Impact of Intaglio Surface Geometry on Biofilm and Fungal Colonization in Full-Arch Implant-Supported Prostheses

Tiago Araujo, Meilai Nunez, Jia Fatima, Debora Dias, Andrea Ravida, Martinna Bertolini

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Introduction

- **Biological complications** remain common in full-arch implant-supported prostheses and are largely driven by biofilm accumulation on prosthetic surfaces.
- **The intaglio surface creates a sheltered, moisture-retentive environment that limits hygiene access and may promote microbial persistence.**
- **Zirconia** is widely regarded as a **biofilm-resistant** material; however, the **complex intaglio geometries** of full-arch prostheses may create protected niches that favor **biofilm and fungal** persistence.

- This study aimed to assess whether **intaglio surface geometry** (vertical and horizontal height/undercuts) of full-arch fixed implant-supported prostheses is associated with **biofilm accumulation and Candida colonization**, thereby testing the **assumption of zirconia's resistance** to microbial colonization.

Figure 1 – A, B, C, and D. Representative images of full-arch zirconia prosthesis intaglio surfaces demonstrating variability in geometry, including vertical height, contour, and peri-implant undercuts, with visible plaque accumulation in sheltered areas.

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Materials &Methods

- This longitudinal study included patients rehabilitated with full-arch fixed implant-supported prostheses at the University of Pittsburgh. Eligible patients had prostheses in function for ≥12 months and consented to participate in standardized longitudinal research visits.

- Prostheses were removed, and the intaglio surfaces were disclosed using a plaque-disclosing agent and photographed under standardized lighting and positioning. Digital image analysis was performed to quantify the percentage of biofilm-covered area on the intaglio surface.

Figure 2. Representative intaglio surface of a full-arch prosthesis before and after plaque disclosure. Disclosed images were used for digital quantification of biofilm-covered surface area under standardized photographic conditions.

- Biofilm samples were collected from intaglio surfaces and cultured on YPD and CHROMagar media to detect and presumptively identify *Candida* species, including *Candida albicans*. Culture results were recorded as positive or negative.

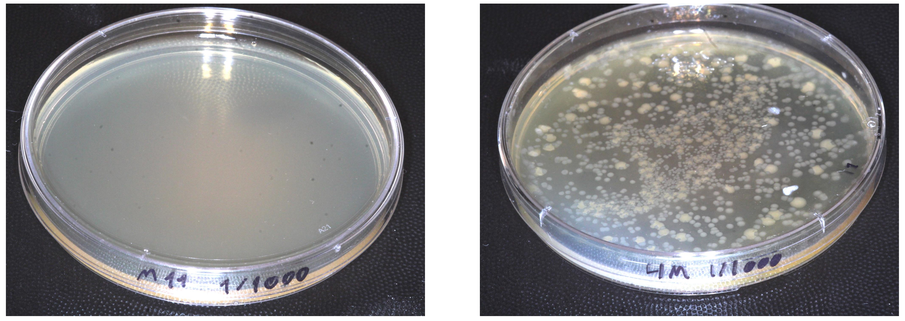

Figure 3. Representative negative and positive fungal cultures from prosthetic biofilm samples grown on YPD and CHROMagar media for detection and presumptive identification of *Candida* species.

- Biofilm accumulation and *Candida* colonization were assessed following prosthesis removal. Intaglio geometry was quantified from 3D scans. Associations were analyzed using correlation analyses and multilevel mixed-effects regression models accounting for patient- and implant-level clustering ($\alpha = 0.05$).

- All statistical analyses were performed using **Stata** (StataCorp, College Station, TX, USA). The primary unit of analysis was the **implant site**, with multiple sites nested within implants and multiple implants nested within patients.

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Results

Study Population and Sample Characteristics

- A total of **12 patients** rehabilitated with full-arch implant-supported prostheses were included in the analysis. Prostheses were present in the maxilla, mandible, or both, resulting in arch-level microbial assessments for superior and inferior prostheses when applicable. Microbial loads were analyzed at the **prosthesis (arch) level**, with fungal and bacterial burden quantified using $\log_{10}$-transformed values.

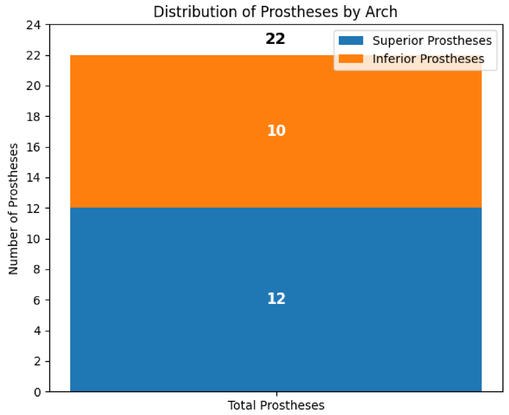

Figure 4. Stacked bar graph illustrating the total number of full-arch implant-supported prostheses analyzed (n = 22), subdivided into superior (blue, n = 12) and inferior (orange, n = 10) arches.

Fungal and Bacterial load distribution

- *Candida* was detected in **9 of 12 patients**, while **3 patients** demonstrated no detectable fungal growth in any sampled prosthesis. Among Candida-positive prostheses, fungal burden varied widely, spanning several orders of magnitude.

- Mean $\log_{10}$ Candida load was **4.46 ± 0.80** for superior prostheses and **4.06 ± 0.92** for inferior prostheses. Individual prosthesis-level values demonstrated substantial heterogeneity within both arches, with no consistent pattern favoring either the maxillary or mandibular prosthesis. Comparison between superior and inferior Candida loads revealed **no statistically significant difference** (p = 0.34).

- Bacterial loads were consistently higher than fungal loads across all prostheses. Mean $\log_{10}$ bacterial load was **4.88 ± 0.98** in superior prostheses and **5.05 ± 0.78** in inferior prostheses. As with Candida, bacterial burden demonstrated overlap between arches, and no significant difference was observed between superior and inferior prostheses (p = 0.65).

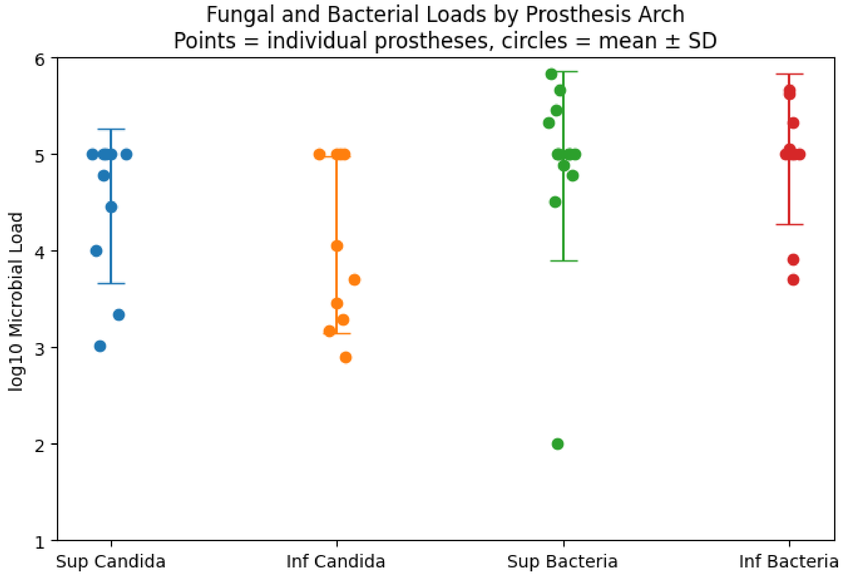

Figure 5. Individual prosthesis-level fungal (*Candida*) and bacterial loads are shown for superior and inferior full-arch implant-supported prostheses. Each dot represents one prosthesis (arch), plotted on a $\log_{10}$ scale. Colored circles indicate group means, with vertical error bars representing ±1 standard deviation. Bacterial loads consistently exceeded fungal loads across both arches, while *Candida* burden demonstrated greater inter-prosthesis variability. No significant differences were observed between superior and inferior prostheses for either fungal or bacterial load.

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Results

Patient-Level Plaque Outcomes by Candida Status

- At the patient level, **mean** modified Plaque Index (mPI) values differed by *Candida* status. Patients without detectable *Candida* demonstrated higher average plaque levels (mean ± SD: **1.83 ± 0.54**, *n* = 3) compared with *Candida*-positive patients (**1.01 ± 0.59**, *n* = 9). These findings indicate that the presence of *Candida* was not associated with increased overall plaque accumulation.

- Assessment of **worst-site** plaque burden revealed a similar pattern. Maximum patient-level mPI values were high in both groups, with *Candida*-negative patients exhibiting a mean maximum mPI of **3.00 ± 0.00**, while *Candida*-positive patients demonstrated a slightly lower mean maximum mPI (**2.56 ± 0.73**). Notably, greater variability in maximum mPI values was observed among *Candida*-positive patients, suggesting heterogeneity in localized plaque accumulation rather than uniformly elevated plaque levels.

- **Together, these patient-level findings support the concept that *Candida* colonization reflects biofilm composition and ecological niche characteristics rather than the magnitude of plaque accumulation alone.**

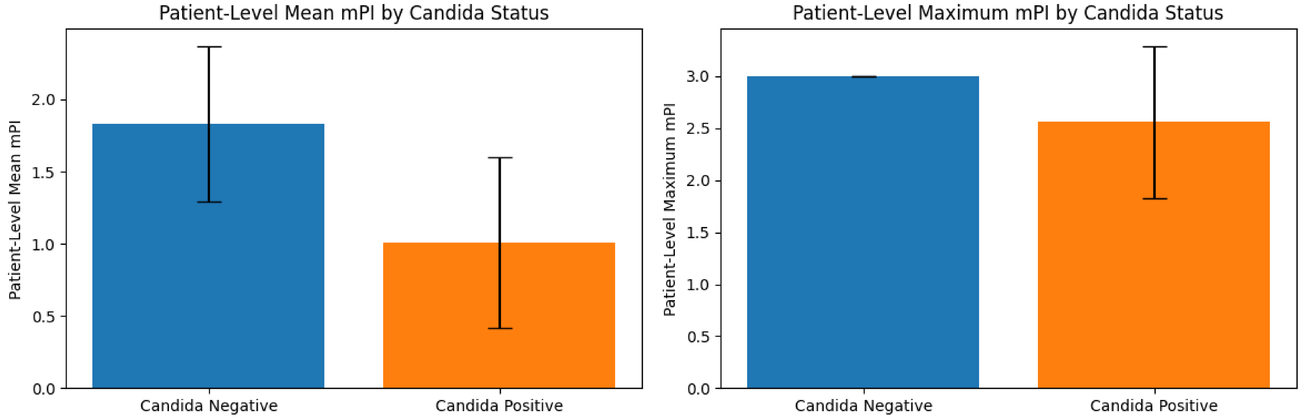

Figure 6. Patient-level modified Plaque Index (mPI) outcomes stratified by *Candida* culture status. *(A)* Mean patient-level mPI values (mean ± SD) for *Candida*-negative and *Candida*-positive patients. *(B)* Maximum (worst-site) patient-level mPI values (mean ± SD) for *Candida*-negative and *Candida*-positive patients. Blue bars represent *Candida*-negative patients and orange bars represent *Candida*-positive patients. Error bars indicate ±1 standard deviation.

- Taken together, these findings indicate that **both superior and inferior full-arch prostheses support substantial microbial colonization**, with bacteria constituting the dominant component of biofilm mass. *Candida* colonization was common but highly heterogeneous, and fungal burden did not differ significantly between arches. These findings indicate that **microbial burden reflects localized prosthetic ecology rather than arch location**.

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Conclusion

- **Both superior and inferior prostheses support high bacterial loads**, indicating that arch location alone does not limit biofilm accumulation.
- **Candida colonization is highly heterogeneous across both arches**, supporting a niche-driven rather than location-driven fungal ecology.
- **Differences between bacterial and fungal loads highlight distinct biological roles**, with bacteria contributing to biofilm mass and Candida reflecting microenvironmental complexity.

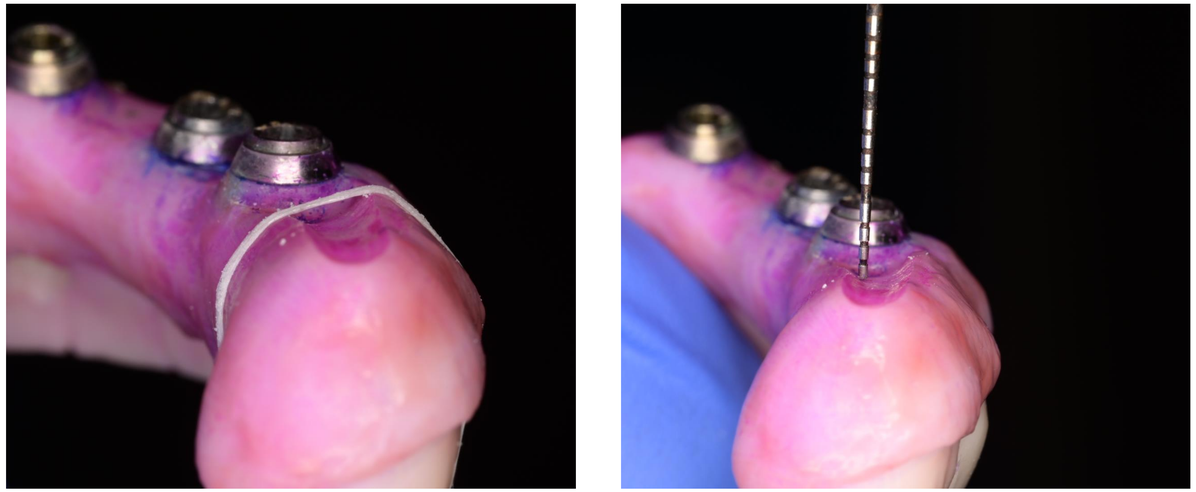

Figure 7. Close-up views of intaglio surface geometry demonstrating localized depth and undercuts that may create protected microbial niches in full-arch prostheses.

Take-Home Message

Prosthetic microenvironment and intaglio geometry may be more important than arch location in shaping microbial ecology in full-arch implant rehabilitation

Clinical Implication

Design strategies minimizing intaglio depth and sheltered undercuts may reduce protected microbial niches and improve long-term peri-implant health.

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