumbar interbody fusion when using a titanium threaded cage device. *J Neurosurg.* 2000;93:45–52.
14. Enker P, Steffee AD. Interbody fusion and instrumentation. *Clin Orthop Relat Res.* 1994;300:90–101.
15. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine.* 2000;25:2940–2952; discussion 2952.
16. Fernyhough JC, White JI, LaRocca H. Fusion rates in multilevel cervical spondylosis comparing allograft fibula with autograft fibula in 126 patients. *Spine.* 1991;16(10 suppl):S561–S564.
17. Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT. 1997 Volvo Award winner in clinical studies: Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation. *Spine.* 1997;22:2807–2812.
18. Fleiss JL. Significance tests have a role in epidemiologic research: reactions to A. M. Walker. *Am J Public Health.* 1986; 76:559–560.
19. Groth AT, Kuklo TR, Klemme WR, Polly DW, Schroeder TM. Comparison of sagittal contour and posterior disc height following interbody fusion: threaded cylindrical cages versus structural allograft versus vertical cages. *J Spinal Disord Tech.* 2005;18:332–336.
20. Hashimoto T, Shigenobu K, Kanayama M, Harada M, Oha F, Ohkoshi Y, Tada H, Yamamoto K, Yamane S. Clinical results of single-level posterior lumbar interbody fusion using the Brantigan I/F carbon cage filled with a mixture of local morselized bone and bioactive ceramic granules. *Spine.* 2002;27: 258–262.
21. Kai Y, Oyama M, Morooka M. Posterior lumbar interbody fusion using local facet joint autograft and pedicle screw fixation. *Spine.* 2004;29:41–46.
22. Kornblum MB, Fischgrund JS, Herkowitz HN, Abraham DA, Berkower DL, Ditkoff JS. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. *Spine.* 2004;29:726–733; discussion 733–724.
23. Kroner AH, Eyb R, Lange A, Lomoschitz K, Mahdi T, Engel A. Magnetic resonance imaging evaluation of posterior lumbar interbody fusion. *Spine.* 2006;31:1365–1371.
24. Kurz LT, Garfin SR, Booth RE Jr. Harvesting autogenous iliac bone grafts: a review of complications and techniques. *Spine.* 1989;14:1324–1331.
25. Kwon BK, Albert TJ. Adult low-grade acquired spondylolytic spondylolisthesis: evaluation and management. *Spine.* 2005;30(6 suppl):S35–S41.
26. La Rosa G, Cacciola F, Conti A, Cardali S, La Torre D, Gambadauro NM, Tomasello F. Posterior fusion compared with posterior interbody fusion in segmental spinal fixation for adult spondylolisthesis. *Neurosurg Focus.* 2001;10:E9.
27. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;33:159–174.
28. Lauber S, Schulte TL, Liljenqvist U, Halm H, Hackenberg L. Clinical and radiologic 2-4-year results of transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. *Spine.* 2006;31:1693–1698.
29. Luczkiewicz P, Smoczynski A, Smoczynski M, Pankowski R, Piotrowski M. [The results of decompression and anterior lumbar interbody fusion with the use of interbody cages for the treatment of degenerative lumbar spondylolisthesis] [in Polish]. *Chir Narzadow Ruchu Ortop Pol.* 2006;71:173–175.
30. Ma GW. Posterior lumbar interbody fusion with specialized instruments. *Clin Orthop Relat Res.* 1985;193:57–63.
31. Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'Neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: a systematic review. *Spine.* 2007;32: 1791–1798.
32. Meyerding HW. Spondylolisthesis; surgical fusion of lumbosacral portion of spinal column and interarticular facets; use of autogenous bone grafts for relief of disabling backache. *J Int Coll Surg.* 1956;26:566–591.
33. Miura Y, Imagama S, Yoda M, Mitsuguchi H, Kachi H. Is local bone viable as a source of bone graft in posterior lumbar interbody fusion? *Spine.* 2003;28:2386–2389.
34. Posner I, White AA 3rd, Edwards WT, Hayes WC. A biomechanical analysis of the clinical stability of the lumbar and lumbosacral spine. *Spine.* 1982;7:374–389.
35. Ray CD. Threaded fusion cages for lumbar interbody fusions: an economic comparison with 360 degrees fusions. *Spine.* 1997;22: 681–685.
36. Ray CD. Threaded titanium cages for lumbar interbody fusions. *Spine.* 1997;22:667–679; discussion 679–680.
37. Santos ER, Goss DG, Morcom RK, Fraser RD. Radiologic assessment of interbody fusion using carbon fiber cages. *Spine.* 2003;28:997–1001.
38. Sarwat AM, O'Brien JP, Renton P, Sutcliffe JC. The use of allograft (and avoidance of autograft) in anterior lumbar interbody fusion: a critical analysis. *Eur Spine J.* 2001;10:237–241.
39. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: restoration of sagittal balance using insert-and-rotate interbody spacers. *Spine J.* 2005;5:170–179.
40. Sears W. Posterior lumbar interbody fusion for lytic spondylolisthesis: restoration of sagittal balance using insert-and-rotate interbody spacers. *Spine J.* 2005;5:161–169.
41. Sengupta DK, Herkowitz HN. Degenerative spondylolisthesis: review of current trends and controversies. *Spine.* 2005;30:S71–S81.
42. Simmons JW. Posterior lumbar interbody fusion with posterior elements as chip grafts. *Clin Orthop Relat Res.* 1985;193:85–89.
43. Skowronski J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. *Ortop Traumatol Rehabil.* 2007;9:149–155.
44. Suk SI, Lee CK, Kim WJ, Lee JH, Cho KJ, Kim HG. Adding posterior lumbar interbody fusion to pedicle screw fixation and

posterolateral fusion after decompression in spondylolytic spondylolisthesis. *Spine*. 1997;22:210–219; discussion 219–220.
45. Tullberg T, Brandt B, Rydberg J, Fritzell P. Fusion rate after posterior lumbar interbody fusion with carbon fiber implant: 1-year follow-up of 51 patients. *Eur Spine J.* 1996;5:178–182.
46. Umehara S, Zindrick MR, Patwardhan AG, Havey RM, Vrbos LA, Knight GW, Miyano S, Kirincic M, Kaneda K, Lorenz MA. The biomechanical effect of postoperative hypolordosis in instrumented lumbar fusion on instrumented and adjacent spinal segments. *Spine*. 2000;25:1617–1624.
47. Wimmer C, Krismer M, Gluch H, Ogon M, Stockl B. Autogenic versus allogenic bone grafts in anterior lumbar interbody fusion. *Clin Orthop Relat Res.* 1999;360:122–126.
48. Yamashita K, Hayashi J, Ohzono K, Hiroshima K. Correlation of patient satisfaction with symptom severity and walking ability after surgical treatment for degenerative lumbar spinal stenosis. *Spine.* 2003;28:2477–2481.
49. Zhao J, Hou T, Wang X, Ma S. Posterior lumbar interbody fusion using one diagonal fusion cage with transpedicular screw/rod fixation. *Eur Spine J.* 2003;12:173–177.