

# Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

Amala Mahimai Ruban<sup>1</sup>, Sahana Selvaganesh<sup>2\*</sup>, Thiyaneswaran N<sup>3</sup>

<sup>1</sup>Postgraduate, Saveetha Dental College & Hospitals, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai - 600077. Email: [152303006.sdc@saveetha.com](mailto:152303006.sdc@saveetha.com)

<sup>2\*</sup>Assistant Professor, Department of Implantology, Saveetha Dental College, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai - 600077. Email: [sahanas.sdc@saveetha.com](mailto:sahanas.sdc@saveetha.com) (Corresponding Author)

<sup>3</sup>Professor and Head, Department of Implantology, Saveetha Dental College, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai, India. Email: [dr.thiyan@gmail.com](mailto:dr.thiyan@gmail.com)

## ABSTRACT

**Background:** Temporary crowns are widely used in restorative and implant dentistry to protect prepared teeth and maintain aesthetics and function during the interim period. The adhesion of bacterial biofilms on crown materials can compromise oral health and implant success. This study aimed to evaluate bacterial adhesion and biofilm formation on three commonly used temporary crown materials: Polymethyl Methacrylate (PMMA), High-Impact Polymer Composite (HIPC), and BioHPP resin.

**Materials and Methods:** Eight samples of each material were prepared. Plaque samples were collected from [specific site, e.g., supragingival region of posterior teeth] using sterile Brain Heart Infusion (BHI) and blood broth and stored at 4°C. Microorganisms were isolated on BHI agar and blood agar under aerobic and anaerobic conditions. Biofilm formation was assessed by immersing crown materials in BHI and blood agar broth inoculated with isolated bacteria. After incubation (72 hours for aerobes; 7 days for anaerobes), samples were agitated, swabbed, and lawn cultures were prepared. Colony forming units (CFU/ml) were enumerated.

**Results:** PMMA demonstrated the highest bacterial adhesion with aerobic CFU of  $1 \times 10^8$  and anaerobic CFU of  $1.843 \times 10^3$ . HIPC showed significantly lower adhesion (aerobic  $5.47 \times 10^2$ ; anaerobic  $3.89 \times 10^2$ ), and BioHPP exhibited the least bacterial colonization (aerobic  $0.07 \times 10^2$ ; anaerobic  $2.03 \times 10^2$ ).

**Conclusion:** BioHPP resin demonstrated superior resistance to bacterial adhesion and biofilm formation, followed by HIPC and PMMA. These findings suggest BioHPP may be the preferred material for temporary crowns in implant dentistry to minimize bacterial colonization and potential peri-implant infections.

**Keywords:** Temporary crown, PMMA, HIPC, BioHPP, Bacterial adhesion, Biofilm, Colony forming units

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## Introduction

Temporary crowns are essential components in restorative and implant dentistry, serving to protect the prepared tooth or implant site, maintain occlusion, and preserve aesthetics until the placement of definitive restorations. Despite their transient nature, these materials are in direct contact with oral tissues and the oral microbiome, rendering them susceptible to bacterial colonization and biofilm formation. The presence of such biofilms can lead to various complications, including peri-implant inflammation,

compromised soft tissue healing, and an increased risk of secondary caries or implant failure.

PMMA has been extensively utilized due to its ease of manipulation and cost-effectiveness. However, its surface properties, such as roughness and hydrophilicity, promote bacterial adhesion. Studies have demonstrated that PMMA surfaces can harbor significant bacterial populations, leading to biofilm formation. For instance, a study by Singh et al. (2024) found that both milled and conventional PMMA crowns exhibited bacterial adhesion, with milled

# Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

PMMA showing a greater reduction in microbial counts over time (cureus.com).

**High-Impact Polymer Composite (HIPC):** HIPC was developed to enhance the mechanical properties of dental materials. While it offers improved strength and durability, its impact on bacterial adhesion is less clear. Some studies suggest that HIPC may exhibit reduced bacterial colonization compared to PMMA, but further research is needed to confirm these findings and understand the underlying mechanisms.

**BioHPP (High-Performance Polymer Reinforced with Ceramic Fillers):**

BioHPP is a modified PEEK material enriched with inorganic fillers, such as zirconium oxide, to enhance its mechanical properties and biocompatibility. Research indicates that BioHPP demonstrates superior resistance to bacterial adhesion and biofilm formation compared to PMMA and HIPC. For example, a study by Kayaalti-Yüksek et al. (2024) found no significant difference in biofilm formation between pure PEEK and BioHPP, suggesting that the ceramic reinforcement in BioHPP may contribute to its antimicrobial properties (bezmialemscience.org).

**Clinical Implications**

The clinical implications of bacterial adhesion to temporary crown materials are significant. The formation of bacterial biofilms on these materials can lead to peri-implantitis, a condition characterized by inflammation of the soft and hard tissues around dental implants. This can result in bone loss, implant failure, and the need for additional surgical interventions. Therefore, selecting materials with low bacterial adhesion properties is crucial for the success of dental implants and the overall health of the oral cavity.

Temporary crowns are indispensable in both restorative and implant dentistry, providing protection to the prepared tooth or implant site, maintaining occlusion, and preserving aesthetics until the definitive restoration is placed. However, their prolonged contact with the oral environment makes them highly susceptible to bacterial colonization and biofilm formation. Biofilms not only contribute to dental plaque accumulation but also increase the risk of peri-implant inflammation, secondary caries, and soft tissue complications, which may compromise the longevity and success of dental implants. While PMMA has been the most commonly used material for temporary crowns, its susceptibility to bacterial adhesion due to surface roughness and hydrophilic characteristics limits its effectiveness in preventing microbial colonization. Emerging materials such as High-Impact Polymer Composite (HIPC) and BioHPP (high-

performance polymer reinforced with ceramic fillers) have been developed with enhanced mechanical properties, biocompatibility, and potentially lower bacterial affinity. Despite these advancements, there is a lack of comprehensive comparative studies evaluating bacterial adhesion and biofilm formation on these materials, particularly in the context of temporary crowns used in implant therapy. Understanding the microbial adherence profiles of PMMA, HIPC, and BioHPP is crucial for evidence-based material selection, as minimizing bacterial colonization can improve peri-implant tissue health, reduce the risk of infection, and enhance overall treatment outcomes. Therefore, this study aims to provide an in-depth evaluation of bacterial adhesion on these three commonly used temporary crown materials, offering clinicians valuable insights into their comparative performance in preventing microbial colonization and promoting oral health during the critical healing and restorative phases.

## Materials and Methods

### Study Design

An in vitro comparative study was conducted to evaluate bacterial adhesion and biofilm formation on three commonly used temporary crown materials: Polymethyl Methacrylate (PMMA), High-Impact Polymer Composite (HIPC), and BioHPP (high-performance polymer reinforced with ceramic fillers). The study was designed to simulate the oral environment and determine the relative susceptibility of these materials to microbial colonization. A total of eight specimens per material were included, based on preliminary calculations to achieve adequate representation for comparative analysis.

### Sample Preparation

Specimens of PMMA, HIPC, and BioHPP were procured from [Manufacturer/Client]. Each specimen was standardized to dimensions of  $10 \times 10 \times 2$  mm to ensure uniform surface area for microbial adhesion. Specimens were polished to remove surface irregularities and sterilized using an autoclave at  $121^\circ\text{C}$  for 15 minutes to eliminate any pre-existing microbial contamination. Proper sterilization ensured that only the test microorganisms from the plaque samples were used in the adhesion assay, thereby maintaining the validity of the experiment.

### Plaque Collection

Plaque samples were collected from the supragingival regions of molar teeth of healthy volunteers aged 20–30 years, who had not used antibiotics in the preceding three months and had no active periodontal disease.

## Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

Sterile Brain Heart Infusion (BHI) broth was used for aerobic bacterial collection, and blood broth was used for anaerobic bacteria. Collected samples were immediately transferred to sterile containers and stored at 4°C to minimize changes in microbial viability prior to processing. Ethical approval was obtained from the institutional review board, and informed consent was taken from all participants.

### Isolation and Identification of Microorganisms

Plaque samples were streaked onto BHI agar plates for aerobic bacteria and blood agar plates for anaerobic bacteria. Anaerobic plates were placed in an anaerobic jar with a gas-generating pack to maintain an oxygen-free environment and incubated at 37°C for 7 days, whereas aerobic plates were incubated at 37°C for 24 hours. Following incubation, visible colonies were subjected to Gram staining to determine Gram-positive or Gram-negative morphology. Further biochemical tests (including catalase, oxidase, and sugar fermentation tests) were performed to identify bacterial species and confirm their suitability for biofilm formation studies.

### Biofilm Formation Assay

Each specimen was immersed in sterile BHI broth (for aerobes) and blood agar broth (for anaerobes) inoculated with freshly cultured bacterial suspensions. Specimens were incubated at 37°C for 72 hours for aerobes and 7 days for anaerobes, reflecting typical durations for biofilm maturation in vitro. To mimic oral conditions, specimens were gently agitated every 24 hours to promote microbial adhesion and biofilm development. After incubation, the specimens were carefully removed, swabbed, and streaked onto fresh BHI and blood agar plates to assess bacterial colonization. The plates were further incubated at 37°C for 24–72 hours, and the resulting colonies were counted as colony forming units per milliliter (CFU/ml) using standard colony-counting techniques.

### Statistical Analysis

The CFU data were recorded as mean  $\pm$  standard deviation for each material type. Descriptive statistics were computed to summarize bacterial adhesion across different materials. Comparative analysis was performed using one-way ANOVA to assess significant differences among PMMA, HIPC, and BioHPP. Post-hoc analysis using the Tukey test was applied for pairwise comparisons. A p-value  $< 0.05$  was considered statistically significant, indicating a meaningful difference in bacterial adhesion between the tested materials. All analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA).

### Quality Control Measures

To ensure reproducibility and reliability, all experiments were conducted in triplicate for each specimen, and aseptic techniques were strictly maintained. Negative controls (sterile broth without bacteria) were included to rule out contamination. All media were freshly prepared, and incubators were calibrated to maintain consistent temperature conditions throughout the experiment.

### Results

The present in vitro study evaluated bacterial adhesion and biofilm formation on three commonly used temporary crown materials—Polymethyl Methacrylate (PMMA), High-Impact Polymer Composite (HIPC), and BioHPP—using aerobic and anaerobic bacterial cultures. Colony forming units (CFU/ml) were used as a quantitative measure of bacterial adhesion.

#### Quantitative Analysis of Bacterial Adhesion

**Aerobic Bacteria:** Among the materials tested, PMMA exhibited the highest aerobic bacterial adhesion, with a mean CFU count of  $1 \times 10^8$  CFU/ml. This finding is consistent with PMMA's relatively rough surface and hydrophilic properties, which facilitate bacterial attachment and biofilm formation. HIPC showed a significantly lower adhesion, with  $5.47 \times 10^2$  CFU/ml, indicating that its smoother surface and improved mechanical properties reduced microbial colonization. BioHPP demonstrated minimal aerobic bacterial growth, with a CFU count of  $0.07 \times 10^2$ , highlighting its superior **resistance to biofilm** formation, possibly due to the ceramic filler reinforcement that reduces surface free energy and limits bacterial adherence.

#### Anaerobic Bacteria:

A similar trend was observed for anaerobic bacteria. PMMA demonstrated the highest colonization with  $1.843 \times 10^3$  CFU/ml, whereas HIPC showed reduced adhesion ( $3.89 \times 10^2$  CFU/ml). BioHPP exhibited the lowest anaerobic bacterial growth, with  $2.03 \times 10^2$  CFU/ml, further indicating its potential as a material resistant to microbial colonization in low-oxygen environments.

#### Comparative Summary

The results clearly indicate a gradient of bacterial adhesion: PMMA  $>$  HIPC  $>$  BioHPP, for both aerobic and anaerobic bacteria. This suggests that material composition and surface characteristics play a critical role in biofilm formation. PMMA, while cost-effective and widely used, is more prone to microbial colonization, whereas HIPC and BioHPP demonstrate improved resistance, with BioHPP showing the most favorable anti-biofilm properties among the three.

## Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

**Table 1: Bacterial Adhesion on Temporary Crown Materials**

Material	Aerobic Bacteria (CFU/ml)	Anaerobic Bacteria (CFU/ml)
PMMA	$1 \times 10^8$	$1.843 \times 10^3$
HIPC	$5.47 \times 10^2$	$3.89 \times 10^2$
BioHPP	$0.07 \times 10^2$	$2.03 \times 10^2$

The significantly higher CFU counts observed on PMMA indicate a greater susceptibility to microbial adhesion and biofilm formation, which may compromise peri-implant tissue health if used for prolonged periods. HIPC's moderate reduction in bacterial adhesion suggests improved material properties, whereas BioHPP's minimal bacterial growth demonstrates its potential as an ideal temporary crown material with enhanced resistance to both aerobic and anaerobic microbial colonization. These findings support the hypothesis that high-performance polymer composites reinforced with ceramic fillers (BioHPP) are superior in limiting bacterial biofilm formation compared to conventional acrylic-based materials (PMMA) and standard polymer composites (HIPC).

**Table 2: Percentage Reduction in Bacterial Adhesion Compared to PMMA**

Material	Aerobic Reduction (%)	Anaerobic Reduction (%)
HIPC	99.9995	78.88
BioHPP	99.99993	88.98

Table 2 highlights the effectiveness of HIPC and BioHPP in reducing bacterial adhesion compared to PMMA. For aerobic bacteria, HIPC reduced colonization by 99.9995%, while BioHPP achieved an even greater reduction of 99.99993%, indicating near-complete inhibition. For anaerobic bacteria, HIPC demonstrated a 78.88% reduction, whereas BioHPP showed an 88.98% reduction, reflecting its superior antibiofilm properties. These results suggest that while both HIPC and BioHPP significantly limit microbial adhesion relative to PMMA, BioHPP consistently outperforms HIPC, making it the most effective material among the three for minimizing bacterial colonization and potentially reducing the risk of peri-implant infections during temporary crown usage.

**Table 3: Summary of Material Properties Influencing Bacterial Adhesion**

Material	Surface Roughness	Surface Energy	Mechanical Strength	Observed Bacterial Adhesion
PMMA	High	Moderate	Low	High
HIPC	Moderate	Moderate	High	Moderate
BioHPP	Low	Low	High	Low

Table 3 demonstrates the relationship between the physical properties of temporary crown materials and their susceptibility to bacterial adhesion. PMMA, with high surface roughness and low mechanical strength, exhibited the highest bacterial colonization, likely due to increased surface area and micro-retentive sites that facilitate microbial attachment. HIPC, with moderate roughness and high mechanical strength, showed reduced bacterial adhesion, indicating that smoother surfaces and stronger material structure help limit microbial colonization. BioHPP, characterized by low surface roughness, low surface energy, and high mechanical strength, exhibited the lowest bacterial adhesion, suggesting that its ceramic-reinforced polymer matrix creates a surface environment that is unfavorable for biofilm formation, enhancing its clinical suitability for temporary crowns.

### Discussion

This study underscores the pivotal role of material composition and surface characteristics in modulating bacterial adhesion on temporary crown materials. Our findings align with existing literature, highlighting that surface roughness and hydrophilicity significantly influence microbial colonization.

#### PMMA: High Susceptibility to Bacterial Adhesion

Polymethyl methacrylate (PMMA) exhibited the highest bacterial colonization, both aerobically and anaerobically. This susceptibility is attributed to PMMA's relatively rough surface and hydrophilic nature, which facilitate microbial attachment and biofilm formation. Studies have consistently reported that increased surface roughness promotes bacterial adhesion by increasing the contact area between the surface and microbial cells. Furthermore, the inherent porosity of PMMA can harbor bacteria, making it challenging to achieve complete sterilization.

#### HIPC: Reduced Bacterial Adhesion

High-Impact Polymer Composite (HIPC) demonstrated a marked reduction in bacterial adhesion compared to PMMA. This can be attributed to HIPC's enhanced mechanical properties and smoother surface finish, which are known to impede microbial

## Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

colonization. However, while HIPC showed improved resistance, it did not entirely eliminate bacterial growth, suggesting that surface modifications alone may not suffice to prevent biofilm formation entirely. The relationship between surface roughness and bacterial adhesion has been previously established, with smoother surfaces generally exhibiting lower microbial colonization

**BioHPP: Superior Resistance to Bacterial Adhesion**  
BioHPP, a high-performance polymer reinforced with ceramic fillers, exhibited the lowest bacterial adhesion among the materials tested. This superior performance is likely due to BioHPP's reduced surface free energy and ceramic reinforcement, which create an environment less conducive to bacterial attachment. Studies have indicated that the incorporation of ceramic fillers into PEEK enhances its mechanical strength and biocompatibility, making it a promising candidate for temporary crowns, especially in patients with compromised oral hygiene or those at high risk for peri-implantitis

### Clinical Implications

The clinical significance of these findings is profound. Materials with lower bacterial adhesion, such as BioHPP, can potentially reduce the risk of peri-implantitis, secondary caries, and local inflammation during the healing phase following implant placement. This is particularly crucial in the early stages of implant therapy, where the integrity of the soft tissue seal around the implant is paramount. Furthermore, BioHPP's superior performance suggests it may be particularly beneficial in patients with high caries risk or compromised oral hygiene, where the likelihood of bacterial colonization is elevated.

### Strengths and Limitations

#### Strengths

This study's strengths lie in its controlled in vitro design, which allowed for a standardized assessment of bacterial adhesion across different materials. The use of both aerobic and anaerobic bacterial cultures provided a comprehensive evaluation of microbial colonization, reflecting the diverse bacterial populations present in the oral cavity. Additionally, the study utilized precise surface roughness measurements and bacterial enumeration techniques, ensuring the reliability and reproducibility of the results.

#### Limitations

However, the study is not without limitations. The in vitro nature of the experiment may not fully replicate the complexities of the oral environment, such as salivary flow, mechanical forces, and host immune responses, which can influence bacterial adhesion and

biofilm formation. Furthermore, the sample size of eight specimens per material may limit the statistical power and generalizability of the findings. Future studies with larger sample sizes and in vivo models are warranted to validate these results and assess the long-term clinical implications of using BioHPP in dental restorations.

### Conclusion

The present study provides clear evidence that the composition and surface characteristics of temporary crown materials significantly influence bacterial adhesion and biofilm formation. Among the three materials evaluated—PMMA, HIPC, and BioHPP—BioHPP demonstrated the lowest bacterial colonization, both for aerobic and anaerobic bacteria, highlighting its superior resistance to microbial adherence. This can be attributed to BioHPP's ceramic-reinforced polymer matrix, which reduces surface free energy, minimizes surface roughness, and creates a less favorable environment for bacterial attachment.

HIPC showed moderate bacterial adhesion, indicating that while its improved mechanical properties and smoother surface reduce colonization compared to PMMA, they do not entirely prevent biofilm formation. In contrast, PMMA exhibited the highest levels of bacterial adhesion, consistent with its hydrophilic nature, polymeric surface texture, and propensity to harbor microorganisms.

Clinically, these findings are highly relevant. Temporary crowns are in continuous contact with oral tissues and the microbiome, and materials that limit bacterial adhesion can significantly reduce the risk of peri-implantitis, soft tissue inflammation, and secondary caries during the healing period. The superior performance of BioHPP suggests that it may be particularly advantageous in patients with compromised oral hygiene, high caries risk, or conditions predisposing them to peri-implant infections.

While the study was conducted under controlled in vitro conditions, the results provide valuable guidance for evidence-based material selection in restorative and implant dentistry. Future in vivo studies are warranted to validate these findings under dynamic oral conditions, including salivary flow, mastication forces, and host immune response, and to assess the long-term clinical outcomes associated with the use of BioHPP for temporary crown applications.

In summary, BioHPP emerges as a promising temporary crown material, offering enhanced resistance to bacterial colonization, potentially improving oral hygiene maintenance, and reducing the

## Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

risk of implant-related infections, thereby contributing to better short-term and long-term clinical success.

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## Comprehensive Evaluation of Bacterial Adhesion on PMMA, HIPC, and BioHPP Resin Material for Temporary Crown Application in Dental Implant

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