

Design and fabrication of a lumbar interbody fusion spine cage combining titanium and peek materials

Yudan Whulanza^{a,c,1}, Sugeng Superiadi^{a,c}, Erry Dwi Prasetyanto^{b,c}, Puspita Anggraini Katili^{b,c},
Tri Kurniawati^{d,e}, A.J. Rahyussalim^{d,e}

^aDepartment of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424

^bDepartment of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424

^cResearch Center for Biomedical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424

^dDepartment of Orthopaedics and Traumatology, Faculty of Medicine Universitas Indonesia, Cipto Mangunkusumo Hospital, Jakarta

^eStem Cell and Tissue Engineering Research Cluster IMERI Faculty of Medicine Universitas Indonesia, Jakarta, Indonesia

¹Email korespondensi: yudan.whulanza@ui.ac.id

Abstract. Lower back pain (LBP) is a common condition that significantly affects a patient's quality of life. One of the pathological causes of LBP is degenerative disk disease (DDD), resulting from the degeneration of the intervertebral disc (IVD). A surgical option for addressing this is transforaminal lumbar interbody fusion (TLIF), which uses an implant, a spine cage, to maintain spacing between vertebrae during bone fusion. Spine cages are commonly made from either polyether ether ketone (PEEK) or titanium, each with distinct advantages and limitations. PEEK exhibits a bone-like elastic modulus but limited osseointegration, whereas titanium offers good osseointegration but an elastic modulus much higher than bone. This study proposes a hybrid spine cage combining both materials: PEEK machined via computer numerical control (CNC) machining and titanium fabricated using selective laser melting (SLM). The cage features a banana shape, nose insertion, pins-and-holes connection system, and dimensions customized for the Indonesian lumbar morphometry. The realized prototype showed a maximum margin of 3.9% for the titanium part and 2.14% for the PEEK part. Further results showed a compressive elastic modulus of 1.36 GPa, indicating that the current model matched the mechanical properties of titanium.

Keywords: Lower back pain, degenerative disk disease, TLIF, spine cage, banana shape, PEEK, titanium, CNC machining, selective laser melting.

Received: 30 September 2025; **Presented:** 9 October 2025; **Publication:** 9 March 2026

DOI: <https://doi.org/10.71452/9j5vvz23>

INTRODUCTION

Degenerative disk disease (DDD) is a pathological condition characterized by structural and biochemical changes in the intervertebral disc (IVD). Although it is a natural aging process, DDD more commonly affects the lumbar region than the thoracic or cervical spine [1]. Lumbar DDD is closely associated with lower back pain (LBP), often caused by nerve compression [2-3]. In 2020, the Global Burden of Disease study reported that 619 million people suffered from LBP, a number projected to reach 843 million by 2050 [4-5].

One curative intervention for lumbar DDD is lumbar interbody fusion (LIF), where one or more lumbar vertebrae are fused by removing the IVD and inserting a spine cage [6]. LIF procedures include ALIF, OLIF, LLIF, TLIF, and PLIF. TLIF is gaining popularity due to its minimally invasive approach and faster postoperative recovery [7]. Banana-shaped cages offer improved outcomes in restoring disc height and lordosis compared to straight designs [8].

METHODOLOGY

Design of Implant

The design process commenced by defining the required dimensions and parameters, which were adapted from the study by Faadhila et al., which

Most TLIF cages are made of either PEEK or titanium. PEEK closely matches the elastic modulus of bone but lacks osseointegration and compressive strength. Titanium, in contrast, offers high osseointegration and strength but induces stress shielding due to its stiffness [9]. Combining both materials into a hybrid spine cage offers a balanced solution—optimal stiffness and improved osseointegration [10-11]. This concept has been explored by Lim et al. though their designs are typically straight-shaped. Faadhila et al. introduced a banana-shaped cage based on Indonesian lumbar morphometry, which served as the dimensional reference in this study [12]. In this study, a spine cage using a combination of titanium and PEEK materials is observed. The geometrical observation and compressive elastic modulus were reported.

provided spine cage measurements based on lumbar morphometry of the Indonesian population. Geometric modeling was performed using Autodesk Fusion 360. The design files were subsequently converted into G-code format using Voxeldance for Selective Laser

Melting (SLM) and Emcotronic TM 02 for CNC machining.

Table 1. Spine cage parameter and dimension

Parameter	Dimension
Length	27.7 mm
Width	8.8 mm
Height	11 mm
Lordosis Angle	7°
Nose Incline	36.5°

Implant Fabrication

The implant fabrication process was carried out to produce a final product that met the intended design specifications. Two manufacturing methods were employed: Selective Laser Melting (SLM) for the titanium component and Computer Numerical Control

(CNC) machining for the PEEK component. The SLM process was conducted using the Truprint-2000 system (Trumpf, Germany) with grade 5 titanium powder as the feedstock material. CNC machining was performed on the EMCO VMC-200 machine using a 30 mm-diameter PEEK rod.

Table 2. Material data

Material	Density (g/cm ³)	Poisson Ratio	Elastic Modulus (GPa)	Tensile Strength (MPa)	Compressive Strength (MPa)
PEEK	1.34	0.37	3.7	96	170
Ti6Al4V	4.43	0.33	114	1100	1070

Compression Testing

Compression tests were performed using an A&D Tensilon RTF-2350 machine with a displacement rate

of 10 mm/min. Specimens were tested with and without stainless steel loading blocks to ensure even pressure distribution.

RESULTS AND DISCUSSION

Design Of Implant

The spine cage design was developed using parameters and dimensions derived from the study by Faadhila et

al. (Table 1) and modelled in Fusion 360, as illustrated in Figure 1. Several additional features were incorporated into the original design, including porous structures on the superior and inferior surfaces and a central cavity for bone graft placement.

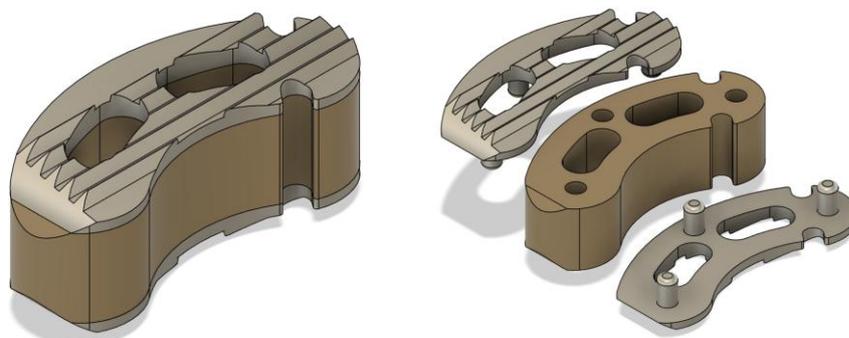


Figure 1. The spine cage design is shown in various perspectives.

Fabrication of a Titanium Component

Titanium fabrication was carried out using the Selective Laser Melting (SLM) technique at the Science Techno Park (STP), Universitas Indonesia.

The SLM process was performed using the Truprint-2000 system. The realization of the titanium part shown in Figure 2, together with the measurement.

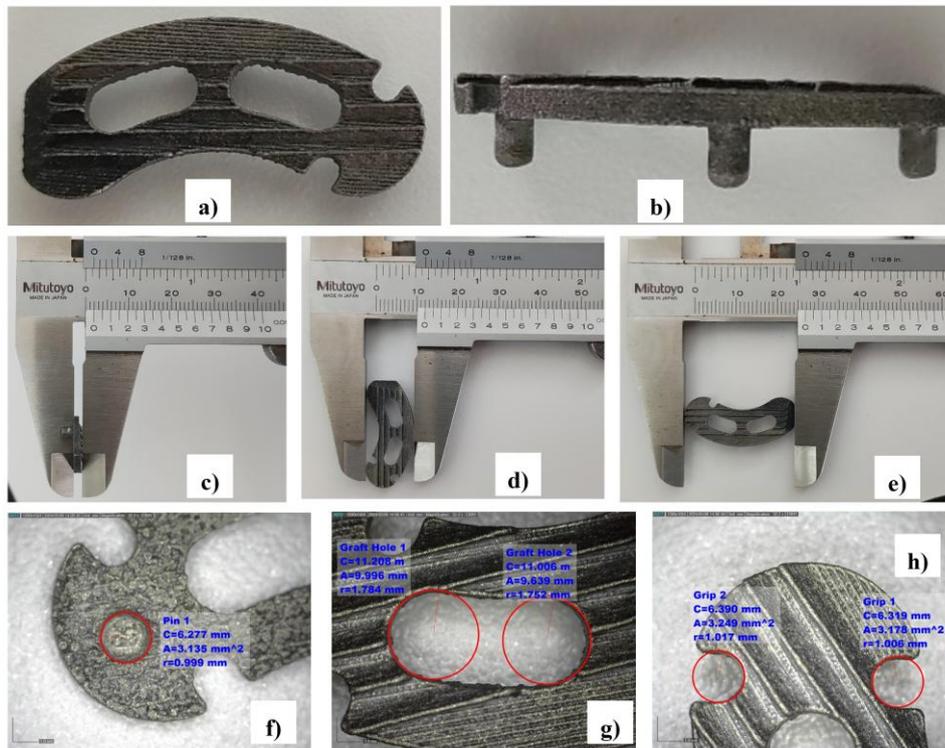


Figure 2. The titanium component is shown in: a) top view, b) side view, c) thickness measurement, d) width measurement, e) length measurement, f) pin feature, g) graft hole feature, and h) grip feature.

Table 3. Dimensional differences between the design and the fabricated titanium component.

Feature	Size (mm)		Margin %
	Design	Realized	
Length	26.80	26.75	0.19%
Wide	8.80	8.85	0.57%
Outer height	1.50	1.45	3.33%
Inner height	0.96	1.00	3.95%
Pin 1	1.00	0.99	0.10%
Pin 2	1.00	1.01	0.80%
Pin 3	1.00	1.02	2.40%
Graft hole 1	1.75	1.78	1.94%
Graft hole 2	1.75	1.75	0.11%
Graft hole 3	1.75	1.77	0.97%
Graft hole 4	1.75	1.77	1.14%
Grip 1	1.00	1.01	0.60%
Grip 2	1.00	1.02	1.70%

Fabrication of the PEEK Component

The PEEK component was successfully fabricated by CNC machining, using a 30 mm-diameter PEEK rod

as the base material. To accommodate the small, intricate features of the implant specimen, endmills with diameters of 2 mm and 6 mm were used. The CNC

machining was performed in the Manufacturing Laboratory using an EMCO milling machine.

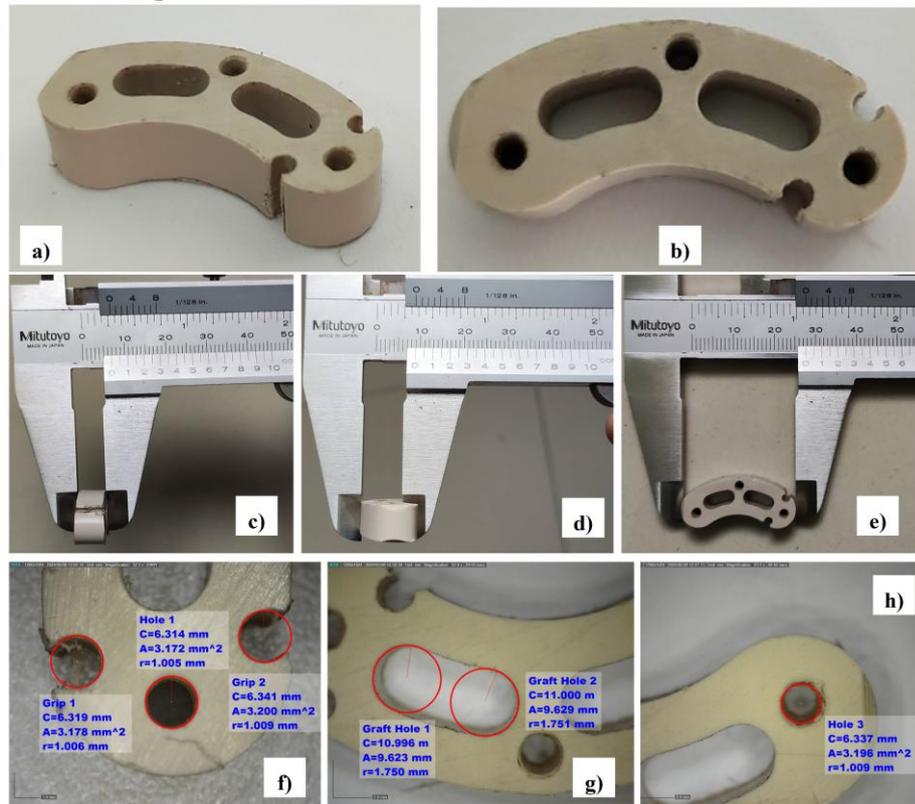


Figure 3. The PEEK component is shown in: a) isometric view, b) top view, c) thickness measurement, d) width measurement, e) length measurement, f) grip feature, g) graft hole feature, and h) pin hole feature.

Table 4. Dimensional differences between the design and the fabricated PEEK component

Feature	Size (mm)		Margin Error, %
	Design	Realized	
Length	27.70	27.60	0.36%
Wide	8.80	8.85	0.57%
Height	7.00	6.85	2.14%
Hole 1	1.00	1.01	0.50%
Hole 2	1.00	1.01	0,60%
Hole 3	1.00	1.01	0,90%
Graft hole 1	1.75	1.75	0,00%
Graft hole 2	1.75	1.75	0,06%
Graft hole 3	1.75	1.76	0,29%
Graft hole 4	1.75	1.76	0,46%
Grip 1	1.00	1.01	0,60%
Grip 2	1.00	1.01	0,90%

Assembly of Titanium and PEEK Components

The titanium and PEEK components were assembled by inserting Pin 1 into Hole 1, Pin 2 into Hole 2, and Pin 3 into Hole 3. The titanium part exhibited

unevenness on its bottom surface, which is in contact with the PEEK component's top surface. As shown in Figure 4c, this uneven surface created a curvature that resulted in a visible gap near the grip area.

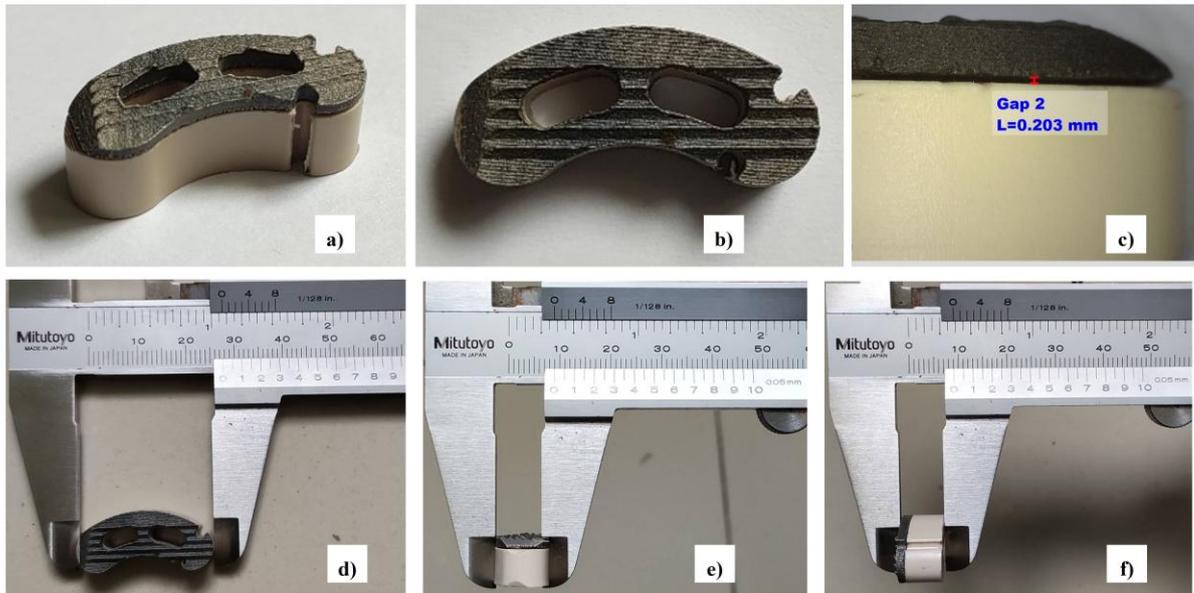


Figure 4. Produk penggabungan tampak: a) isometri, b) atas, c) pengukuran gap, d) pengukuran panjang, e) pengukuran lebar; dan f) pengukuran ketebalan.

Table 5. Height discrepancy between the design and the assembled PEEK–titanium component.

Bagian	Ukuran		Error
	Desain	Realisasi	
Tinggi Lingkar Luar	8.50	8.90	4.71%
Tinggi Lingkar Dalam	8.00	8.30	3.75%

Compression Testing of PEEK Component

The first compression test was conducted on a PEEK specimen with a thickness of 6.85 mm, using a loading rate of 3 mm/min and a maximum load of 400 N. The

test was successfully carried out and is shown in Figure 5. Further analysis showed that the elastic modulus of the PEEK part is approximately 693 MPa (after linearization of the elastic segment).

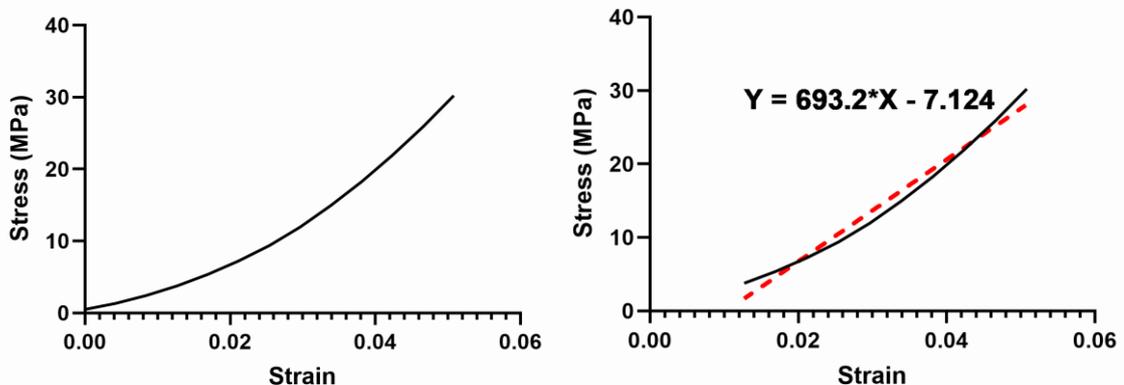


Figure 5. Results of the PEEK component testing: a) stress–strain curve, and b) extraction of the elastic region for Young’s modulus calculation.

Compression Testing of PEEK–Titanium Implant Specimens

The implant specimens feature a 3.5° incline on both the upper and lower surfaces. To accommodate this, a custom testing block (fixture) with matching 3.5° inclinations was used to ensure uniform load distribution during compression testing. The testing setup consisted of the titanium component placed on the top surface, followed by the PEEK component, and finally the stainless-steel fixture at the bottom. The

fixture was made of 17-4PH stainless steel, measuring 40 × 20 × 7 mm, and possessing an elastic modulus of 196 GPa.

Due to its high stiffness, the fixture's deformation under compressive loading is theoretically negligible, thereby minimizing interference with the test results. Compression testing was conducted on three specimens using an elongation parameter of 0.4 mm and a loading rate of 0.1 mm/min. The result of the compression test show elastic modulus of around 1.36 GPa.

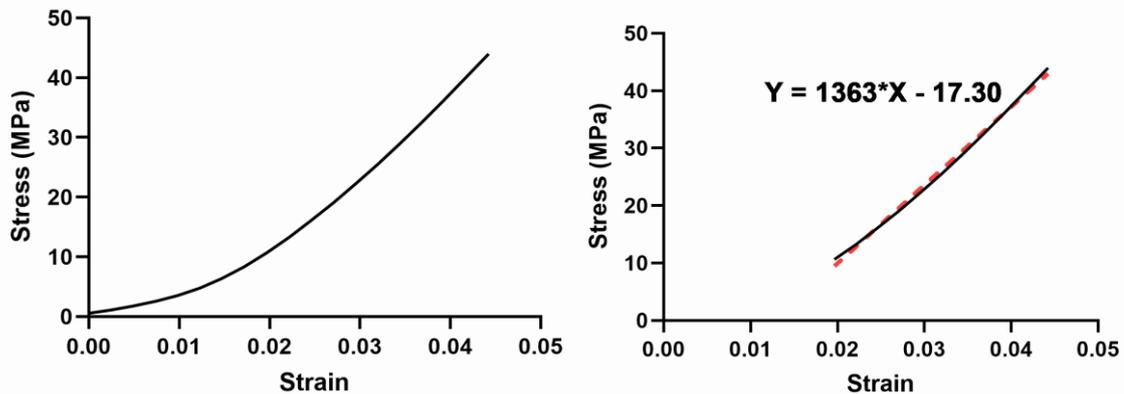


Figure 6. Results of compression testing on the hybrid titanium–PEEK implant: a) stress–strain curve, and b) extraction of the elastic region for Young's modulus calculation.

CONCLUSION

The spine cage was successfully fabricated using the Selective Laser Melting (SLM) method for the titanium component with grade 5 titanium powder, and Computer Numerical Control (CNC) machining for the PEEK component using a PEEK rod. Geometric complexity was concentrated in the titanium section, as SLM enables the production of intricate structures. Conversely, the PEEK geometry was intentionally simplified to facilitate fabrication using 3-axis CNC

machining. The SLM-fabricated titanium component exhibited a higher dimensional error margin than the CNC-machined PEEK component, particularly in specimen height. This error margin increased further when the two components were assembled, due to a gap between the titanium and PEEK surfaces. Based on compression testing, the hybrid titanium–PEEK implant achieved an elastic modulus of 1.196 GPa, whereas the PEEK-only implant yielded an elastic modulus of 0.693 GPa.

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