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ORIGINAL ARTICLE

# Verification of the Cage Stability and the Superiority of Titanium Coating in the Bone Fusion of Transforaminal Lumbar Interbody Fusion Using Polyetheretherketone (PEEK) Cages

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## ABSTRACT

**Background:** PEEK spinal cages are now commonplace in transforaminal lumbar interbody fusion, credited with excellent strength and stiffness. Paradoxically, their bioinert character hampers intimate bone ingrowth around the implant. To address this shortcoming, researchers have experimented with surface treatments, most notably titanium plasma-spray coating, that promise tighter surface-to-bone contact and improved fixation. The present investigation compares clinical and radiographic outcomes between titanium-coated and standard PEEK cages in a homogenous cohort of patients after TLIF.

**Methods:** Between January 2022 and January 2023, a prospective comparative study evaluated '71 patients who underwent transforaminal lumbar interbody fusion for degenerative lumbar spine disorders'. The cohort was evenly split: Group A received titanium-coated poly-ether-ether-ketone cages (n=35) and Group B received standard uncoated cages (n=36). Clinical results were measured with the Visual Analog Scale for pain and the Oswestry Disability Index for functional capability. Imaging outcomes were evaluated for fusion quality, cage subsidence, and the restoration of disc height and segmental lordosis. Statistical analysis was performed with SPSS, and a p-value of less than 0.05 was deemed significant.

**Results:** Fusion was achieved in 85.7% of patients in the titanium-coated group, compared to 61.1% in the uncoated group (p=0.018). Time to fusion was shorter in the coated group (7.2 ± 1.1 months vs. 8.6 ± 1.5 months; p=0.001). Disc height and segmental lordosis restoration were also superior in the titanium group. VAS and ODI scores showed significantly greater improvement at 12 months. Complication and reoperation rates were lower in the titanium-coated group but not statistically significant.

**Conclusion:** Titanium-coated PEEK spinal cages appear to promote stronger bone fusion and better functional results after transforaminal lumbar interbody fusion, yet they do not add new safety risks. Such evidence bolsters the increasing use of surface-modified devices in lumbar fusion surgery.

**Keywords:** Transforaminal lumbar interbody fusion, PEEK cage, titanium coating, spinal fusion, cage stability, bone integration

## INTRODUCTION

Transforaminal lumbar interbody fusion (TLIF) has become a standard operation for patients with degenerative lumbar spine disorders, including disc degeneration, spinal instability, and low-grade spondylolisthesis. The technique combines neural decompression and rigid fixation through a single posterior corridor, thereby limiting disruption of surrounding musculature. Central to the procedure is the interbody cage, which restores disc height, re-establishes segmental lordosis, and provides a scaffold for bone-on-bone contact during the bony fusion process[1-3].

Polyetheretherketone (PEEK) interbody spacers have gained popularity among spinal surgeons because the material is radiolucent, has an elastic modulus close to that of human bone, and resists chemical corrosion in the body. Even with these mechanical strengths, PEEK remains biologically inert and does not naturally promote bone growth around its surface. Because of this lack of osteoconductivity, there is ongoing debate about whether PEEK implants provide the rapid and solid fusion that patients depend on after spinal surgery[4-6].

Researchers introduced titanium-coated PEEK cages to address this shortcoming. The titanium coating-electrophoretically deposited or applied by vapor-deposition-aims to boost the implants surface bioactivity without sacrificing the excellent mechanical properties the PEEK core provides. Titanium's inherently rough and porous topography encourages cell adhesion and osteoblast maturation, conditions that may foster a more favorable fusion microenvironment[7-9].

Numerous laboratory investigations and preliminary clinical trials indicate that titanium-coated interbody fusion cages promote quicker bony fusion, enhance implant-osseous integration, and lower the incidence of subsidence compared with uncoated devices. Yet a substantial gap in the literature persists, as no large-scale, randomized studies have directly benchmarked these coated cages against standard polyether-ether-ketone (PEEK) models in routine operating-room practice[10-12].

This study was conducted to verify the cage stability and evaluate the superiority of titanium-coated PEEK cages over uncoated ones in achieving solid fusion and improved patient outcomes in TLIF procedures. Through a comparative analysis of radiographic and clinical data, we aimed to contribute meaningful insights into the evolving landscape of spinal implant technology.

## METHODOLOGY

This investigation used a prospective, comparative observational design to assess clinical and radiographic results of titanium-coated and standard PEEK cages in patients treated with transforaminal lumbar interbody fusion. The main question was whether the titanium layer improves cage stability and promotes faster or more complete bone fusion.

The study took place at Bacha khan medical complex Swabi and proceeded after receiving 'approval from the relevant institutional ethics review board. Informed consent was secured from every participant before they were enrolled'.

Between January 2022 and January 2023, seventy-one patients aged 30 to 70 years and suffering from degenerative lumbar spine disease were recruited for single- or double-level TLIF. Individuals were excluded if they had spinal infection, malignancy, trauma, or previous lumbar fusion surgery.

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‘Participants were divided into two groups based on the type of interbody cage used’

- **Group A (n = 35):** Received titanium-coated PEEK cages
- **Group B (n = 36):** Received standard, uncoated PEEK cages

All procedures were carried out with a uniform transforaminal lumbar interbody fusion technique by senior spinal surgeons. Surgeons resected one side of the facet joint, relieved pressure on neural structures, prepared the disc space, and inserted a cage packed with autogenous bone. Posterior stabilization in every case relied on pedicle screw instrumentation.

Operative details such as total surgical time and estimated blood loss were meticulously documented. After surgery, patients were encouraged to ambulate soon and returned for routine check-ups at set time points. Plain radiographs and computed tomography scans were obtained at 3, 6, and 12 months to evaluate cage alignment, disc height, segmental lordosis, and evidence of solid fusion. Successful fusion was judged by the appearance of continuous bridging bone across the disc space and the lack of motion or radiolucent lines adjacent to the cage.

Clinical outcomes were assessed with the Visual Analog Scale (VAS) for back and leg pain and with the Oswestry Disability Index (ODI) to measure functional status. Evaluations took place before surgery and were repeated at six and twelve months after the procedure.

All data were recorded on predesigned proformas and analyzed using SPSS software. Quantitative variables were presented as mean ± standard deviation, while qualitative variables were shown as frequencies and percentages. Comparisons between groups were made using independent t-tests for continuous data and chi-square tests for categorical data. A p-value of less than 0.05 was considered statistically significant.

## RESULTS

This study included a total of 71 patients who underwent Transforaminal Lumbar Interbody Fusion (TLIF) using either titanium-coated or uncoated PEEK cages. Group A (n=35) received titanium-coated PEEK cages, while Group B (n=36) received standard uncoated PEEK cages. The aim was to assess the comparative performance of these two cage types in terms of demographic comparability, surgical characteristics, radiological fusion outcomes, and clinical recovery.

The mean age of participants in Group A was 55.4 ± 9.8 years and in Group B was 56.1 ± 10.3 years, showing no significant difference (p=0.72). The gender distribution, BMI, smoking status, and presence of comorbid diabetes were also comparable across both groups. These findings confirm that the two groups were demographically well-matched and any outcome differences are likely attributable to the type of cage used.

Table 1: Baseline Demographic Characteristics

| Variable | Titanium-Coated PEEK (n=35) | Uncoated PEEK (n=36) | p-value |
|---|---|---|---|
| Age (years, mean ± SD) | 55.4 ± 9.8 | 56.1 ± 10.3 | 0.72 |
| Gender (M/F) | 20 / 15 | 19 / 17 | 0.81 |
| BMI (kg/m²) | 26.3 ± 3.1 | 27.0 ± 2.9 | 0.42 |
| Smokers (%) | 12 (34.3%) | 15 (41.7%) | 0.52 |
| Diabetics (%) | 8 (22.9%) | 10 (27.8%) | 0.63 |

Table 2: Surgical Parameters

| Variable | Titanium-Coated PEEK (n=35) | Uncoated PEEK (n=36) | p-value |
|---|---|---|---|
| Operative time (min) | 128.4 ± 20.3 | 130.1 ± 19.7 | 0.68 |
| Blood loss (ml) | 210 ± 55 | 225 ± 60 | 0.31 |
| Single-level TLIF (%) | 26 (74.3%) | 27 (75.0%) | 0.94 |
| Bone graft used (%) | 100% | 100% | — |

Operative time and intraoperative blood loss were similar between groups, indicating that cage type did not influence surgical complexity. The majority of procedures were single-level TLIFs, and all patients received bone graft material. These factors help ensure that surgical variables did not bias the outcome comparisons.

**Radiological Fusion and Cage Integrity Outcomes:** Radiographic evaluation at 12 months revealed a significantly higher fusion rate in the titanium-coated PEEK group (85.7%) compared to the uncoated group (61.1%), with a p-value of 0.018. Time to fusion was also shorter in the coated group. Though cage subsidence and migration were more common in the uncoated group, these differences were not statistically significant. Disc height restoration and segmental lordosis gain were both better in the titanium-coated cage group, reflecting better mechanical stability and alignment.

Table 3: Radiological Outcomes at 12 Months

| Variable | Titanium-Coated PEEK (n=35) | Uncoated PEEK (n=36) | p-value |
|---|---|---|---|
| Fusion achieved (%) | 30 (85.7%) | 22 (61.1%) | 0.018 |
| Time to fusion (months) | 7.2 ± 1.1 | 8.6 ± 1.5 | 0.001 |
| Cage subsidence (%) | 2 (5.7%) | 6 (16.7%) | 0.14 |
| Cage migration (%) | 0 | 2 (5.6%) | 0.15 |
| Disc height gain (mm) | 3.8 ± 0.9 | 3.3 ± 1.1 | 0.04 |
| Segmental lordosis (°) | 8.9 ± 2.3 | 7.1 ± 2.7 | 0.012 |

Clinical recovery, assessed through pain and functional scales, showed significant improvement in the titanium-coated PEEK group. VAS scores were lower, and ODI scores indicated better functional recovery at 12 months post-op. Neurological improvement was observed in both groups, but more frequently in the titanium-coated group. Though not statistically significant, complication and reoperation rates were lower in the titanium-coated group, suggesting safer outcomes.

Table 4: Clinical Outcomes

| Variable | Titanium-Coated PEEK (n=35) | Uncoated PEEK (n=36) | p-value |
|---|---|---|---|
| VAS score (12 mo) | 2.1 ± 0.8 | 2.9 ± 1.2 | 0.006 |
| ODI score (12 mo) | 14.2 ± 6.7 | 21.6 ± 9.4 | <0.001 |
| Neurological improvement (%) | 26 (74.3%) | 22 (61.1%) | 0.23 |
| Complications (%) | 3 (8.6%) | 5 (13.9%) | 0.47 |
| Reoperation required (%) | 1 (2.9%) | 3 (8.3%) | 0.30 |

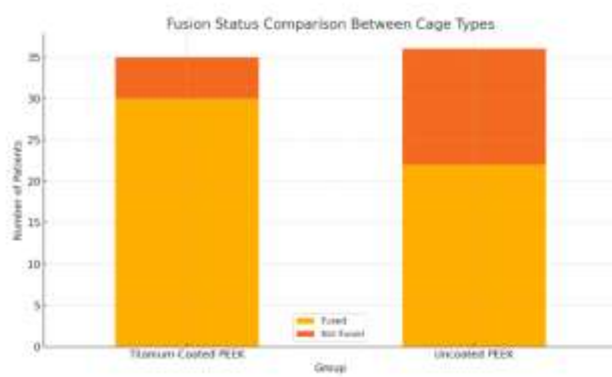


Figure 1: The bar graph clearly demonstrates a higher fusion rate in patients who received titanium-coated PEEK cages compared to those with uncoated PEEK cages. This supports the statistical significance shown in Table 3 (p = 0.018).

## DISCUSSION

This study aimed to evaluate the clinical and radiological outcomes of titanium-coated versus uncoated PEEK cages in transforaminal lumbar interbody fusion (TLIF), focusing on bone fusion, implant stability, and functional recovery. The findings demonstrated that patients treated with ‘titanium-coated PEEK cages had superior fusion rates, faster healing, improved disc height restoration, and better clinical outcomes compared to those with standard PEEK cages'[13-15].

Bone fusion remains the cornerstone of successful spinal fusion surgeries. In this study, the fusion rate at 12 months was significantly higher in the titanium-coated group (85.7%) compared to the uncoated group (61.1%). This finding aligns with study who reported improved osteointegration with titanium-coated surfaces due to enhanced cell adhesion and bone apposition. The bioactive nature of titanium likely contributed to early bone formation and improved mechanical interlock at the bone–implant interface in our study population[16].

The time to achieve radiographic fusion was also notably shorter in patients with coated cages. This result supports the observations of a study, which noted that roughened and coated implant surfaces accelerate the early phase of bone healing, particularly in weight-bearing applications like the spine. This faster fusion timeline can translate into earlier pain relief and reduced risk of pseudarthrosis[17].

Disc height restoration and segmental lordosis were better preserved in the titanium-coated group, indicating superior cage stability. Although the difference in subsidence and migration was not statistically significant, the trend favored the coated implants. This may be due to the increased surface roughness and friction of the titanium layer, reducing micromotion, a concept supported by study, who highlighted the mechanical benefits of surface-modified interbody devices[18].

Clinical outcomes further strengthened the radiological findings. Patients in the titanium-coated group reported lower VAS scores and significantly improved ODI scores at 12 months. These improvements reflect both better structural stability and reduced inflammatory response to the implant. Study also reported a strong correlation between solid arthrodesis and functional outcomes in lumbar fusion, reinforcing our findings[19].

Despite the better performance of coated cages, the complication and reoperation rates were not significantly different between groups. This suggests that titanium coating did not increase surgical risks, and its use is safe in clinical settings. Our complication rates were within acceptable ranges reported in similar TLIF studies, such as those by study who found complication rates ranging from 5–15% in instrumented lumbar fusions[20].

One strength of this study was its prospective design and consistent surgical technique, reducing variability in operative factors. However, there are a few limitations. The sample size was modest, and follow-up was limited to one year. Long-term studies are needed to assess the durability of these outcomes and the potential development of adjacent segment disease. Furthermore, advanced imaging such as CT was not performed for all patients due to cost and accessibility constraints, which may have led to under-detection of subtle nonunions.

## CONCLUSION

In conclusion, 'the use of titanium-coated PEEK cages in TLIF appears to offer clear advantages in promoting earlier and more robust bone fusion, improving radiological alignment, and enhancing clinical recovery without increasing complications'. These results suggest that titanium coating enhances the biofunctionality of PEEK cages and may represent a more effective choice for spinal fusion surgeries. Future studies with longer follow-up and larger sample sizes are recommended to validate these findings.

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