Original Article

Standalone titanium/polyetheretherketone interbody cage for anterior lumbar interbody fusion: Clinical and radiological results at 24 months

ABSTRACT

Context: Anterior lumbar interbody fusion (ALIF) is a common procedure for patients suffering degenerative, deformity, or posttraumatic pathologies of the lumbar spine.

Aims: The aim of this study is to evaluate the clinical and radiological outcomes of a combination Titanium/Polyetheretherketone (Ti/PEEK) 3-screw fixation ALIF cage.

Settings and Design: This was a prospective multisurgeon series of 87 patients (105 implants), with a minimum 24-month follow-up. Twelve patients (12/87) were supplemented with posterior percutaneous pedicle screw fixation for additional stability for pars defect spondylolisthesis correction. Radiological follow-up with fine-cut computed tomography (CT) scan occurred at 4–6 months, and again at 18–24 months if no fusion observed on initial CT, was performed to evaluate early and final fusion rates, and integration of the Ti/PEEK cage at the end-plate junction. Clinical follow-up included the subjective measures of pain and functional status and objective wearable device monitoring.

Results: The fusion rate was 85% (97/105 implants) 6 months postoperatively, with no implant-related complications, and 95% at 24 months, based on independent radiological assessment. Patients experienced statistically significant improvement in subjective pain and functional outcomes compared to preoperative status. The objective measures revealed a daily step count with a 27% improvement, and gait velocity with a mean increase from 0.97 m/s to 1.18 m/s, at 3 months postoperatively.

Conclusions: A Ti/PEEK cage, with allograft and bone morphogenetic protein-2 (BMP-2), achieved rapid interbody progression to fusion and is an effective implant for use in anterior lumbar surgery with high early fusion rates and no peri-endplate lucency. Supercritical CO_2 allograft provided an osteoconductive scaffold and combined well with BMP-2 to facilitate fusion.

Keywords: Anterior lumbar interbody fusion, bone morphogenetic protein-2, integral fixation, polyetheretherketone, supercritical CO2 allograft, titanium

INTRODUCTION

Bony fusion has a considerable impact on the clinical outcomes of spinal fusion.[1-5]

A composite Titanium (Ti) Polyetheretherketone (PEEK) device aims to enhance fusion by harnessing the advantages of both materials: a device with sufficient compliance and fusion similar to that of PEEK, coupled with the ability of appropriate flexibility and resistance in excessive motion once implanted.[6,7] This article aims to assess the radiological and clinical outcomes of anterior lumbar interbody fusion (ALIF)

Access this article online	
Website: www.jcvjs.com	Quick Response Code
DOI: 10.4103/jcvjs.jcvjs_133_21	

Ralph J. Mobbs[1,2,3,4], Tajrian Amin[1,2,3,4], Kevin Phan[1,2,3,4], Darweesh Al Khawaja[5], Wen Jie Choy[1,2,3,4], William C.H. Parr[1,2,3], Vedran Lovric[1,2], William R. Walsh[1,2,3]

[1]Faculty of Medicine, University of New South Wales (UNSW), [3]NeuroSpine Surgery Research Group (NSURG), [5]Nepean Neurosurgery, Nepean, Sydney, [2]Surgical Orthopedic Research Lab (SORL), Prince of Wales Hospital, [4]NeuroSpine Clinic, Prince of Wales Private Hospital, Randwick, Australia

Address for correspondence: Dr. Tajrian Amin, Prince of Wales Private Hospital, 320-346 Barker Street, Randwick, NSW 2031, Australia.
E-mail: tajamin1998@gmail.com

Submitted: 17-Oct-21 **Accepted:** 28-Oct-21
Published: 09-Mar-22

How to cite this article: Mobbs RJ, Amin T, Phan K, Al Khawaja D, Choy WJ, Parr WC, *et al*. Standalone titanium/polyetheretherketone interbody cage for anterior lumbar interbody fusion: Clinical and radiological results at 24 months. J Craniovert Jun Spine 2022;13:42-7.

surgery using a Ti/PEEK cage [Figure 1] and supercritical fluid treated allograft (Australian Biotechnologies, Sydney, Australia) combined with bone morphogenetic protein-2 (BMP-2).

MATERIALS AND METHODS

Ethics approval

This research has been approved by the Institutional Review Board of the authors' affiliated institution.

Patient data

Over a 15-month time period, 87 patients with 105 ALIF levels performed, were operated and data prospectively collected. There were 75 patients who had stand-alone ALIF with integral fixation [Figure 2], and 12 with additional posterior percutaneous pedicle screw fixation [Figure 3]. There were 46 males and 41 females, with a mean age of 54 years (range, 28–82). There were 13 smokers, 17 diabetics (Type 2) and 11 workers compensation cases. The inclusion criteria were persistent back pain and/or radiculopathy, unresponsive to prolonged conservative treatment and pain specialist review who deemed that ongoing pain management and injection therapies were not appropriate. The specific indications for surgery included: Three re-recurrent (multiple) disc herniation; Three isthmic spondylolisthesis; two with degenerative scoliosis; and nine with discogenic low back pain. All patients presented with a combination of mechanical back pain and/or radiculopathy related to foraminal stenosis or re-recurrent disc herniation. The mean preoperative symptom length was 16 months (range, 5–57 months).

Surgical procedure

All patients were operated on by one of two surgeons and the interbody device used was a Ti/PEEK ALIF "Redmond" x3 screw device (A-Spine ASIA, Taipei, Taiwan). All patients underwent an open ALIF technique, using an anterior approach to the lumbosacral spine. A vascular surgeon assisted with the approach in all procedures. Heparin was not used during the procedure. The incision varied on the approach level, and the number of levels performed, with a mini Pfanenstiel incision used for access to the L5/S1 level, and a midline vertical incision used for other levels and multilevel approaches. A left-sided retroperitoneal dissection and exposure of the affected anterior vertebral disc and retraction with an Anterior Frame (Phantom AL, TeDan Innovations, USA) were performed. In all cases, the left ureter was identified and retracted medially. Major anterior vessels (Aorta and iliac veins/arteries) were mobilized and retracted. The level of pathology was confirmed with X-ray before disc removal [Figure 2], and endplate preparation. Decortication of the vertebral endplates was performed to optimize the bone-graft interface. A trial cage was inserted to confirm the height of the disc space. A x3 Screw Ti/PEEK ALIF cage [Figure 1] was packed with bone

Figure 1: Titanium/polyetheretherketone Integral fixation 3-screw Anterior Lumbar Interbody Fusion Implant. Porous titanium endplates with Polyetheretherketone forming the body of the implant. ×3 screw integral fixation.(Redmond-L Implant, A-Spine ASIA, Taiwan)

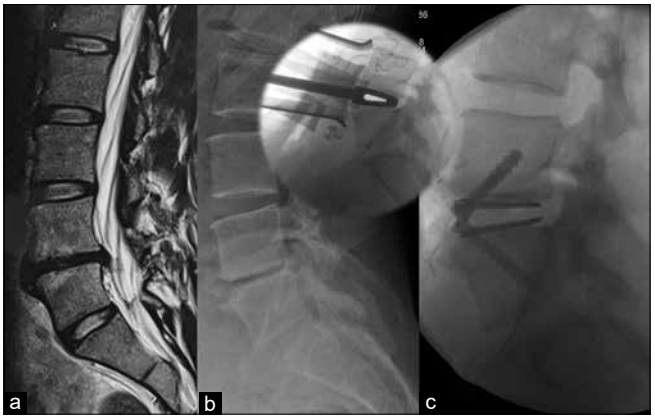

Figure 2: L4/5 Anterior Lumbar Interbody Fusion. (a) Severe degenerative disc disease following multiple microdiscectomy procedures with progressive disc height loss, foraminal stenosis with symptoms of discogenic low back pain and L4 radiculopathy. (b) Preoperative lateral X-ray. (c) L4/5 Anterior Lumbar Interbody Fusion with Titanium/Polyetheretherketone device.(Insert) Intraoperative trial prosthesis

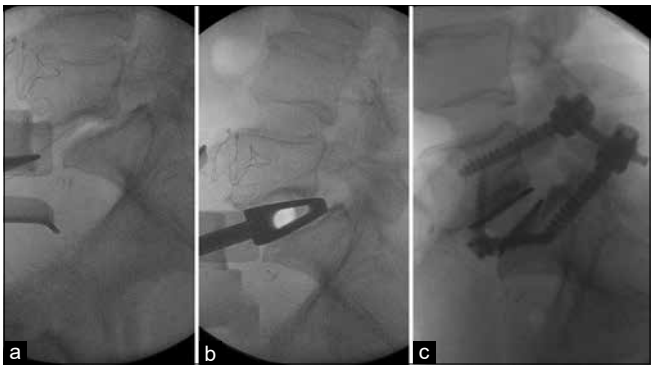

Figure 3: Anterior Lumbar Interbody Fusion with Percutaneous Pedicle Screw Fixation. (a) Intraoperative level check. (b) Trial prosthesis to confirm position and restoration of foraminal volume. (c) Percutaneous fixation to assist with posterior tension band

graft, inserted and fixated with integral screws. Intraoperative X-ray was used to confirm correct placement and antibiotic irrigation was used prior to closure.

Interbody graft

Allograft Supercritical CO_2 ($SCCO_2$) sterilized "crunch" from a local supplier, ("Allovance," Australian Biotechnologies, Sydney, Australia) was used along with BMP-2 (INFUSE, Medtronic) and included collagen sponge. A small dose (4.2 mg rhBMP-2) was used for each level performed. The BMP-2 was mixed evenly throughout the Allograft preparation. Fourteen patients had a combination of $SCCO_2$ Allograft and demineralised bone matrix Fibers (Australian Biotechnologies, Sydney, Australia), without BMP based on patient preference to avoid perceived issues with Bone Morphogenetic Proteins [Figure 4].

Outcome measures

Radiographic fusion was assessed by an independent radiologist. Plain radiographs were performed at day 1 and 6 weeks postoperative for radiographic assessment of the interbody device to confirm no implant failure or movement from the implantation position. Computed tomography (CT) scan was performed at the 4–6 months mark to assess early fusion status both through, and around, the implant and evaluating for lucency of the porous titanium endplates. Fusion was considered successful if bridging bone incorporating the graft and adjoining endplates in and around the cage aperture was apparent [Figure 5], with additional loss of radiolucency, restoration of interbody space and no hardware failure.

The clinical outcome was assessed using a variety of parameters, both subjective and objective.

The subjective measures included Visual Analog Scale (VAS) pain scores and Patient Satisfaction Index (PSI). Patients were asked to quantify their overall pain score (VAS) ranging from 0 (no pain/discomfort) to 10 (worst pain/discomfort imaginable) pre- and postoperatively. Patient satisfaction with their procedure was elicited using the PSI as described by Palit *et al*.[8] at the final follow-up.

The objective outcome measures were included for the later part of the study period. Step count preintervention and up to 3-month postoperative was recorded using MiBand-2 (Xiaomi, China) and average Gait Velocity (GV) (timed distance travelled by trained assessor).

Statistical analysis

Descriptive data are represented as means ± standard deviation (range, minimum–maximum). All the data sets were tested for normality with the D'Agostino and Pearson omnibus normality test. Nonparametric data were analyzed using the Mann–Whitney *U*-test and parametric unrelated data with the unpaired *t*-test for comparison of the results. A paired *t*-test was used for comparison between pre- and postoperative continuous variables within patient groups. Statistical significance was set at level of $P < 0.05$. All analyses and graphs were generated using a commercial software package (Graph Pad Prism version 5.01, GraphPad Software, Inc., USA).

RESULTS

From 87 patients in the original dataset, all 87 patients were available for follow-up observation with adequate data points of radiological and clinical follow-up at 24 months. The average

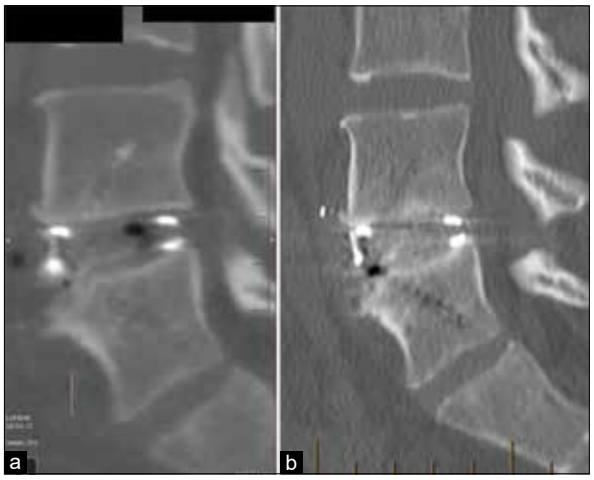

Figure 4: L4/5 Anterior Lumbar Interbody Fusion. Solid fusion at 6-month postoperative using Allograft and Fibermatt Demineralized-Bone-Matrix graft. (a) Day-1 Postop computer tomography. (b) 6-month Postop Computer Tomography with osseointegration through and behind implant. No halo/lucency at Titanium/bone junction; consistent with Ttanium incorporation into bony endplate. No subsidence

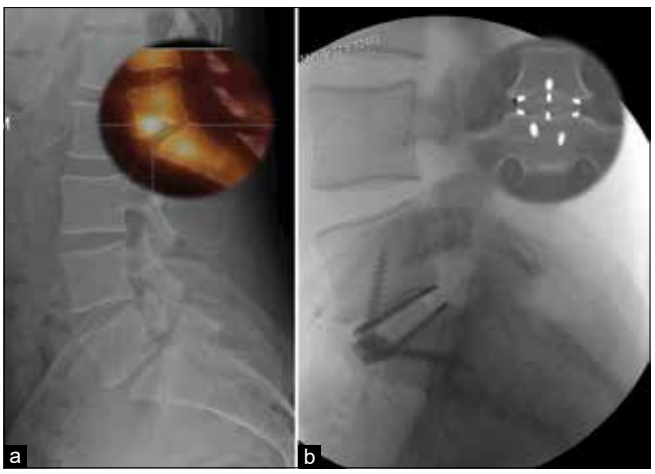

Figure 5: Stand alone Anterior Lumbar Interbody Fusion for Isthmic Spondylolisthesis. (a) Standing X-ray. Degenerative Disc Disease with low-grade spondylolisthesis and pars defect. *Insert*. Discovertebral uptake on bone scan. (b) 6-month postoperative X-ray and (*Insert*) computer tomography demonstrating restored disc height, evidence of early graft integration and no subsidence or lucency

length of stay was 4.3 days (range 1–7 days). The average operative time was 79 min, with an average blood loss of 90cc. Clinical data were collected independently by a practice nurse and research team with no bias of reporting. Both subjective (VAS, PSI) and objective, using wearable activity monitors (Mi-Band-2, Xiamoi, China) outcome scores were collected.

Radiological outcomes

An 87% radiographic fusion rate (91/105 implants) was achieved at 6 months postoperatively and 94% (99/105 implants) at 24 months. The 3/6 nonunion patient was deemed to have a "locked nonunion" with improvement in preoperative clinical symptoms, and therefore, no further intervention, or surgery, was necessary. Three patients had revision of their fusion through a posterior approach. Twelve ALIF implants demonstrated subsidence of more than 2–3 mm. There were no cases of graft or implant migration and no screw backout or breakage.

Comparison of Visual Analog Scale pain scores

Overall pain scores as measured by VAS showed significant improvement ($P < 0.0001$) when compared with the preoperative scores. Overall combined back/leg pain improved on average from 7.1 preoperatively to 1.8 postoperatively, with a mean improvement of 5.7 ± 2.1 (range, 1–9).

Patient satisfaction index

At 6 months postoperative, 80/105 patients achieved either excellent or good outcomes according to the PSI criteria and 92/105 patients by 24 months. Two patients self-classified as a poor outcome due to significant postoperative complications related to cardiac issues and hip pathology requiring total hip arthroplasty in another patient that was identified post-ALIF.

Objective outcome assessment

Forty-seven patients had objective activity data collected with an overall 27% improvement at 3 months in step count post-ALIF, with GV pre and post intervention measurements evaluated with an increase in GV from a mean of 0.97 m/s to 1.18 m/s.

Complications

There were no cases of retrograde ejaculation in the male cohort. Ileus was experienced in two patients, both with two level ALIF procedures. There were no wound-related complications and no blood transfusions were necessary. A single patient had a myocardial infarct 72 h postsurgery and required further cardiac management.

DISCUSSION

Autograft is still widely considered as the gold standard in lumbar fusion.[9] A Cochrane systematic review concluded that fusion techniques utilizing autograft yielded higher fusion rates than allograft and synthetic bone substitute techniques; however, other outcomes were not able to be assessed due to the lack of standardized outcome measures within the literature.[10] Hence, donor site morbidity associated with autograft has fueled the growing interest in alternative bone grafting materials,[11] namely ceramics, as fusion substrates for lumbar arthrodesis. In this study, the combination of a Ti/PEEK cage with allograft and BMP-2 proved to be an effective and safe materials combination, resulting in significant improvements in pain and function.

Interbody cage properties

PEEK, a radiolucent semi-crystalline polyaromatic linear polymer and thermoplastic material, has the properties of high-molecular weight, whilst being biologically inert and nonresorbable,[12] with long clinical history.[13] Using a host in a rat air pouch model, Moore and Rhoad demonstrated PEEK elicits minimal cytotoxicity and inflammatory response.[14] In addition, other biomechanical properties of PEEK include resistance to radiation and chemical damage, compatibility with various reinforcing agents (e.g., titanium and carbon fiber) and reasonably greater strength (per mass basis) than many metals.[13] Hence, PEEK cages provide a hard frame which can withstand spinal loading. The elastic modulus of PEEK is 3.5 GPa, which is comparable to that of cortical bone in the range of 15–20 GPa and cancellous bone at 1 GPa,[7] which is likely to minimize graft subsidence.[15] Despite remodeling of bone graft within the implant cavity, spinal alignment can be maintained. However, some studies have described suboptimal osseointegration of PEEK at the adjacent vertebral endplate following implant insertion. A "PEEK-Halo" effect was seen on CT at up to 12 months following an ALIF procedure, delineated by a radiolucent rim on axial view.[16] The peri-implant halo likely indicates the presence of fibrous tissue interface surrounding the PEEK implant.[17]

Titanium has the propensity to be altered to improve osseointegration. Ongrowth of the bone refers to the direct apposition of bone onto implant surface; while ingrowth requires a 3-dimensional structure with pores connecting the outside, allowing bone growth and interlocking "into" the surface of an implant. Additional modifications of implants are targeted at influencing the way tissues incorporate and interact with the implant material. The combination of these two biomaterials has the advantage of the modulus of elasticity of PEEK with the on growth benefits of porous Titanium. *In vitro* studies have demonstrated that Ti/PEEK implants have superior cell attachment, proliferation, and osteoblastic differentiation compared to pure PEEK substrates.[17,18] It was suggested that Ti/PEEK implants may

provide better biocompatibility compared to pure PEEK substrates. Bone ongrowth to titanium is well established[19] as well as titanium-coated PEEK.[13,20] This study further supports this combination of these biomaterials to assist in the fusion process following the ALIF procedure when used in combination with allograft and an inductive factor BMP-2.

Posterior stabilization/fixation

The use of posterior fixation may further reduce micromotion between the graft-host interface, promoting graft settling, however increasing operative time, risks, and costs.[21] Whilst posterior fixation with facet and pedicle screws is commonly employed to stabilize fusions, there have also been reports of associated morbidity, namely instrumentation failure.[22] We believe that there is a role for additional posterior fixation in pathologies such as isthmic spondylolisthesis, osteoporosis, and multilevel procedures.[23,24]

It is the author's expectation that with bioactive endplate technologies, cage integration with the adjacent endplate is more rapid as compared with PEEK cages alone, therefore reducing the necessity for additional posterior fixation. In our series, there was one case of L5/S1 low grade spondylolisthesis with bilateral pars defects managed with integral fixation alone [Figure 5] and two cases of spondylolisthesis Grade 1+ requiring percutaneous fixation with pedicle screws. The combination of a Large implant (Redmond-L, A-Spine ASIA, 43 mm × 32 mm dimensions), with rigid initial fixation and porous Titanium endplates resulted in an excellent early radiological and clinical result, avoiding the need for additional posterior fixation in the majority of cases.

Limitations

A chief limitation of this study is the relatively small numbers involved. The assessment of interbody fusion and the integration of the titanium endplate remains a challenge. As there are no universally accepted criteria for determining radiological fusion, it is often difficult to arrive at a true assessment of fusion based on plain radiography alone particularly when synthetic cages are utilized. Fine-cut CT scans with reconstruction have been shown to be more reliable and sensitive for the detection of pseudoarthrosis than plain radiography;[25,26] therefore, this technique was instituted in all patients.

CONCLUSIONS

In this study, we have found that utilizing an ALIF Ti/PEEK interbody cage containing Allograft and 4.2 mg BMP-2 per level, in one and two level ALIF procedures, proved to be an effective treatment for low grade lumbar isthmic spondylolisthesis, spondylotic radiculopathy, and discogenic low back pain. There were no cases of lucency or halo adjacent to the Titanium endplates at the 6-month postoperative mark, consistent with bone/Porous Titanium incorporation. Bioactive conversion of PEEK cages with Porous Titanium alloy endplates is likely to assist with early integration of the prosthesis with the surrounding bone/vertebral endplate.

Both animal studies and evolving human data on rapid osseointegation of bioactive implant surfaces is promising and may one day lead to implant technology relying on the device alone, without addition of bone grafting. It is likely that achieving bone integration with the interbody implant will aid in fusion and improve implant longevity by limiting subsidence as well as stress shielding and associated complications. Surface modification and/or conversion of implant surfaces into bioactive areas are intended to improve ingrowth and ongrowth, bringing with it associated clinical benefits.

Acknowledgments

The authors would like to thank The NeuroSpine Surgery Research Group (*NSURG)* which aided with manuscript production. The *NeuroSpineClinic*, Sydney Australia, provided clinic assistance for authors.

Financial support and sponsorship

Nil.

Conflicts of interest

Prof Ralph J. Mobbs is a research and design consultant for A-Spine ASIA. Prof William R. Walsh is a research and design consultant for SeaSpine, USA. Dr William C.H. Parr is founder and director of 3DMorphic Pty Ltd, Sydney, Australia. None of the other authors have any relevant conflicts of interest to declare.

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