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Comparative Evaluation of Coated and Uncoated 3D-Printed Porous Implants for Antibacterial and Biological Performance

Sanjay Kumar Sarmol[1*], Abdul Azim Reza[2], Mohammad Sahadat Hossain[3]

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*Corresponding author

ABSTRACT

Background: 3D-printed porous implants offer potential advantages in orthopaedic surgery, while surface coatings may improve antibacterial activity and biological integration. This study aimed to compare the antibacterial and biological performance of coated and uncoated 3D-printed porous implants. **Methods & Materials:** This prospective comparative study was conducted in the Department of Orthopaedic Surgery, 250 Bed General Hospital, Naogaon, Bangladesh, from January 2025 to June 2026. A total of 40 patients were enrolled and divided into coated (Group A, n=20) and uncoated (Group B, n=20) implant groups. Demographic, clinical, antibacterial and biological outcomes were assessed, including infection, bacterial isolates, radiographic union, implant stability and bone ingrowth. **Results:** The mean age was 44.2 ± 14.8 years and 67.5% of participants were male. Culture-positive infection occurred in 15.0% of the coated group compared with 45.0% of the uncoated group (p=0.082). Postoperative antibiotic requirements were significantly lower in the coated group (25.0% vs. 60.0%, p=0.027). Staphylococcus aureus was the predominant isolate (58.3%). Radiographic union was observed in 90.0% and 80.0% of the coated and uncoated groups, respectively. Mean bone ingrowth scores were 3.2 ± 0.8 and 2.7 ± 0.9, respectively (p=0.08). **Conclusion:** Coated implants demonstrated lower infection rates and generally more favorable biological outcomes. However, most differences were not statistically significant, warranting further investigation in larger studies.

Keywords: *3D printing, porous implants, antibacterial activity, implant coating, osseointegration, orthopaedic surgery.*

1. *Junior Consultant, Department of Orthopedic Surgery, 250 Bed General Hospital, Naogaon, Bangladesh (ORCID: 0009-0006-2101-3638)*
2. *Assistant Professor (In Situ), Department of Orthopedic Surgery, Upazila Health Complex, Mohonpur, Rajshahi, Bangladesh (ORCID: 0009-0005-2675-8033)*
3. *Assistant Professor (OSD), Department of Orthopedic Surgery, Directorate General of Health Services (DGHS), Dhaka, Attachment: Naogaon Medical College, Naogaon, Bangladesh (ORCID: 0009-0005-1933-7679)*

INTRODUCTION

The management of orthopedic trauma in resource-constrained settings continues to face substantial challenges, particularly regarding postoperative infection and implant failure [1]. These complications not only compromise patient outcomes but also impose significant burdens on healthcare systems, often requiring prolonged hospitalization, additional surgical interventions and extended antibiotic therapy [2]. In low- and middle-income countries, the burden is further amplified by limited access to advanced implant technologies and constrained infection control infrastructure [3].

The emergence of additive manufacturing, or three-dimensional (3D) printing, has introduced new possibilities for orthopedic implant design [4]. This technology enables the fabrication of highly porous structures with controlled architecture, facilitating bone ingrowth and biological fixation while allowing customization to match patient anatomy [5]. Porous titanium implants produced through selective laser melting or electron beam melting have demonstrated promising osseointegration characteristics, with interconnected porosity that promotes vascularization and tissue integration [6].

Despite these advantages, a persistent limitation of porous metallic implants is their inherent lack of antibacterial activity. The porous architecture that supports bone ingrowth also provides an environment conducive to bacterial colonization and biofilm formation [7]. Biofilms on implant surfaces exhibit remarkable resistance to systemic antibiotics and host immune defenses, frequently necessitating implant removal and revision surgery [8]. Consequently, researchers have explored surface modification strategies to impart antibacterial functionality to porous implants [9].

Antibacterial coatings represent a promising approach to address this challenge. Various strategies have been investigated, including antibiotic-eluting coatings, silver or copper-based coatings and bioactive coatings that combine osteoconductive and antimicrobial properties [10]. These coatings aim to prevent bacterial adhesion and colonization while preserving or enhancing the biological performance of the implant [11]. However, the comparative performance of coated versus uncoated porous implants remains an area requiring further clinical investigation, particularly in settings where implant-associated infections pose substantial clinical challenges.

This study was designed to comparatively evaluate coated and uncoated 3D-printed porous implants with respect to antibacterial efficacy and biological performance. The findings may contribute to understanding whether surface modification strategies offer tangible clinical benefits in orthopedic trauma management.

METHODS & MATERIALS

This prospective comparative study was conducted in the Department of Orthopaedic Surgery, 250 Bed General Hospital, Naogaon, Bangladesh, from January 2025 to June 2026. A total of 40 patients requiring orthopedic implant surgery were enrolled and divided into two groups: Group A (coated implants, n=20) and Group B (uncoated implants, n=20). Inclusion criteria were patients aged 18–65 years with closed or open fractures requiring internal fixation, providing informed consent. Exclusion criteria were active infection, immunosuppression, malignancy, or inability to complete 12-week follow-up. Written informed consent was obtained from all participants in both Bangla and English. Data were collected using a structured questionnaire and clinical assessment forms, including demographic variables, infection parameters and osseointegration outcomes at 12 weeks. Statistical analysis was performed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequency and percentage and compared using Fisher's exact test. Continuous variables were expressed as mean ±

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standard deviation and compared using independent samples t-test or Mann–Whitney U test as appropriate. A p-value <0.05 was considered statistically significant.

RESULT

Table I presents the demographic and clinical characteristics of the 40 study participants, divided equally into coated (n=20) and uncoated (n=20) groups. The majority of patients were male (67.5%) and the most common age group was 31–45 years (37.5%), with a mean age of 44.2 ± 14.8 years. Diabetes mellitus was present in 32.5% of participants, while 45.0% had no comorbidity. Closed fractures were most frequent (52.5%), followed by Gustilo I–II open fractures (35.0%) and Gustilo III fractures (12.5%). The tibia was the most common implant site (40.0%), followed by the femur (27.5%), humerus (17.5%) and other sites (15.0%). All baseline characteristics were well-matched between the two groups, with no statistically significant differences (all p>0.05), confirming comparability of the study population.

Table I
Demographic and Clinical Characteristics of Our Study Participants (*n* = 40).

Characteristic	Category	Coated (n=20) n (%)	Uncoated (n=20) n (%)	Total (n=40) n (%)	p-value
Age Group	18–30 years	4 (20.0)	5 (25.0)	9 (22.5)	0.72
	31–45 years	8 (40.0)	7 (35.0)	15 (37.5)	
	46–60 years	6 (30.0)	6 (30.0)	12 (30.0)	
	>60 years	2 (10.0)	2 (10.0)	4 (10.0)	
Sex	Male	14 (70.0)	13 (65.0)	27 (67.5)	0.74
	Female	6 (30.0)	7 (35.0)	13 (32.5)	
Comorbidity	Diabetes Mellitus	6 (30.0)	7 (35.0)	13 (32.5)	0.74
	Hypertension	4 (20.0)	5 (25.0)	9 (22.5)	
	None	10 (50.0)	8 (40.0)	18 (45.0)	
Fracture Type	Closed	11 (55.0)	10 (50.0)	21 (52.5)	0.75
	Open (Gustilo I–II)	7 (35.0)	7 (35.0)	14 (35.0)	
	Open (Gustilo III)	2 (10.0)	3 (15.0)	5 (12.5)	
Implant Site	Tibia	8 (40.0)	8 (40.0)	16 (40.0)	0.91
	Femur	6 (30.0)	5 (25.0)	11 (27.5)	
	Humerus	3 (15.0)	4 (20.0)	7 (17.5)	
	Other	3 (15.0)	3 (15.0)	6 (15.0)	
Mean Age (years)		43.8 ± 14.2	44.6 ± 15.4	44.2 ± 14.8	0.86

Table II compares the antibacterial performance between the coated and uncoated groups. Culture-positive infection occurred in 3 (15.0%) patients in the coated group versus 9 (45.0%) in the uncoated group (RR 0.33, 95% CI 0.11–1.03; p=0.082). Superficial infection was observed in 2 (10.0%) coated versus 5 (25.0%) uncoated patients (p=0.41), while deep or implant-related infection occurred in 1 (5.0%) versus 4 (20.0%) patients, respectively (p=0.34). Post-operative antibiotic requirement was significantly lower in the coated group, affecting 5 (25.0%) patients compared to 12 (60.0%) in the uncoated group (RR 0.42, 95% CI 0.18–0.97; p=0.027*). Additional surgical intervention was needed in 2 (10.0%) coated versus 6 (30.0%) uncoated patients (p=0.24). At 12 weeks, 17 (85.0%) coated patients remained infection-free compared to 11 (55.0%) uncoated patients (p=0.082).

Table II
Antibacterial Performance by Group.

Outcome	Coated (n=20) n (%)	Uncoated (n=20) n (%)	Risk Ratio	95% CI	p-value
Culture-positive infection	3 (15.0)	9 (45.0)	0.33	0.11–1.03	0.082
Superficial infection	2 (10.0)	5 (25.0)	0.4	0.09–1.83	0.41
Deep/implant-related infection	1 (5.0)	4 (20.0)	0.25	0.03–2.05	0.34
Antibiotic required post-op	5 (25.0)	12 (60.0)	0.42	0.18–0.97	0.027*
Additional surgical intervention	2 (10.0)	6 (30.0)	0.33	0.08–1.44	0.24
Infection-free at 12 weeks	17 (85.0)	11 (55.0)	—	—	0.082

Table III presents the bacterial isolates obtained from the 12 culture-positive cases, comprising 3 from the coated group and 9 from the uncoated group. *Staphylococcus aureus* was the predominant pathogen, isolated in 7 cases (58.3% of total isolates), including 2 from the coated group and 5 from the uncoated group. *Pseudomonas aeruginosa* was identified in 2 cases (16.7%), both from the uncoated group, while *Escherichia coli* was isolated in 2 cases (16.7%), with 1 from each group. *Klebsiella pneumoniae* was found in 1 case (8.3%), originating from the uncoated group. Overall, Gram-positive organisms accounted for 58.3% of isolates, while Gram-negative organisms accounted for 41.7%.

Table III
Bacterial Isolates from Infected Cases (Subgroup Analysis).

Bacterial Isolate	Coated (n=3) n	Uncoated (n=9) n	Total (n=12) n	% of Total
Staphylococcus aureus	2	5	7	58.3
Pseudomonas aeruginosa	0	2	2	16.7
Escherichia coli	1	1	2	16.7
Klebsiella pneumoniae	0	1	1	8.3
Total	3	9	12	100

Table IV summarizes the biological performance and osseointegration outcomes at 12 weeks. Radiographic union was achieved in 18 (90.0%) patients in the coated group compared to 16 (80.0%) in the uncoated group (p=0.66). Implant stability without loosening was observed in 19 (95.0%) coated versus 17 (85.0%) uncoated patients (p=0.60). The mean bone ingrowth score was 3.2 ± 0.8 in the coated group versus 2.7 ± 0.9 in the uncoated group (p=0.08), showing a trend toward better osseointegration with coating. Peri-implant radiolucency was detected in 1 (5.0%) coated patient compared to 4 (20.0%) uncoated patients (p=0.34). The mean follow-up duration was 14.2 ± 3.1 weeks for the coated group and 13.8 ± 3.4 weeks for the uncoated group (p=0.70).

Table IV
Biological Performance (Osseointegration) at 12 Weeks.

Parameter	Coated (n=20)	Uncoated (n=20)	p-value
Radiographic union	18 (90.0%)	16 (80.0%)	0.66
Implant stability (no loosening)	19 (95.0%)	17 (85.0%)	0.60
Bone ingrowth score (0–4)	3.2 ± 0.8	2.7 ± 0.9	0.08
Peri-implant radiolucency	1 (5.0%)	4 (20.0%)	0.34
Mean follow-up (weeks)	14.2 ± 3.1	13.8 ± 3.4	0.70

DISCUSSION

The present study compared the antibacterial and biological performance of coated and uncoated 3D-printed porous implants in 40 patients. The coated group showed lower infection rates and generally more favorable osseointegration outcomes than the uncoated group, although most differences in biological outcomes were not statistically significant.

In the present study, culture-positive infection occurred in 15.0% of the coated group compared with 45.0% of the uncoated group. Similarly, postoperative antibiotic requirements were lower in the coated group (25.0% vs. 60.0%). These findings are consistent with the potential of antimicrobial surface functionalization to reduce bacterial colonization. Poudel et al. demonstrated the potential of gentamicin-eluting 3D-printed implants for preventing postsurgical infections in bone fractures [12]. Similarly, Zhang et al. investigated amikacin-coated 3D-printed metal devices for infection prevention, supporting the rationale for antimicrobial coatings in orthopaedic applications [13].

The bacterial isolates in the present study were predominantly Staphylococcus aureus, accounting for 58.3% of culture-positive cases, followed by Pseudomonas aeruginosa and Escherichia coli, each accounting for 16.7%. This distribution highlights the importance of considering both Gram-positive and Gram-negative organisms when evaluating implant-associated infections. Merlo et al. investigated polydopamine and silver nanoparticle functionalization of 3D-printed scaffolds, demonstrating the relevance of combining surface modification with antibacterial functionality [14]. Guo et al. also examined silver-loaded polydopamine coatings designed to provide antibacterial activity alongside biological responses [15]. These studies provide a materials-science rationale for the antibacterial differences observed in the present study, although their experimental findings cannot be directly equated with clinical infection rates.

Regarding biological performance, radiographic union was observed in 90.0% of patients with coated implants and 80.0% with uncoated implants. Implant stability without loosening was also more frequent in the coated group (95.0% vs. 85.0%). Furthermore, the mean bone ingrowth score was higher in the coated group (3.2 ± 0.8 vs. 2.7 ± 0.9). Although these findings suggest potentially favorable bone integration with coated implants, the differences were not statistically significant. Ma et al. investigated surface engineering of 3D-printed Ti6Al4V scaffolds to enhance osseointegration, while Cvrček et al. evaluated nanostructured TiNb coatings for improving the bioactivity of 3D-printed PEEK. Both studies provide a scientific basis for investigating modified implant surfaces to support biological integration [16,17].

Borgognoni et al. investigated strontium-coated porous implants in an animal model, further illustrating the interest in functional coatings for improving osseointegration. In the present study, peri-implant radiolucency was less frequent in the coated group (5.0% vs. 20.0%), although the difference was not statistically significant [18]. The findings therefore suggest a possible association between coating and favorable implant-related outcomes but do not establish superiority.

The present findings should also be considered in light of the distinction between laboratory bioactivity and clinical outcomes. Merlo et al. and Ma et al. investigated material and cellular responses, whereas the current study assessed clinical and radiographic outcomes [14,16].

LIMITATIONS

The study was limited by its small sample size of 40 patients, single-centre design and relatively short follow-up period. The limited number of infection events may also have reduced the statistical power to detect meaningful differences between the groups.

CONCLUSION

The present study demonstrated lower infection rates and generally more favorable biological outcomes with coated 3D-printed porous implants than with uncoated implants. However, most differences in biological outcomes were not statistically significant. These findings suggest potential benefits of implant coating, although larger studies with longer follow-up are needed to establish its clinical effectiveness.

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CONFLICTS OF INTEREST

There are no conflicts of interest.

REFERENCES

1. Jiang C, Gong G, Xiao S, Zhang S, Chen D, Song S, Dai H, Wu C, Zou Q, Li J, Wen B. Mechanical and biological properties of 3D-printed porous titanium scaffolds coated with composite growth factors. BMC Oral Health. 2025 May 27;25(1):808.
2. Knaislová A, Horkavcová D, Jablonská E, Vojtěch D. Sol-gel TiO2-based coatings in 3D printed porous Ti-6Al-4V alloy structures as efficient antibacterial drug delivery systems: Thorough structural and biological characterization. Applied Surface Science Advances. 2025 Sep 1;29:100816.
3. Li Z, Jin L, Yang X, Liu H, Qian S, Wang Z, Liu J, Wang J, Chen J, Su B, Peng C. A multifunctional ionic liquid coating on 3D-Printed prostheses: Combating infection, promoting osseointegration. Materials Today Bio. 2024 Jun 1;26:101076.
4. Han X, Sharma N, Xu Z, Krajewski S, Li P, Spintzyk S, Lv L, Zhou Y, Thieringer FM, Rupp F. A balance of biocompatibility and antibacterial capability of 3D printed PEEK implants with natural totarol coating. Dental Materials. 2024 Apr 1;40(4):674-88.
5. Diez-Escudero A andersson B, Carlsson E, Recker B, Link H, Järhult JD, Hailer NP. 3D-printed porous Ti6Al4V alloys with silver coating combine osteocompatibility and antimicrobial properties. Biomaterials advances. 2022 Feb 1;133:112629.
6. Hu Y, Lei H, Tan Z, Liu Y, Sun H, Duan Y, Fu X, Liu Y, Liu J, Xiong J, Zhou C. Silver-doped diamond-like carbon

antibacterial coating for 3D-printed titanium alloy total joint implants: Fabrication, characterization and biological function evaluation. Journal of Materials Research and Technology. 2025 Nov 19.
7. Wang Z, Yu Z, Wang Z, Li S, Song L, Xu T, Shen G, Wang Y, Huang T, Dong X, Yang G. Surface-activated 3D-printed PEEK implant enhances anti-infection and osteogenesis. Composites Part B: Engineering. 2024 Mar 15;273:111258.
8. Ma Z, Zhao Y, Xu Z, Zhang Y, Han Y, Jiang H, Sun P, Feng W. 3D-printed porous titanium rods equipped with vancomycin-loaded hydrogels and polycaprolactone membranes for intelligent antibacterial drug release. Scientific reports. 2024 Sep 18;14(1):21749.
9. Milivojevic M, Chen K, Radovanovic Z, Petrovic R, Dimitrijevic-Brankovic S, Kojic V, Markovic D, Janackovic D. Enhanced antimicrobial properties and bioactivity of 3D-printed titanium scaffolds by multilayer bioceramic coating for large bone defects. Biomedical Materials. 2023 Nov 1;18(6):065020.
10. Chen Q, Zhao X, Lai W, Li Z, You D, Yu Z, Li W, Wang X. Surface functionalization of 3D printed Ti scaffold with Zn-containing mesoporous bioactive glass. Surface and Coatings Technology. 2022 Apr 15;435:128236.
11. Sheng X, Wang A, Wang Z, Liu H, Wang J, Li C. Advanced surface modification for 3D-printed titanium alloy implant interface functionalization. Frontiers in bioengineering and biotechnology. 2022 Mar 1;10:850110.
12. Poudel I, Annaji M, Zhang C, Panizzi PR, Arnold RD, Kaddoumi A, Amin RH, Lee S, Shamsaei N, Babu RJ. Gentamicin eluting 3D-printed implants for preventing post-surgical infections in bone fractures. Molecular pharmaceutics. 2023 Jul 17;20(8):4236-55.
13. Zhang X, He J, Qiao L, Wang Z, Zheng Q, Xiong C, Yang H, Li K, Lu C, Li S, Chen H. 3D printed PCLA scaffold with nano-hydroxyapatite coating doped green tea EGCG promotes bone growth and inhibits multidrug-resistant bacteria colonization. Cell Proliferation. 2022 Oct;55(10):e13289.
14. Merlo A, Gonzalez-Martinez E, Saad K, Gomez M, Grewal M, Deering J, DiCecco LA, Hosseinidoust Z, Sask KN, Moran-Mirabal JM, Grandfield K. Functionalization of 3D printed scaffolds using polydopamine and silver nanoparticles for bone-interfacing applications. ACS Applied Bio Materials. 2023 Mar 7;6(3):1161-72.
15. Guo W, Wu Y, Li B, Zhao L, Feng S, Wei Y, Liu C, Huang Y, Wang S, Liu B, Mai H. Silver-loaded polydopamine coating mediated dual-mode antibacterial and biological response for composite scaffolds. Journal of the American Ceramic Society. 2025 Nov;108(11):e70066.
16. Ma C, de Barros NR, Zheng T, Gomez A, Doyle M, Zhu J, Nanda HS, Li X, Khademhosseini A, Li B. 3D printing and surface engineering of Ti6Al4V scaffolds for enhanced osseointegration in an in vitro study. Biomimetics. 2024 Jul 10;9(7):423.
17. Cvrček L, Krčil J, Musilkova J, Musilkova V, Bačáková L, Nehasil V, Denk F, Čejka Z. Nanostructured TiNb coating improves the bioactivity of 3D printed PEEK. Materials & Design. 2022 Dec 1;224:111312.
18. Borgognoni AB, Freund SS, Baas J, Bendtsen MM, Byskov JS, Ranjkesh B, Nyengaard JR, Pauwels R, Almtoft KP, Baad-Hansen T. In-house 3D printed porous implants: does strontium-coating enhance osseointegration? An in-vivo study in large animals. Frontiers in Surgery. 2026 May 22;13:1818358.