ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at:www.ijdsir.com

Volume – 9, Issue – 5, October – 2026, Page No. : 178 – 187

Evaluation of the Osteogenic Response of Bioengineered Peek and Zirconia Implant Materials Using Polydopamine and Lactoferrin - Comparative in-Vitro Study

[1]Sujana N A, Postgraduate, Department of Prosthodontics and Crown and Bridge, Vokkaligara Sangha Dental College and Hospital, Rajiv Gandhi University of Health Sciences (RGUHS), Bengaluru, India

[2]Surendra Kumar G P, Professor and HOD, Department of Prosthodontics and Crown and Bridge, Vokkaligara Sangha Dental College and Hospital, Bengaluru, India

[3]Nalinakshamma M, Reader, Department of Prosthodontics and Crown and Bridge, Vokkaligara Sangha Dental College and Hospital, Bengaluru, India

[4]Ashwini H V, Senior Lecturer, Department of Prosthodontics and Crown and Bridge, Vokkaligara Sangha Dental College and Hospital, Bengaluru, India

Corresponding Author: Sujana N A, Postgraduate, Department of Prosthodontics and Crown and Bridge, Vokkaligara Sangha Dental College and Hospital, Rajiv Gandhi University of Health Sciences (RGUHS), Bengaluru, India

Citation of this Article: Sujana N A, Surendra Kumar G P, Nalinakshamma M, Ashwini H V, "Evaluation of the Osteogenic Response of Bioengineered Peek and Zirconia Implant Materials Using Polydopamine and Lactoferrin - Comparative in-Vitro Study", IJDSIR – October – 2026, Volume – 9, Issue – 4, P. No. 178 – 187.

Copyright: ©2026 Sujana N A, et al. This is an open access journal and article distributed under the terms of the creative common's attribution non-commercial License. Which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given, and the new creations are licensed under the identical terms.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Introduction: Polyetheretherketone (PEEK) has favorable mechanical and physical characteristics for implant applications; however, its relatively bioinert and hydrophobic surface can limit favorable cellular interactions at the bone-implant interface. Surface bioengineering with polydopamine (PDA) and lactoferrin (LF) may modify this biological behavior. PDA provides a bioinspired surface-modification platform, while LF is a bioactive glycoprotein associated with osteoblast activity and osteogenic differentiation.

AIM: To comparatively evaluate the osteogenic response of bioengineered PEEK and zirconia implant materials using polydopamine and lactoferrin.

Materials and Methodology: Fifty-six disc-shaped specimens (10 mm diameter × 2 mm thickness) were used: 28 PEEK and 28 zirconia specimens. Each material was divided into four subgroups (n=7): untreated, LF-treated, PDA-treated, and PDA+LF-treated. Surface modification was characterized by Fourier-transform infrared spectroscopy (FTIR). MG-63 osteoblast-like cells were cultured on the specimens. Cellular response was assessed by viable-cell count and MTT metabolic activity, while osteogenic differentiation was assessed by

alkaline phosphatase (ALP) activity on days 7 and 14. One-way ANOVA with Tukey post-hoc testing was used for intergroup comparisons and paired t-tests for within-group ALP change over time, with significance set at 5%.

Results: Viable-cell values differed significantly among the eight groups (ANOVA, $p<0.001$). PEEK+PDA showed the highest viable-cell mean among PEEK groups (1.386 ± 0.033), whereas Zr+PDA+LF showed the highest value among zirconia groups (2.499 ± 0.189). MTT values also differed significantly among groups ($p<0.001$); Zr+LF showed the highest mean metabolic activity (0.3254 ± 0.0017). ALP activity increased significantly from day 7 to day 14 in all groups. The greatest increase among PEEK groups occurred with PEEK+PDA (+0.740), while Zr+LF showed the greatest increase among zirconia groups (+0.435).

Conclusion: PDA and LF surface bioengineering influenced cellular and osteogenic responses in a substrate-dependent manner. PDA produced the greatest increase in ALP activity over time in PEEK, whereas LF produced the greatest increase among zirconia groups. Combined PDA+LF treatment was beneficial for selected outcomes but was not uniformly superior across all assays.

Clinical Significance: Surface bioengineering of relatively bioinert implant materials such as PEEK may improve early cellular events relevant to bone formation. These in vitro findings should not be interpreted as direct evidence of enhanced clinical osseointegration.

Keywords: PEEK; Zirconia, Polydopamine, Lactoferrin, Surface Bioengineering, Osteogenic Response; Alkaline Phosphatase, Implant Materials.

Introduction

Polyetheretherketone (PEEK) is a high-performance thermoplastic polymer that has attracted attention for dental and implant applications because of its favorable mechanical behavior, biocompatibility and radiolucency. Its relatively inert, hydrophobic surface and low surface energy, however, can limit favorable biological and interfacial interactions, making surface modification an important strategy for improving its biological performance.[1,2]

Polydopamine (PDA), inspired by mussel adhesive chemistry, offers a versatile bioinspired coating platform. PDA can deposit on diverse substrates under mild alkaline conditions and provides a surface that can support cell-interface engineering and subsequent immobilization of biomolecules.[3,4] This makes PDA particularly relevant when attempting to modify biologically inert polymer surfaces such as PEEK.

Lactoferrin (LF) is a multifunctional iron-binding glycoprotein with antimicrobial, anti-inflammatory and bone-related biological activities. Experimental evidence has shown that LF can stimulate osteoblast proliferation and bone formation, while also influencing osteoclastogenesis.[5,6] Reviews in contemporary dentistry and bone regeneration further support its potential as an osteogenic biomolecule, while emphasizing that clinical evidence remains limited.[7,8]

The concept of using LF as an implant-surface biomolecule is supported by studies in which LF-containing or LF-coated biomaterials enhanced osteogenic responses. Studies show that LF released from gelatin hydrogel promoted bone regeneration,[9] and LF coating of nanostructured titanium improved osteogenic as well as antibacterial properties.[10] These observations provide a biological basis for investigating LF on other implant substrates.

PEEK possesses several properties favorable for implant applications; however, its relatively bioinert surface limits favorable cellular interactions at the bone-implant interface. Surface bioengineering using PDA and LF may

©2026 IJDSIR, All Rights Reserved

provide a strategy to modify this biological behavior and promote osteoblast attachment, cellular activity and early osteogenic differentiation. Evaluating these responses in PEEK and comparing them with similarly bioengineered zirconia may provide insight into the influence of surface bioengineering on early cellular events relevant to osseointegration.

Accordingly, this in vitro study comparatively evaluated viable-cell response, metabolic activity and alkaline phosphatase (ALP) activity of untreated and bioengineered PEEK and zirconia surfaces using MG-63 osteoblast-like cells.

Aim and Objectives

Aim: To comparatively evaluate the osteogenic response of bioengineered PEEK and zirconia implant materials using polydopamine and lactoferrin.

1. To assess the cytocompatibility of bioengineered PEEK and zirconia.
2. To evaluate cellular metabolic activity on bioengineered PEEK and zirconia.
3. To assess osteogenic differentiation on bioengineered PEEK and zirconia. .
4. To compare the biological performance of bioengineered PEEK with zirconia.

Materials and Methodology

Study design and sample allocation

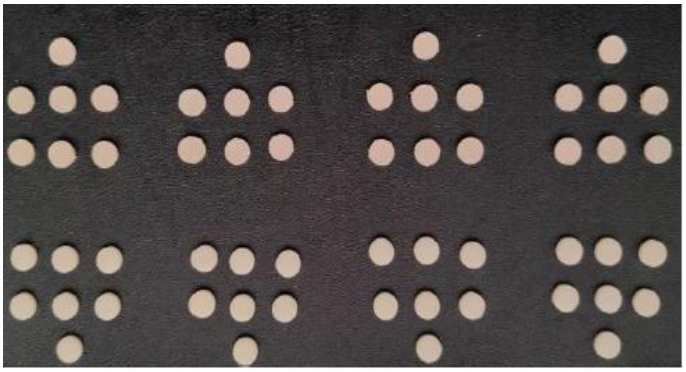
An in vitro comparative experimental study was performed using 56 disc-shaped specimens: 28 PEEK and 28 zirconia specimens. Each material was divided into four subgroups (n=7): untreated control, LF-treated, PDA-treated, and PDA+LF-treated.

Material	Subgroup	Surface condition	n
PEEK	PEEK	Untreated	7
PEEK	PEEK+LF	Lactoferrin	7
PEEK	PEEK+PDA	Polydopamine	7
PEEK	PEEK+PDA+LF	Polydopamine + lactoferrin	7
Zirconia	Zirconia	Untreated	7
Zirconia	Zirconia+LF	Lactoferrin	7
Zirconia	Zirconia+PDA	Polydopamine	7
Zirconia	Zirconia+PDA+LF	Polydopamine + lactoferrin	7

Specimen dimensions and surface bioengineering

Disc-shaped PEEK and zirconia specimens measuring 10 mm in diameter and 2 mm in thickness were prepared. All specimens were ultrasonically cleaned in 70% ethanol for 10 minutes, followed by deionized water for 10 minutes, and dried before surface functionalization. For direct lactoferrin (LF) treatment, specimens were immersed in 100 µg/mL LF prepared in phosphate-buffered saline (PBS) at 4°C for 12 hours, gently rinsed with PBS, and air dried. For polydopamine (PDA) treatment, specimens were immersed in freshly prepared dopamine hydrochloride (2 mg/mL) in 10 mM Tris buffer (pH 8.5) for 24 hours at room temperature under mild agitation, then rinsed with deionized water and air dried. For combined PDA+LF treatment, PDA-coated specimens were subsequently immersed in 100 µg/mL LF in PBS at 4°C for 12 hours under gentle shaking, followed by three rinses with 1× PBS to remove unbound LF. Untreated specimens served as controls.

Figure 1: Experimental materials from the study:



(A) PEEK (above) and zirconia (below) disc specimens,

©2026 IJDSIR, All Rights Reserved



(B) polydopamine (PDA), and



(C) lactoferrin (LF).

Surface characterization

Surface chemical characterization was carried out by attenuated-total-reflectance Fourier-transform infrared spectroscopy (ATR-FTIR), using a PerkinElmer FTIR spectrophotometer across 400–4000 cm^{-1}, as specified in the laboratory protocol. FTIR was used to examine characteristic functional-group bands of the substrate and coated specimens; the extent of coating coverage, binding efficiency and stability cannot be established by FTIR alone.



Figure 2: Specimen dimensions and surface characterization: (A-B) PEEK diameter and thickness, (C-D) zirconia diameter and thickness.

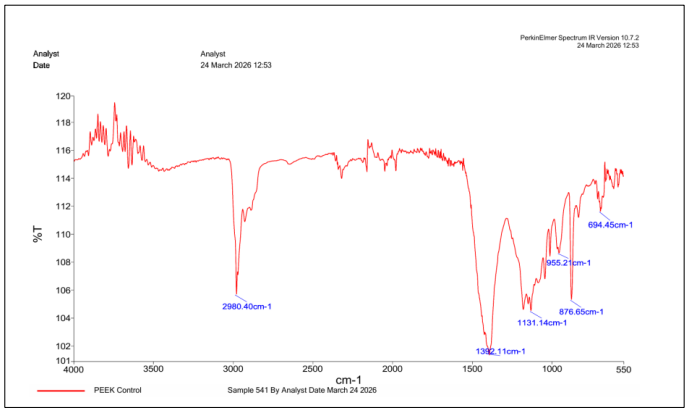


Figure 3: FTIR spectrum: PEEK control

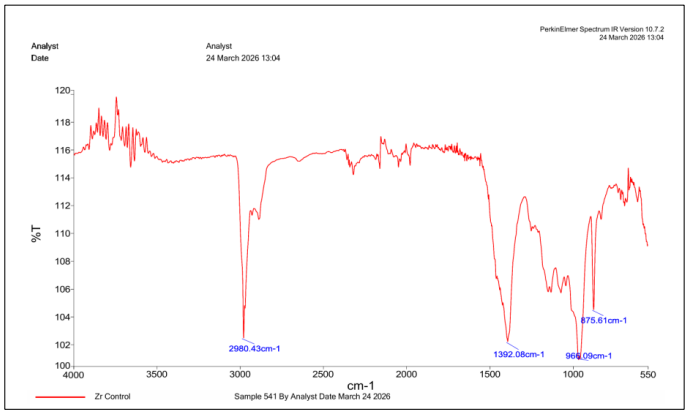


Figure 4: FTIR spectrum: Zirconia control

©2026 IJDSIR, All Rights Reserved

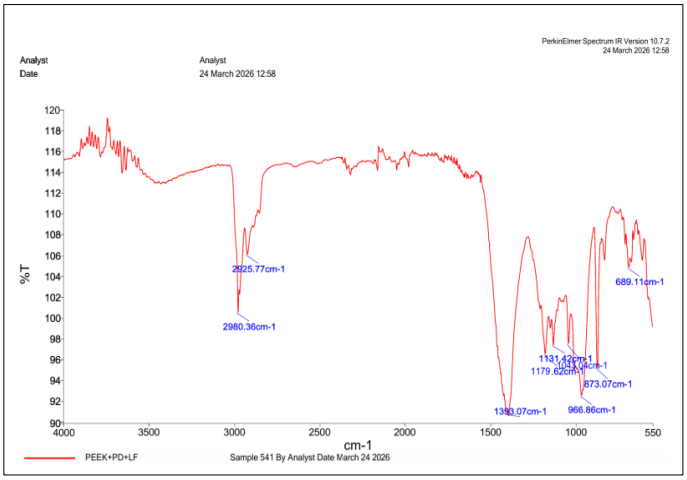


Figure 5: FTIR spectrum: PEEK+PDA+LF

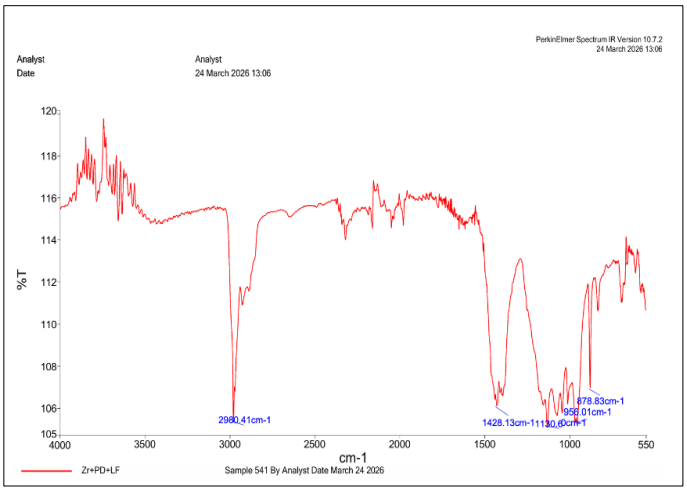


Figure 6: FTIR spectrum: Zr+PDA+LF

Cell culture and sample sterilization

MG-63 human osteoblast-like osteosarcoma cells were cultured in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10% fetal bovine serum and 1× antibiotic solution containing penicillin, streptomycin and amphotericin B. At confluence, cells were detached with trypsin–EDTA and subcultured. Specimens were immersed in 90% ethanol for 30 minutes, rinsed with 1× phosphate-buffered saline (PBS) and exposed to ultraviolet light before cell seeding.

MTT assay

MG-63 cells were seeded at 0.05 × 10^6 cells per specimen and cultured for 3 days. MTT reagent [3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide] was added. Following removal of the medium, 100 µL of 0.05% MTT reagent was added to each well and incubated at 37°C for 2 hours. Purple formazan crystals were dissolved in dimethyl sulfoxide (DMSO), and absorbance was measured at 570 nm. MTT absorbance was interpreted as cellular metabolic activity rather than a direct count of viable cells.

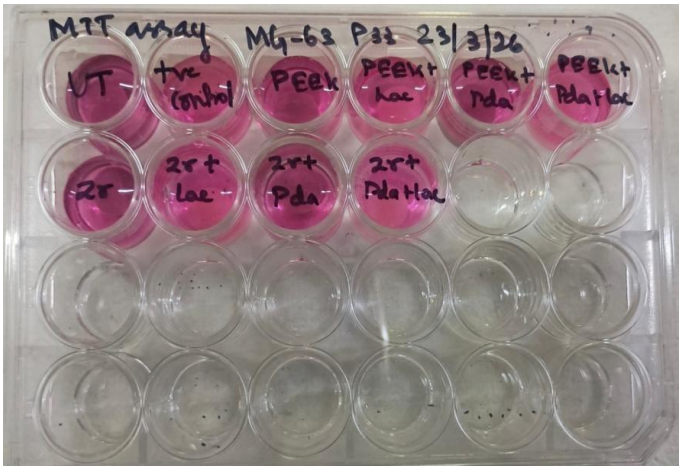


Figure 7: 24-well plate showing the MTT assay performed with MG-63 cells on the experimental groups

Cell count and viability assay

Cell count and viability were assessed to quantify the viable-cell population and complement the MTT assay. Automated cell analysis, fluorescence microscopy, and plate-reader-based assessment were performed. MG-63 cells were seeded at 0.05 × 10^6 cells per specimen and cultured for 3 days. Cells were detached using trypsin, centrifuged at 1200 rpm for 5 minutes, resuspended in fresh medium and mixed with viability reagent before assessment using a MUSE™ cell analyzer. Fluorescein diacetate (FDA) staining (0.3 × 10^6 cells; 30 µg/mL FDA; 20× fluorescence microscopy) was performed.

©2026 IJDSIR, All Rights Reserved

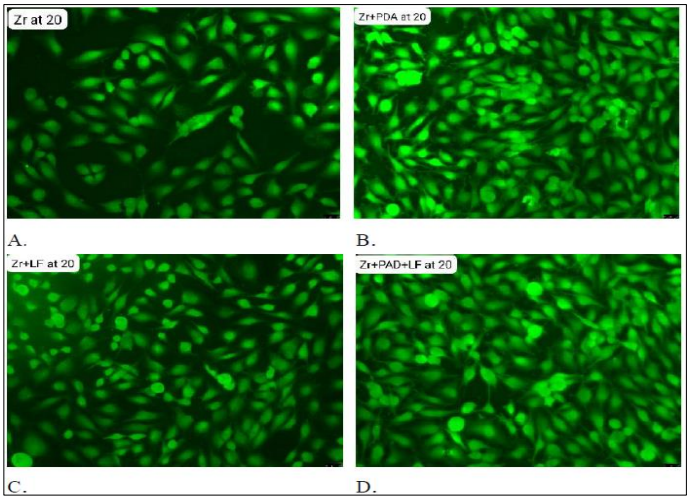


Figure 8: Fluorescent microscopy images of MG-63 cells at 20X: (A) Zr, (B) Zr+PDA, (C) Zr+LF, (D) Zr+PDA+LF

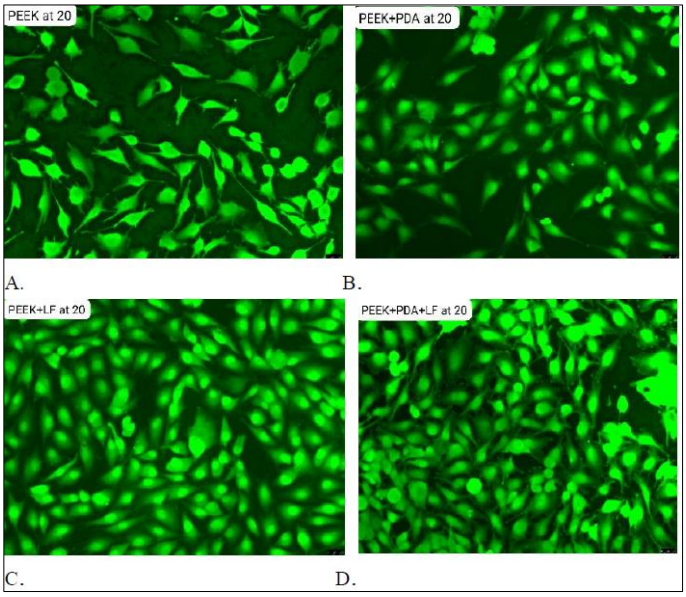


Figure 9: Fluorescent microscopy images of MG-63 cells at 20X: (A) PEEK, (B) PEEK+PDA, (C) PEEK+LF, (D) PEEK+PDA+LF

Alkaline phosphatase assay

ALP activity was evaluated on days 7 and 14 as an early marker of osteogenic differentiation. Enzyme activity was determined by conversion of the assay substrate to a colored product, with absorbance measured at 405 nm.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 23. Quantitative data were summarized as mean and standard deviation. One-way analysis of variance (ANOVA) was used to compare cell-count/viability, MTT and ALP values among groups, with Tukey's HSD test for post-hoc intergroup comparisons. Paired t-tests were used to compare ALP activity at day 7 and day 14 within each group. Statistical significance was set at $p<0.05$.

Results

Results are expressed as mean ± standard deviation (SD) based on seven observations per experimental group.

Table 1: Comparison of viable-cell values among the experimental groups.

Group	n	Mean ± SD
PEEK	7	1.093 ± 0.090
PEEK+LF	7	1.329 ± 0.031
PEEK+PDA	7	1.386 ± 0.033
PEEK+PDA+LF	7	1.254 ± 0.032
Zr	7	2.077 ± 0.037
Zr+LF	7	2.041 ± 0.031
Zr+PDA	7	2.066 ± 0.024
Zr+PDA+LF	7	2.499 ± 0.189

The overall difference among groups was statistically significant (one-way ANOVA, $F=295.18$, $p<0.001$). Among PEEK groups, PEEK+PDA showed the highest numerical mean (1.386 ± 0.033), followed by PEEK+LF, PEEK+PDA+LF and untreated PEEK. Among zirconia groups, Zr+PDA+LF showed the highest mean (2.499 ± 0.189).

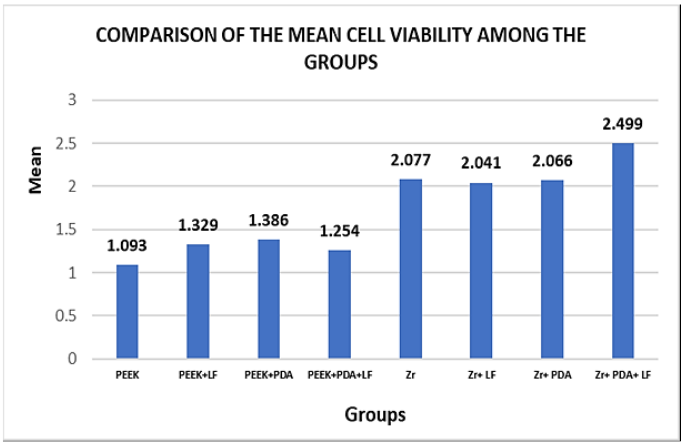


Figure 10: Comparison of mean viable-cell values among the eight experimental groups.

©2026 IJDSIR, All Rights Reserved

Table 2: MTT metabolic activity among the experimental groups.

Group	n	Mean ± SD
PEEK	7	0.3234 ± 0.0025
PEEK+LF	7	0.3213 ± 0.0013
PEEK+PDA	7	0.3134 ± 0.0017
PEEK+PDA+LF	7	0.3230 ± 0.0016
Zr	7	0.3191 ± 0.0050
Zr+LF	7	0.3254 ± 0.0017
Zr+PDA	7	0.3174 ± 0.0041
Zr+PDA+LF	7	0.3203 ± 0.0005

MTT values differed significantly among groups (one-way ANOVA, F=13.75, p<0.001). The source statistical summary reported that PEEK+PDA was significantly lower than PEEK+PDA+LF (p=0.001). Within zirconia groups, Zr+LF was significantly higher than Zr (p=0.002), Zr+PDA (p=0.001), and Zr+PDA+LF (p=0.024).

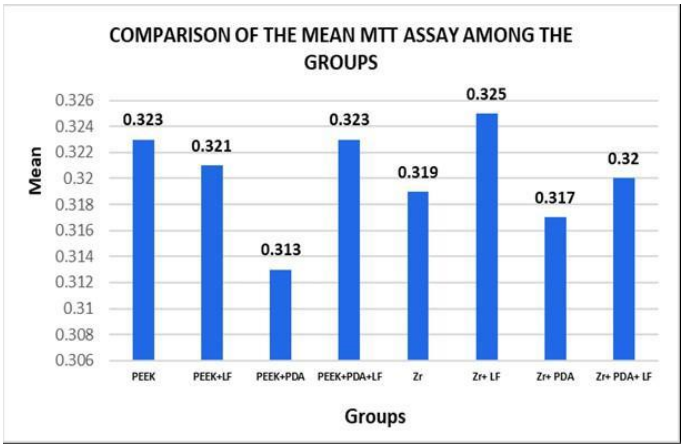


Figure 11: Comparison of mean MTT metabolic activity among the eight experimental groups.

Table 3: ALP activity at day 7 and day 14 and change in ALP activity over time.

Group	n	Day 7 Mean ± SD	Day 14 Mean ± SD	Mean increase
PEEK	7	0.451 ± 0.001	0.980 ± 0.005	0.529
PEEK+LF	7	0.353 ± 0.005	0.722 ± 0.003	0.369
PEEK+PDA	7	0.522 ± 0.003	1.261 ± 0.005	0.740
PEEK+PDA+LF	7	0.721 ± 0.008	1.222 ± 0.006	0.501
Zr	7	0.328 ± 0.014	0.602 ± 0.007	0.274
Zr+LF	7	0.592 ± 0.004	1.027 ± 0.004	0.435
Zr+PDA	7	0.235 ± 0.002	0.566 ± 0.005	0.331
Zr+PDA+LF	7	0.672 ± 0.004	0.982 ± 0.001	0.310

ALP activity differed significantly among groups at day 7 (F=5294.92, p<0.001) and day 14 (F=21243.31, p<0.001). ALP increased significantly from day 7 to day 14 within every group (paired t-test, all p<0.001). Among PEEK groups, the greatest increase was observed with PEEK+PDA (+0.740), followed by untreated PEEK (+0.529), PEEK+PDA+LF (+0.501) and PEEK+LF (+0.369).

Among zirconia groups, the greatest increase occurred with Zr+LF (+0.435), followed by Zr+PDA (+0.331), Zr+PDA+LF (+0.310) and untreated Zr (+0.274).

The combined PDA+LF treatment therefore did not demonstrate uniform superiority across all evaluated outcomes.

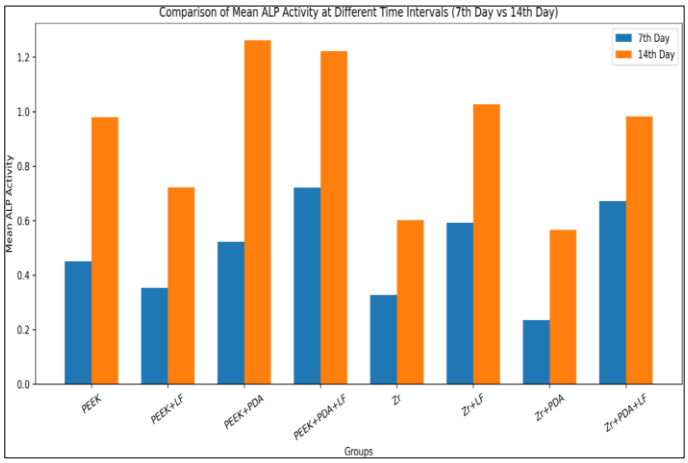


Figure 12: Comparison of mean ALP activity at day 7 and day 14 among the eight experimental groups.

Discussion

The present in vitro study evaluated whether PDA- and LF-based surface bioengineering could modify the cellular and early osteogenic response of PEEK and zirconia implant materials. Three complementary outcomes were examined: viable-cell response, MTT metabolic activity and ALP activity at two time points. The central finding was that the biological effect of surface modification depended on the underlying substrate and on the outcome assessed.

©2026 IJDSIR, All Rights Reserved

PEEK was selected because its favorable material characteristics are accompanied by a relatively inert and hydrophobic surface, a limitation repeatedly identified in the PEEK literature.[1,2] In the present viable-cell assessment, untreated PEEK had the lowest mean among the PEEK groups, whereas PDA-treated PEEK showed the highest numerical value. This finding is biologically plausible because PDA has been developed as a broadly applicable coating for controlling cell-surface interactions,[3] and PDA-based modification of PEEK has previously been shown to improve surface-related performance without compromising cellular biocompatibility.[2]

The MTT assay provided a different view of cellular behavior because it reflects cellular metabolic activity rather than direct cell number. PEEK+PDA had a lower MTT value than PEEK+PDA+LF, and the post-hoc analysis identified this difference as significant. Thus, addition of LF altered the metabolic response of cells on PDA-treated PEEK even though PDA alone showed the highest viable-cell mean. This divergence emphasizes that viable-cell count and MTT should be interpreted as complementary, rather than interchangeable, outcomes.

ALP activity was evaluated as an early marker of osteogenic differentiation. All groups showed an increase from day 7 to day 14. Among PEEK groups, PDA treatment produced the greatest increase in ALP activity over time. The combined PDA+LF group showed a higher absolute ALP value at day 7 but a smaller day-7-to-day-14 increase than PDA alone. Accordingly, absolute ALP activity at a specific time point and change in ALP activity over time should be interpreted separately.

The zirconia groups showed a different treatment pattern. Baseline viable-cell values were higher than those of PEEK, and Zr+PDA+LF produced the highest viable-cell mean overall. In contrast, LF alone produced the highest MTT mean among zirconia groups and the greatest increase in ALP activity from day 7 to day 14. This substrate-dependent pattern is important as the same surface bioengineering strategy did not produce identical responses on PEEK and zirconia.

The LF-related findings are consistent with the broader bone-regeneration literature. Cornish et al. demonstrated that LF is a potent regulator of bone-cell activity and increases bone formation in vivo,[5] while Takaoka et al. reported bone regeneration with LF released from a gelatin hydrogel.[9] Trybek et al. summarized evidence that LF promotes osteoblast growth and differentiation and can reduce osteoclastogenesis,[7] and Yin et al. demonstrated improved osteogenic properties after LF coating of a nanostructured titanium surface.[10] More recent preclinical synthesis nevertheless concludes that evidence for routine use of LF in oral surgery remains insufficient and requires controlled clinical investigation.[8]

PDA is widely described as a versatile bioinspired coating platform capable of depositing on diverse substrates and supporting subsequent biofunctionalization.[3,4] This provides the conceptual basis for using PDA to alter PEEK surface behavior and to immobilize bioactive molecules. Importantly, the combination of PDA and LF did not consistently produce better results than either coating used alone. While the PDA+LF coating showed better performance for certain outcomes, PDA alone or LF alone showed greater effects for others, indicating that the biological response depended on the type of coating and the parameter evaluated.

The present findings therefore support a more precise interpretation than simply claiming 'enhanced osseointegration.' The measured outcomes represent early

©2026 IJDSIR, All Rights Reserved

in vitro cellular events relevant to osteogenesis. This distinction is consistent with the current LF literature, in which promising bone-regenerative effects coexist with limited clinical evidence.[8] A recent pilot study around dental implants reported higher ALP levels with LF than with Bio-Oss at several postoperative time points, but also called for larger samples and longer clinical follow-up.[11] Direct osseointegration, bone-implant contact, mechanical fixation and long-term in vivo remodeling were not measured in the present study.

Limitations

- The study used an MG-63 osteoblast-like cell line hence responses may differ from primary human osteoblasts or mesenchymal stem cells.
- The experiment was in vitro and did not reproduce the vascular, immune, mechanical-loading and remodeling environment of living bone.
- ALP is an early osteogenic marker and does not alone establish matrix mineralization or mature bone formation.
- Surface characterization in the available study record is limited to FTIR; complementary analyses such as contact angle, surface roughness/topography, XPS and coating stability would strengthen mechanistic interpretation.

Future scope

Future studies should validate the findings using primary osteogenic cells, mineralization assays and additional osteogenic markers, characterize surface chemistry and topography more comprehensively, assess coating stability and dose-response relationships, and progress to appropriate in vivo models evaluating bone-implant contact and mechanical integration. The relative performance of PDA, LF and combined PDA+LF should be investigated separately for each implant substrate rather than assuming a universal synergistic effect.

Conclusion

1. **Cytocompatibility:** Among the PEEK groups, PDA-bioengineered PEEK showed the highest viable-cell response. Untreated zirconia demonstrated higher viable-cell values than untreated PEEK under the present experimental conditions.
2. **Cellular metabolic activity:** In PEEK, combined PDA+LF treatment showed significantly greater cellular metabolic activity than PDA alone, whereas LF-treated zirconia demonstrated the highest metabolic activity among the zirconia groups, indicating that the effect of LF was dependent on the underlying substrate.
3. **Osteogenic differentiation:** PDA-treated PEEK showed the greatest increase in ALP activity from day 7 to day 14 among the PEEK groups, whereas LF-treated zirconia showed the greatest increase among the zirconia groups, demonstrating a substrate-dependent effect of surface bioengineering on early osteogenic differentiation.
4. **Overall comparison:** PEEK and zirconia exhibited distinct biological responses to surface bioengineering. Although zirconia showed higher viable-cell values, bioengineered PEEK demonstrated favorable cellular and osteogenic responses, particularly following PDA treatment. Overall, the effects of PDA and LF were dependent on the implant substrate and biological outcome evaluated, supporting further investigation of surface-bioengineered PEEK as a potential implant material.

Clinical Implication

Surface bioengineering may provide a strategy for improving the biological interaction of relatively bioinert implant materials such as PEEK. The present findings identify PDA and LF as promising modifiers of early

©2026 IJDSIR, All Rights Reserved

osteoblast-like cell responses, while also demonstrating that the optimal modification may depend on the implant substrate. Translation to clinical implant osseointegration requires confirmation through more comprehensive surface characterization, primary-cell studies and in vivo investigations.

References

1. Pidhatika B, Widyaya VT, Nalam PC, Swasono YA, Ardhani R. Surface modifications of high-performance polymer polyetheretherketone (PEEK) to improve its biological performance in dentistry. Polymers (Basel). 2022;14(24):5526.
2. Teng R, Meng Y, Zhao X, Liu J, Ding R, Cheng Y, et al. Combination of polydopamine coating and plasma pretreatment to improve bond ability between PEEK and primary teeth. Front Bioeng Biotechnol. 2021;8:630094. doi:10.3389/fbioe.2020.630094.
3. Lynge ME, van der Westen R, Postma A, Städler B. Polydopamine-a nature-inspired polymer coating for biomedical science. Nanoscale. 2011;3(12):4916-4928. doi:10.1039/c1nr10969c.
4. Sarkari S, Khajehmohammadi M, Davari N, Li D, Yu B. The effects of process parameters on polydopamine coatings employed in tissue engineering applications. Front Bioeng Biotechnol. 2022;10:1005413.
5. Cornish J, Callon KE, Naot D, Palmano KP, Banovic T, Bava U, et al. Lactoferrin is a potent regulator of bone cell activity and increases bone formation in vivo. Endocrinology. 2004;145(9):4366-4374.
6. Lorget F, Clough J, Oliveira M, Daury MC, Sabokbar A, Offord E. Lactoferrin reduces in vitro osteoclast differentiation and resorbing activity. Biochem Biophys Res Commun. 2002;296(2):261-266.
7. Trybek G, Misiakiewicz-Has K, Preuss O, Szumilas K, Szumilas P, Aniko-Włodarczyk M, et al. Osteogenic activity of lactoferrin and its application in contemporary dentistry. Pomeranian J Life Sci. 2020;66(1):22-28. doi:10.21164/pomjlifesci.521.
8. León Malaga FN, Espinoza MA, Munive-Degregori A, Barja-Ore J, Mauricio-Vilchez C, Mayta-Tovalino F. Uses and applications of lactoferrin in preclinical studies for successful bone regeneration process: a literature review. J Int Oral Health. 2023;15:337-341. doi:10.4103/jioh.jioh_221_22.
9. Takaoka R, Hikasa Y, Hayashi K, Tabata Y. Bone regeneration by lactoferrin released from a gelatin hydrogel. J Biomater Sci Polym Ed. 2011;22 (12):1581-1589.
10. Yin D, Hong Y, Chen L, Komasa S, Yang Y, Zhang H, et al. Lactoferrin coating improves the antibacterial and osteogenic properties of alkali-treated titanium with nanonetwork structures. J Nanomater. 2020;2020:2516975. doi:10.1155/ 2020/ 2516975.
11. Natarajan P, et al. The efficacy of bone regeneration potential of lactoferrin around dental implants: a pilot study. Afr J Biomed Res. 2024;27(4S):5817 doi:10. 53555/AJBR.v27i4S.4520.

©2026 IJDSIR, All Rights Reserved