〈Regular Article〉

Comparison of titanium and polyetheretherketone (PEEK) cages in the surgical treatment of single level lumbar spondylolisthesis

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ABSTRACT **Background**: Pseudarthrosis is one of the complications after posterior lumbar intervertebral body fusion (PLIF). We reviewed our initial experience with PLIF using a 3D-printed porous titanium cage and examined the pertinent literature for this report.

Patients and methods: This study included 20 patients who underwent one level PLIF for lumbar spondylolisthesis. All patients were followed for at least 1 year. The median follow-up duration was 23 months (range, 12 to 96). Between July 2012 and January 2014, 10 patients underwent PLIF using a PEEK carbon cage (PK group). Between November 2017 and June 2019, 10 patients underwent PLIF using a 3D porous titanium alloy cage (3DTA group). We evaluated bone fusion by CT multi-planar reconstruction at 3 days, 3 months, 6 months, and 12 months postoperatively.

Results: Bony union was achieved in 8 of 10 cases in the PK group and in all cases in the 3DTA group. In the 3DTA group, all patients had bony fusion within one year. Median bone fusion periods were 6.0 months in the PK group and 6.0 months in the 3DTA group. There was no screw loosening or correction loss in either group. Cage subsidence occurred in 5 cases in the PK group and 3 cases in the 3DTA group.

Conclusions: all patients in the 3DTA group achieved bone fusion within one year. The 3D porous titanium alloy cage can be expected to achieve bone fusion as good as the PEEK cage in single level PLIF surgery. doi：10.11482/KMJ-E202349001 *(Accepted on March 29, 2023)*

Key words：Posterior lumbar intervertebral body fusion, 3D-printed porous titanium cage, Fusion rate, PEEK cage

INTRODUCTION

Degenerative spondylolisthesis is a common pathology that often causes lumbar canal stenosis. Lumbar spinal fusion is an established surgical technique with different surgical approaches to establish a biomechanically-lasting interbody union. Today, posterior lumbar intervertebral body fusion (PLIF) is the gold standard for spinal arthrodesis.

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The goal of PLIF is to stabilize the motion segment and facilitate the fusion process. Many types of cages such as steel[1], Titanium[2], Carbon[3] and PEEK[4] have been used for PLIF spacers. Titanium cages are the most popular and have shown good clinical results[5]. However three disadvantages have emerged with the use of metal cages: subsidence of the cage into adjacent vertebrae, difficulties in assessing fusion with radiological imaging, and stiffness of the material[5]. Stiffness reduces mechanical stimulation needed for the bone grafts; delayed fusion may occur with this shielding of the bone graft. To overcome these problems, PEEK cages have been introduced. PEEK is a polymer that is biomechanically similar to cortical bone. In addition, it is radiolucent.

In spinal fusion procedures, PEEK is used for intervertebral cages instead of titanium to take advantage of PEEK's biomechanical superiority. However, whether PEEK cages are superior in their radiological outcomes remains controversial[6]. Schimmel *et al*. recently reported unfavorable radiological outcomes in patients treated with PEEK cages[7]. CT scans revealed that, of 95 patients who received an anterior lumbar interbody fusion with a PEEK cage, 24% required reoperation for symptomatic pseudarthrosis[7]. Osseointegration of titanium intervertebral cages is a favorable property because direct bonding between bone and implant surfaces can promote early fixation of the cages[8]. This osseointegration is not commonly observed on the surfaces of pure PEEK materials because they are often surrounded by relatively dense fibrous tissue after bone implantation[8].

Pseudarthrosis is one of the complications after PLIF. Osseointegration surrounding the interbody cage is an important process for achieving a solid spinal fusion following PLIF. Advancements in 3D printing technology permit commonly used titanium interbody cages to be designed with unique architectures, such as a highly interconnected and specific porous structure that mimics the architecture of trabecular bone. These 3D-printed porous biomimetic titanium implants have already been clinically applied in total hip arthroplasty and dentistry. Interbody cages with a microscale surface roughness and biomimetic porosity may improve bony ongrowth and ingrowth compared to traditional materials such as polyetheretherketone (PEEK).

The purpose of this study was to compare the differences in bone fusion rates between 3D porous titanium alloy and PEEK carbon cages. We reviewed our initial experience with PLIF using a 3D-printed porous titanium cage and examined the pertinent literature for this report.

PATIENTS AND METHODS

The institutional ethics committee approved this study protocol (approval number 5780-00). All patients consented to collection and use of their data for publication. This study included 20 patients who underwent one level PLIF for lumbar spondylolisthesis. We excluded patients who had a spinal fracture, pyogenic spondylitis or spinal metastasis. All patients were followed for at least 1 year. The median follow-up duration was 23 months (range, 12 to 96).

We placed a total of 80 pedicle screws and 40 PLIF cages. We made a small midline incision (6 cm) for decompression and cage insertion. Pedicle screws were placed percutaneously using fluoroscopy. The intervertebral joints were preserved bilaterally. The cages and lumbar interbody spaces were filled with local bone obtained during the decompressive procedure. There are no conflicts of interest for the implants used in this study.

PEEK carbon cage group (PK group)

Between July 2012 and January 2014, 10 patients underwent one level PLIF using a PEEK carbon cage (JAGUAR, DePuy, USA) for lumbar spondylolisthesis (Table 1). Because the PEEK cage is radiographically visible, it can be seen during intraoperative fluoroscopy, and the determination of bone fusion on postoperative CT is simplified.

The 10 patients included 5 men and 5 women with a median age at surgery of 69 years (range, 48-81). The PLIF level was L3/4 in 2 patients, L4/5 in 7 patients and L5/S1 in one patient. The median follow-up duration was 48 months (range, 17 to 96).

3D porous titanium alloy cage group (3DTA group)

Between November 2017 and June 2019, 10 patients underwent one level PLIF using a 3D porous titanium alloy cage (TM Ardis, ZimVie, USA) for lumbar spondylolisthesis (Table 1). The 3D porous titanium alloy cage serves as an osteoconductive scaffold for bone growth into the implant material and vascularization. There were 5 men and 5 women with a median age at surgery of 73 years (range, 48-84). The PLIF level was L3/4 in one patient, L4/5 in 6 patients and L5/S1 in 3 patients. The median follow-up duration was 20 months (range, 12 to 30).

Table 1.

	PK group	3DTA group
Patients	10	10
Sex (males/females)	5/5	5/5
Median age (yrs) (range)	69 (48-81)	73 (48-84)
Number of fusion levels	10	10
L3/4	2	1
L4/5	7	6
L5/S1	1	3
Median follow up (months) (range)	48 (17-96)	20 (12-30)

Radiological assessment

We evaluated bone fusion by CT multi-planar reconstruction (MPR) at 3 days, 3 months, 6 months, and 12 months postoperatively. Screw loosening was defined as having a clear zone around the screw on CT. Corrective loss was defined as an increase in slip of 3 mm or more or an increase in kyphosis of 5° or more. We assessed and defined cage subsidence as cage entry into the vertebral endplate of 3mm or more. We examined the sagittal and coronal planes of the CT-MPR carefully to identify any vertebral endplate cysts, a finding suspicious for a delayed union. Since the TM Ardis cage causes metal artifacts on CT, we employed SEMAR (single-energy metal artifact reduction) software to assess bony union. A solid fusion was defined as the presence of bridging bone within and around the cage both on the coronal and sagittal MPR CT images.

Statistical analysis

We adjusted the Mann-Whitney U-test and Fisher's exact test to compare the PK and 3DTA groups. Significance was defined as $P < 0.05$.

RESULTS

There were no significant differences in surgical time, total blood loss and bony union between the two groups (Table 2). One patient without bony

Table 2.

	PK group	3DTA group	*p* value
Median surgical time	203 min	202 min	0.81
Median total blood loss	130 ml	243 ml	0.13
Bony union	8 of 10 cases	10 of 10 cases	0.47
Median bone fusion periods	6.0 months	6.0 months	0.81
Screw loosening	0	0	
Correction loss	0	0	
Cage subsidence	5	3	0.65
Vertebral endplate cyst	1	0	0.79
Deep wound infection	0	0	
Neurological deficit	0	0	
Proximal junctional Kyphosis	2	1	> 0.99

Fig. 1. Postoperative CT

union was a 64-year-old man with diabetes mellitus. The other was a 48-year-old male heavy smoker. In the 3DTA group, all patients had bony fusion within one year. There was no screw loosening or correction loss in either group. Cage subsidence occurred in 5 cases in the PK group and 3 cases in the 3DTA group. Vertebral endplate cyst occurred in one case in the PK group. No patient developed deep wound infection or neurological deficit after surgery. Proximal junctional kyphosis occurred in two patients in the PK group and one patient in the 3DTA group after surgery. No statistically significant differences were found in any of the survey items.

Case presentation 1

A 66-year-old man suffered from back pain and sciatica on the right side. He was diagnosed with lumbar spinal canal stenosis on MRI and treated conservatively without symptomatic improvement. Preoperative blood biochemistry tests were normal. He underwent PLIF at the L5/S1 level using 3D porous titanium alloy cages. Bone fusion around the cages was already visible at 3 months postoperatively (Fig 1). At 6 months postoperatively, bone fusion was complete with no signs of screw loosening, cage subsidence, or a vertebral endplate cyst.

Case presentation 2

A 64-year-old man suffered from back pain and sciatica on the bilateral side. He was diagnosed with lumbar degenerative spondylolisthesis on radiograph and MRI. He had been treated for diabetes. He underwent PLIF at the L4/L5 level using 3D porous PEEK carbon cages. Cage subsidence was visible at 3 months postoperatively (Fig 2). At 3 years postoperatively, bone fusion was not achieved with a vertebral endplate cyst.

DISCUSSION

In this study, all patients in the 3DTA group achieved bone fusion within one year, however two patients in the PK group failed to achieved bone union. Median bone fusion periods were 6.0 months in the PK group and 6.0 months in the 3DTA group. These bone fusion rates and periods are not significantly different. Two patients in the PK group failed to achieve bone union: one was a diabetic and the other a heavy smoker. In vivo preclinical animal studies, showed 3D-printed porous, biomimetic titanium-alloy interbody spacers facilitated greater total bony ingrowth at 6 weeks and greater bony ongrowth postoperatively at both 6 and 12 weeks compared to solid PEEK and titanium-alloy implants[9]. Tanida *et al*. reported that the postoperative bone union rate after lumbar interbody

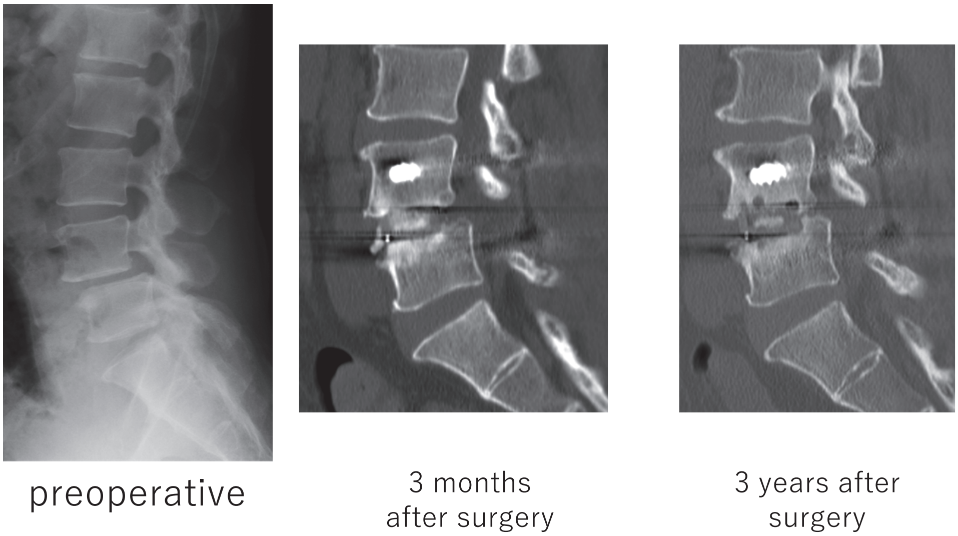

Fig. 2. Preoperative radiograph and postoperative CT

fusion was 75.2% and 74.5% at 1 year, and 82.8% and 80.4% at 2 years for Titanium and PEEK cage groups, respectively[6]. They concluded that the bone union rate after lumbar interbody fusion did not differ significantly between the two groups[6]. Nemoto *et al*. showed fusion rates of 100% and 76% at 24 months for Titanium and PEEK cage groups, respectively[5]. They concluded that the bone union rate after lumbar interbody fusion differed significantly between the two groups[5].

In this study, cage subsidence occurred in 5 cases in the PK group and 3 cases in the 3DTA group. Cage subsidence was less in the 3DTA group than in the PK group, but there was no statistical difference. Risk factors for cage subsidence include osteoporosis and intraoperative endplate injury. In the current study, there were no differences in age, gender, fixed level, or activity between the PK and 3DTA groups. Nemoto *et al*. observed cage subsidence at 24 months in 8 of 23 patients (35%) in their Titanium group and 7 of 25 patients (28%) in their PEEK group, but the difference was not significant ($p = 0.613$)[5]. Meta analysis showed a statistically significant higher subsidence rate in titanium vs. PEEK cages[10].

The disadvantage of using a titanium cage is the difficulty in determining bone fusion with conventional CT. Single Energy Metal Artifact Reduction (SEMAR) is a raw-data based technique that minimizes metal artifacts by segmenting the metal implant in the image domain followed by forward projection to produce metal-free projection data[11]. In the present study, our use of SEMAR software reduced metal artifacts and facilitated bone fusion determination.

The current study has several limitations. First, selection bias existed because of the single-site study. Second, the sample size was relatively small. All patients in the 3DTA group achieved bone fusion within one year, however two patients in the PK group failed to achieved bone union. Additional studies with a larger number of cases may result in significant differences. Third, we did not consider the presence or absence of osteoporosis and its treatment in the patients.

In conclusion, all patients in the 3DTA group achieved bone fusion within one year, and the time to bone fusion tended to be shorter than in the PK group. The 3D porous titanium alloy cage can be expected to achieve bone fusion as good as the PEEK cage in single level PLIF surgery.

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