Protocol validation and preliminary results for the long-term effectiveness of zirconia glaze removal and polish as an adjunct to non-surgical therapy in treatment of persistent peri-implant mucositis

By

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Abstract

Objective:

Peri-implant mucositis is a precursor to irreversible bone loss, with recent *in-vitro* evidence suggesting that zirconia crown glaze may be a contributing risk factor. This study aims to clinically determine the effectiveness of non-surgical debridement in removing submucosal plaque from the implant crowns and assess the impact of glaze removal on the resolution of peri-implant mucositis in the short and long term.

Methods:

A randomized clinical trial protocol for removal of submucosal glazed zirconia with a three-step polishing system was developed and first validated *in-vitro* with zirconia discs. Surface roughness (Ra) was analysed directly and via polyvinyl siloxane impressions (PVS) using gypsum and acrylic duplicates. Clinically, implants with peri-implant mucositis were debrided with titanium scalers and ultrasonic instruments. Crowns were then removed to assess residual plaque, before randomly assigned to either the treatment group (glaze removal/polishing) or the control group. Clinical parameters and peri-implant crevicular fluid (PICF) were collected at baseline, 2 months and 12 months.

Results:

The three-step polishing system successfully removed the glaze *in-vitro*, maintaining a surface roughness not significantly greater than 0.2µm ($p = 0.31$). While gypsum models were significantly rougher than original discs ($p < 0.001$), they demonstrated a consistent 3:1 roughness ratio, validating the replication protocol. Clinical observations revealed residual plaque covering 17% of the subgingival surfaces, with the plaque front extending up to the implant-abutment interface.

Conclusion:

The three-step polishing system can predictably be used clinically for removal of glazed zirconia. Preliminary findings indicate that standard debridement fails to achieve total decontamination, leaving significant residual plaque near the implant-abutment junction. Continued recruitment is required to determine how emergence angles and profiles (straight, concave, convex) influence plaque retention and determine how pro-inflammatory and anti-inflammatory cytokines in the PICF changes in response to treatment.

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Introduction

A common treatment option for restoring an edentulous space is with the placement and restoration of implant (Elani et al., 2018). The prevalence of implants in the general adult population has been increasing over time and has been predicted to reach up to 23% in the United States (Elani et al., 2018).

Implant restorations vary based on crown material and the method of attachment to the implant fixture. While single-unit implants were traditionally restored with porcelain-fused-to-metal (PFM) crowns, monolithic zirconia crowns have become a viable alternative due to a lower risk of porcelain fracture, a similar tissue response, and excellent survival rates (Kim et al., 2023; Tajti et al., 2023). Many zirconia crowns are currently glazed to improve aesthetic appearance (Barreto et al., 2023). While crowns can be either cemented or screw-retained, the latter offers significant advantages, including ease of retrievability for superstructure repair and the avoidance of cement-induced peri-implant disease (Ma & Fenton, 2015; Priest, 2017).

As alluded to with the cement-induced peri-implant disease, implants are still susceptible to inflammatory diseases similar to those found around natural teeth. Peri-implant mucositis is a peri-implant disease where plaque accumulation leads to inflammation in the surrounding soft tissue. This condition elevates the risk for developing peri-implantitis, a more severe disease characterized by irreversible loss of supporting bone (Jepsen et al., 2015). Peri-implant mucositis is a common disease with an implant- and subject-based prevalence of 29% and 47%, respectively (Lee et al., 2017). Given these figures, it is imperative to treat mucositis effectively to prevent progression to peri-implantitis (Renvert et al., 2019).

The standard of care for peri-implant mucositis focuses heavily on biofilm control through effective home care and professional non-surgical mechanical debridement (Jepsen et al., 2015; Renvert et al., 2019). Adjunctive therapies such as air-powder abrasives with glycine powder or chitosan brush,

adjunctive photodynamic therapy, local antiseptics, probiotics and antiseptic home care mouth rinses do not show any favourable effects compared to mechanical debridement in the treatment of peri-implant mucositis (Ramanauskaite et al., 2021). Debridement with ultrasonics and hand scalers remains the most effective method for reducing active inflammation (Ramanauskaite et al., 2021). However, with our current treatment options, long-term resolution of peri-implant mucositis is still not predictable. Peri-implant mucositis treated with appropriate oral hygiene instructions and non-surgical mechanical debridement only yielded a reduction in clinical signs of inflammation in 76% of implants following one month and only 38% of implants had complete resolution of the inflammation following three months (Heitz-Mayfield et al., 2011). If mucositis is non-responsive to conventional therapy, the current recommendation is the removal of the implant suprastructure to facilitate debridement (Renvert et al., 2019).

Surface irregularities, such as grooves and scratches, contribute to plaque accumulation and serve as predisposing factors for peri-implant mucositis (Louropoulou et al., 2012). Glazed zirconia has been shown to possess irregular surface pores compared to highly polished zirconia (Scotti et al., 2006). Polished zirconia surfaces with a surface roughness (Ra) of 0.2µm or less prevent bacterial adhesion and provide a more favourable surface for soft tissue attachment compared to glazed surfaces (Brunot-Gohin et al., 2013; Furuhashi et al., 2021; Yu et al., 2016). We propose that in cases of persistent peri-implant mucositis involving a screw-retained glazed zirconia crown, superior resolution of inflammation may be achieved by removing the subgingival glaze and highly polishing the zirconia surface.

The study's objectives are:

1. To determine whether a smooth crown surface (Ra <0.2µm) can be established *in-vitro* after glaze removal and polishing based on adapted protocol.
2. To determine the effectiveness of submucosal non-surgical hand and powered instrumentation in removal of plaque.

3. To assess the short- and long-term effectiveness of submucosal zirconia glaze removal and polishing as an adjunct to non-surgical therapy for treatment of persistent peri-implant mucositis. Persistent peri-implant mucositis is defined as peri-implant mucositis that has failed to resolve following previous treatment in the previous 6 months

The null hypothesis is that the polishing protocol will not produce significant differences in the resolution of inflammation compared to crown removal as part of the non-surgical debridement.

Materials/Methods

In-vitro study

To determine whether a smooth crown surface (Ra < 0.2μm) could be established following glaze removal and polishing, an *in-vitro* study was designed. Zirconium oxide with 5% yttrium oxide discs[1] were sectioned in a green state and sintered according to the manufacturer's directions (1520°C for 130 minutes). The discs were then coated with a porcelain glaze[2] and baked at 140°C for 24 minutes.

Following the baking process, the glaze was removed using a coarse polisher[3]. The specimens were subsequently polished using a sequential protocol involving medium[4] and fine polishers[5]. Each polishing stage was performed at 10,000 rpm for one minute. To ensure the removal of all surface debris between stages, a cotton gauze soaked in 70% isopropyl alcohol was utilized. A single laboratory technician (JC) performed all polishing procedures to minimize inter-operator variability. This polishing protocol was adapted from Mai et al. (2019).

[1] Cercon HT, Dentsply Sirona, Charlotte, North Carolina, USA
[2] IPS e.max® CAD Crystall Glaze, Ivoclar Vivadent Inc, Schann, Liechtenstein
[3] Coarse 9735H-050-HP-TRQ, Meisinger, Colorado, USA
[4] Medium DCA06-170-HP-BL / O, Meisinger, Colorado, USA
[5] Fine DCA12-170-HP-BRN / O, Meisinger, Colorado, USA

Surface roughness (Ra) was assessed directly following the glaze removal and polishing protocol using a profilometer[6]. To verify an indirect assessment method, a polyvinyl siloxane (PVS)[7] impression was taken of the polished discs, and replicas were fabricated using Type IV gypsum[8] and acrylic[9]. A power analysis was conducted to determine the required sample size (β= 0.80, α=0.05). Assuming a standard deviation of 0.03µm (Mai et al., 2019) and an equivalence margin of 0.05µm, it was determined that a minimum of four discs were required to detect whether the polishing protocol maintained a clinically acceptable surface roughness (< 0.2µm). To increase the robustness of the data, a sample size of 10 discs was utilized. A schematic of the *in-vitro* study design is outline in Figure 1.

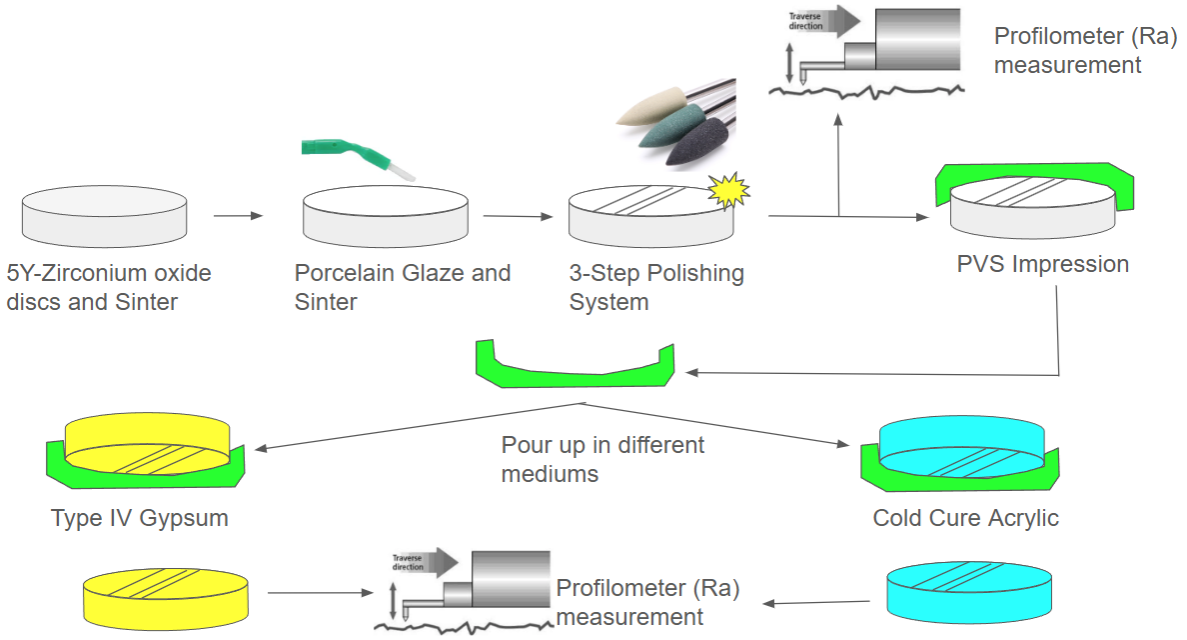

Figure 1: *In-Vitro* Arm Study Design. Zirconium oxide with 5% yttrium oxide discs were sectioned in a green state and sintered according to the manufacturer's directions (1520°C for 130 minutes). The discs were then coated with a porcelain glaze and baked at 140°C for 24 minutes. Following the baking process, the glaze was removed using a coarse polisher. The specimens were subsequently polished using a sequential protocol involving medium and fine polishers. Each polishing stage was performed at 10,000 rpm for one minute. Surface roughness (Ra) was assessed directly following the glaze removal and polishing protocol using a profilometer. To verify an indirect assessment method, a polyvinyl siloxane (PVS) impression was taken of the polished discs, and replicas were fabricated using Type IV gypsum and acrylic. Surface roughness (Ra) was assessed on the acrylic and gypsum replicas.

[6] Surftest SJ-210, Mitutoyo, Kanagawa, Japan
[7] Affinis® Perfect Impressions Light Body, Coltene, Altstätten, Switzerland
[8] New Fujirock ® Type IV, GC Corporation, Tokyo, Japan
[9] ProBase® Cold, Ivoclar Vivadent Inc, Schann, Liechtenstein

Clinical trial

A single-centre, double-blinded, randomized controlled clinical trial was designed to evaluate the short- and long-term effectiveness of submucosal zirconia glaze removal and polishing as an adjunct to non-surgical therapy for persistent peri-implant mucositis. The study was approved by the University of Manitoba Bannatyne Campus Research Ethics Board and subsequently registered with the ClinicalTrials.gov database. The research ethics approval number for this study is HS26321 (H2024:048).

Participants

Volunteers who met the inclusion and exclusion criteria were invited to participate in the study.

Inclusion Criteria:

To be eligible for the study, participants were required to be adults with at least one single, screw-retained, glazed zirconia implant crown that had been in function for at least 1 year. Additional criteria included:

- Submucosal crown margins
- No adjacent implants
- Adequate keratinized tissue (≥2 mm)
- Peri-implant mucositis (Renvert et al., 2018) that persists despite non-surgical debridement performed within the previous 6 months
    - At least one site with positive profuse (line/drop) bleeding on probing (BOP)
    - No probing depth (PD) ≥ 6mm
    - No radiographic bone loss > 2mm past the roughened surface of the implant fixture
- No contraindications to routine dental treatment

Exclusion Criteria:

Patients were excluded based on the following:

- Patients under the age of 18
- Splinted or removable implant prosthesis
- Peri-implant Health or Peri-implantitis defined by Renvert et al., 2018
- Systemic antibiotic use within the last 2 weeks
- Gingival recession past the implant platform
- Current heavy smokers (≥10 cigarettes/day)
- Uncontrolled Diabetes (Type I or II), defined as HbA1C ≥7.0%

Screening and Consent Process

The dental records at the Dr. Gerald Niznick College of Dentistry, University of Manitoba, were searched to identify eligible patients. Potential participants were invited for screening and recruitment at the Dr. Sam Borden Periodontology Clinic. Additionally, recruitment was supported by outreach to general practitioners and local private practice periodontists.

Eligible patients received the study information and were provided the opportunity to ask questions before providing informed consent. To minimize bias, the consent form was reviewed with the patient by personnel not involved in the study. Only patients who provided written informed consent were enrolled. Intra-oral radiographs were obtained during screening if no diagnostic films from the previous 6 months were available. Patients diagnosed with peri-implant mucositis with no history of therapy in the last 6 months underwent conventional non-surgical therapy and were rescreened for eligibility 4 weeks later.

Sample size calculation

To determine the required sample size for the clinical trial, a power analysis was conducted based on previously reported mBI scores. With an expected mBI of 0.63 ± 0.92 for healthy implants and 1.39 ±

0.78 for implants with peri-implant mucositis (Ata-Ali et al., 2013), a target power of 80% ($\beta = 0.20$) and a significance level of $\alpha = 0.05$ were established. The calculation indicated that a total of 44 crowns (22 per group) were necessary to detect a statistically significant difference in the resolution of inflammation between the treatment and control groups.

Randomization and Blinding

Participants were randomly assigned to either the treatment or control group. To maintain a double-blinded design, only the laboratory technician (JC) was aware of the group assignments while the examiner (DS) and the participants remained blinded throughout the study.

Randomization for the first eight participants was performed using block randomization in blocks of four (Kang et al., 2008). Subsequent participants were assigned using Pocock and Simon's method of covariate adaptive randomization (Kang et al., 2008). This method was employed to balance the groups based on tooth type (molar, premolar, or incisor/canine) and contour profile (convex, straight, or concave).

The randomization process was managed by the clinician (VH), whose role was limited to the removal and re-insertion of the implant crowns. Following randomization, the group assignments were sealed in envelopes labelled with the participant's identification code and delivered directly to the laboratory technician (JC).

Baseline Parameters

At the initial appointment, the blinded examiner (DS) collected baseline peri-implant crevicular fluid (PICF) for cytokine analysis (IL-1 β, IL-2, IL-4, IL-6, IL-8, IL-10, TNF-α, and IFN-γ). Additionally, baseline clinical data were recorded for all participants. The specific parameters collected at the implant site included:

- Visualized Plaque Index (PI; Ainamo & Bay, 1975)

- Modified Sulcus Bleeding Index (mBI; Mombelli et al., 1987)
- Peri-implant probing depths (PD)
- Periodontal Screening and Recording (PSR; Landry & Jean, 2002)
- Full Mouth Plaque Score (FMPS) (Ainamo & Bay, 1975)
- Full Mouth Bleeding Score (FMBS)
- Emergence angle (Katafuchi et al., 2018)
- Restoration profile (concave, straight, or convex; Katafuchi et al., 2018)
- Years in function
- Implant system

Data and Sample Collection

Peri-Implant Crevicular Fluid (PICF) Collection

Prior to the collection of PICF, the peri-implant site was dried and isolated using cotton rolls and a saliva ejector. Periopaper[10] strips were used to absorb PICF from the sulcus. At each site, the strip was inserted 1 mm into the gingival sulcus and removed after 30 seconds or upon sufficient saturation. This process was performed at the mesio-buccal (MB), disto-buccal (DB), mesio-lingual (ML), and disto-lingual (DL) sites. The collected strips were placed in Eppendorf tubes and stored at -80°C for subsequent analysis.

Clinical Indices

The visualized Plaque Index (PI; Ainamo & Bay, 1975) was assessed by applying a liquid plaque disclosing agent[11] to the gingival margin of the implant using a cotton tip. After gentle rinsing, plaque was evaluated at six sites (mesio-buccal (MB), straight buccal (B), disto-buccal (DB), mesio-lingual (ML), straight lingual (L), and disto-lingual (DL)) and scored either as a 0 (no visible plaque) or 1 (visible plaque). These scores were averaged to provide a final implant-level PI.

[10]PerioPaper® GCF Collection Strips, Sarasota, Florida, USA
[11]2Tone™ Disclosing Solution, Young Dental Manufacturing Co., Earth City, Missouri, USA

Probing depths (PD) were measured at the same six sites using a plastic probe[12] with a standardized probing force of 0.2N (Herrera et al., 2023). The modified Sulcus Bleeding Index (mBI; Mombelli et al., 1987) was recorded 10 seconds after probing for the same six sites. The scores ranged from 0 to 3:

- 0: No bleeding
- 1: Isolated pinpoint bleeding
- 2: Confluent line of blood along the gingival margin
- 3: Profuse drop of blood

The interproximal emergence angle was measured on radiographs using ImageJ software (Katafuchi et al., 2018). The angle was defined between the long axis of the implant and a line tangent to the restoration surface, starting from the outer collar of the implant platform (Figure 2). The largest possible emergence angle for both mesial and distal aspects was recorded twice by a single examiner (DS) and the mean was utilized as the final value.

The restoration profile (concave, straight, or convex) was also assessed (Katafuchi et al., 2018). Interproximal profiles were determined radiographically, while the buccal profiles were assessed using clinical photographs. For the interproximal profiles, the reference line was drawn between the outer collar of the implant platform to base on the interproximal contact. For the buccal profile, the reference line was drawn between implant-abutment interface to the marked gingival margin line. The profile was determined based on a reference line drawn from the implant platform to the apical aspect of the contact point:

- Convex: crown contours in excess to the reference line
- Straight: crown contours outlined by the reference line
- Concave: crown contours deficient to the reference line

[12]UNC-12 Colorvue™ Probe Tips, Hu_Friedy Manufacturing Co., LLC, Chicago, Illinois

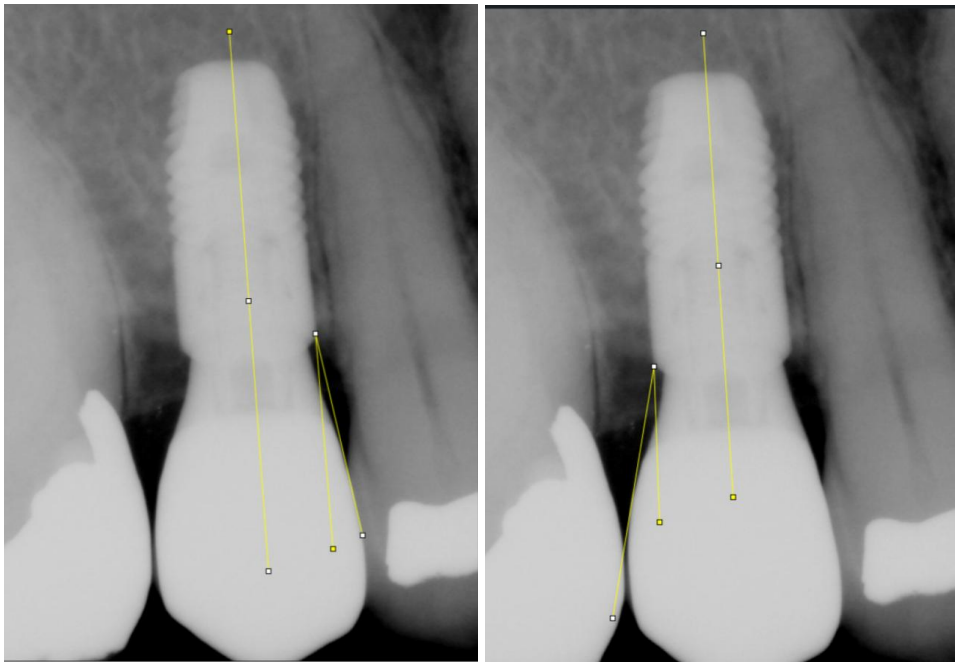

Figure 2: The radiograph of the emergence angle and interproximal profile being calculated. This calculation was performed on the mesial and distal aspect of the #15 implant. The angle calculated in this case was 9.1° and 12.5°, respectively. Based on this radiograph, given the restorative material being deficient to the line drawn from the implant platform to the point just apical to the interproximal contact, this interproximal profile was classified as concave.

The FMPS was assessed only on the natural dentition and was based on the Visual Plaque Index (Ainamo & Bay, 1975). To improve patient compliance, the protocol was modified to exclude the use of a plaque disclosing agent for the remaining dentition. Each tooth was assessed at six sites and scored dichotomously (0 or 1). The FMPS was reported as the proportion of sites scoring 1.

The FMBS was also restricted to natural teeth and was based on BOP. Each tooth was measured at six sites using a UNC-15 probe inserted into the sulcus with an attempted force of 0.20N. Bleeding was assessed 10 seconds after probing and scored as 0 (absence of bleeding) or 1 (presence of bleeding). The FMBS was reported as the proportion of sites scoring 1.

Simultaneously with the FMBS, the PSR was recorded for the natural dentition (Landry & Jean, 2002). Each sextant was assigned a numerical score between 0 and 4:

- Score 0: Absence of bleeding on probing (BOP), calculus, or defective margins; PD < 3.5mm.
- Score 1: Presence of BOP; PD < 3.5mm; absence of calculus or defective margins.
- Score 2: Presence of calculus, defective margins, or BOP; PD < 3.5mm.

- Score 3: At least one site with PD between 3.5mm and 5.5mm.
- Score 4: At least one site with PD > 5.5mm.
- Score X: Sextant with fewer than two teeth.

Residual Plaque Analysis

The retrieved crowns were handled exclusively by the coronal one-third to avoid disturbing the residual subgingival plaque. Residual plaque was identified by immersing the subgingival area in liquid plaque disclosing agent, followed by gentle immersion in water to remove excess dye. Using a surgical microscope at 10x magnification, the buccal, lingual, mesial, and distal surfaces were photographed.

These images were analysed using Adobe Photoshop (CS6 Version 13.0) to detect the presence of residual submucosal plaque. Plaque was quantified at the four surfaces (mesial, distal, buccal, and lingual), and the proportion of the subgingival area occupied by plaque was calculated (Sirinirund et al., 2023).

Cytokines analysis

A Meso Scale Discovery (MSD) V-PLEX 7-plex custom panel Human Inflammatory Cytokine Kit[13] will be used for the detection and quantification of the above-mentioned cytokines in PICF samples as before. For protein extraction, Periopaper® samples will be incubated in 70µl of extraction solution for one hour on ice, followed by a brief centrifugation at 4 ºC. Protein estimation in the samples will be analysed using BioRad DC protein assay and other methods as described previously (Xie et al., 2011). Then, 50µl of the supernatant containing equal amount of protein will be added to the V-PLEX 96 well 10 spot plate.

The solution for extraction will be 1X PBS, and 0.05%Tween-20. The samples and the standard solution will be incubated at room temperature for 2 hours on a plate shaker followed by 3 washes using MSD

[13] Meso Scale Diagnostics LLC, Rockville, Maryland, USA

wash buffer. Next, a detection antibodies mixture will be added in 25µl into each well and incubated at room temperature for 2 hours. Data will be read using a MSD SECTOR Imager 2400[13] after adding 150µl of read buffer as provided by Kit and the units of the readings will be expressed in pg/ml. The detection limit for each of the eight cytokines are as follows: IL-1β (0.646-375pg/mL), IFN-γ (0.37-938pg/mL), IL-2 (0.09-938pg/mL), IL-4 (0.02-158pg/mL), IL-6 (0.06-488pg/mL), IL-8 (0.07-375pg/mL), IL-10 (0.04-233pg/mL), and TNF-α (0.04-248pg/mL), respectively. As sample collection is ongoing, cytokine results will be analysed and reported in a subsequent report.

Calibration

The primary examiner (DS) underwent calibration with 10 patients with dental implants (Iorio-Siciliano et al., 2020). Intra-examiner reproducibility for PI, PD, and mBI was assessed by performing repeat measurements on the same implants one hour apart.

Additionally, the examiner calibrated the probing force to 0.2N (Herrera et al., 2023) following a protocol adapted from Eickholz et al. (2001). The examiner (DS) applied a UNC-12 Colorvue probe perpendicularly to a precision scale with an intended force of 0.2N. To ensure objectivity, a separate examiner viewed and recorded the scale readings while the primary examiner remained blinded to the weight display.

Treatment

Non-surgical Therapy

Following data collection, non-surgical debridement without local anaesthetics was performed by the examiner (DS) using titanium curettes and titanium ultrasonic piezo tips. Debridement performed with magnification loupes was continued until the operator was clinically confident that all plaque had been removed.

[13] Meso Scale Diagnostics LLC, Rockville, Maryland, USA

Crown removal

The implant crowns were removed for all participants by the second clinician (VH). To facilitate removal, access to the screw channel was obtained using a high-speed handpiece and a round diamond bur. The polytetrafluoroethylene (PTFE) tape covering the screw was removed, and the screw was reversed out of the implant fixture.

Once the crown was retrieved, the peri-implant mucosal height was recorded at six sites (MB, B, DB, ML, L, and DL). These measurements were subsequently transposed onto the crown, and a continuous line was drawn to connect these points. This line served as the boundary for the subgingival portion of the crown that would be targeted for intervention in the treatment group.

While the suprastructure was removed, the exposed external surface of the implant fixture was gently debrided using titanium curettes and titanium ultrasonic piezo tips. The area was subsequently rinsed with sterile saline. If more than 2mm of the implant fixture was exposed on any surface (indicating bone loss beyond the inclusion threshold), a diagnosis of peri-implantitis was made. In such cases, the participant was excluded from the study and referred for tailored peri-implantitis management.

Intervention

The laboratory technician (JC) performed the glaze removal and polishing of the subgingival area for the treatment group, utilizing the protocol established during the *in-vitro* phase of the study. Precise care was taken to avoid polishing the interproximal contact areas to ensure the maintenance of contact strength. The control group received no modifications to the zirconia surface.

To standardize the procedure across both groups, all crowns underwent extra-oral debridement using a polishing cup[14] and prophylaxis paste[15]. Following debridement, surface debris was removed by wiping

[14] Prophy Cups Latch Type – Ribbed and Webbed – Latex, Sinclair Dental, North Vancouver, British Columbia, Canada
[15] Kolorz Fine Prophylaxis Paste, DMG America, Ridgefield Park, New Jersey, USA

the crowns with cotton gauze soaked in 70% isopropyl alcohol. The crowns were then returned to the second clinician (VH) for re-insertion.

Crown Re-Insertion

The implant screw was inspected for signs of wear or damage and replaced with a new screw if necessary. Prior to re-insertion, the second clinician (VH) immersed the crown in 0.12% chlorhexidine for 5 minutes. The crown was then seated and re-torqued to the manufacturer's specifications. This sequence was performed in the absence of the primary examiner (DS) to ensure the continued blinding of the clinical assessment.

Following re-insertion, a periapical radiograph was obtained to confirm proper seating of the crown. Once verified, the screw access channel was sealed with polytetrafluoroethylene (PTFE) tape and covered with flowable composite resin. Occlusal contacts were adjusted as needed, and the composite was provided a final polish. Finally, the blinded examiner (DS) provided each participant with personalized hygiene instructions tailed to the implant site. A schematic of the clinical intervention is shown in Figure 3.

Post-Treatment Follow-Up

Follow-up assessments were conducted by the same blinded examiner (DS) at 2 months (exact time was 60–70 days) and 12 months (exact time was 12-13 months) following the intervention. At each follow-up appointment, PICF samples were collected, and the PI, mBI, PD, FMPS, FMBS, and PSR were recorded.

Participants were advised to continue receiving regular periodontal and peri-implant maintenance at 6-month intervals with their primary periodontal provider (Renvert et al., 2019). At the 12-month follow-up, participants were provided with a questionnaire to assess their compliance with the recommended periodontal maintenance protocol over the preceding year.

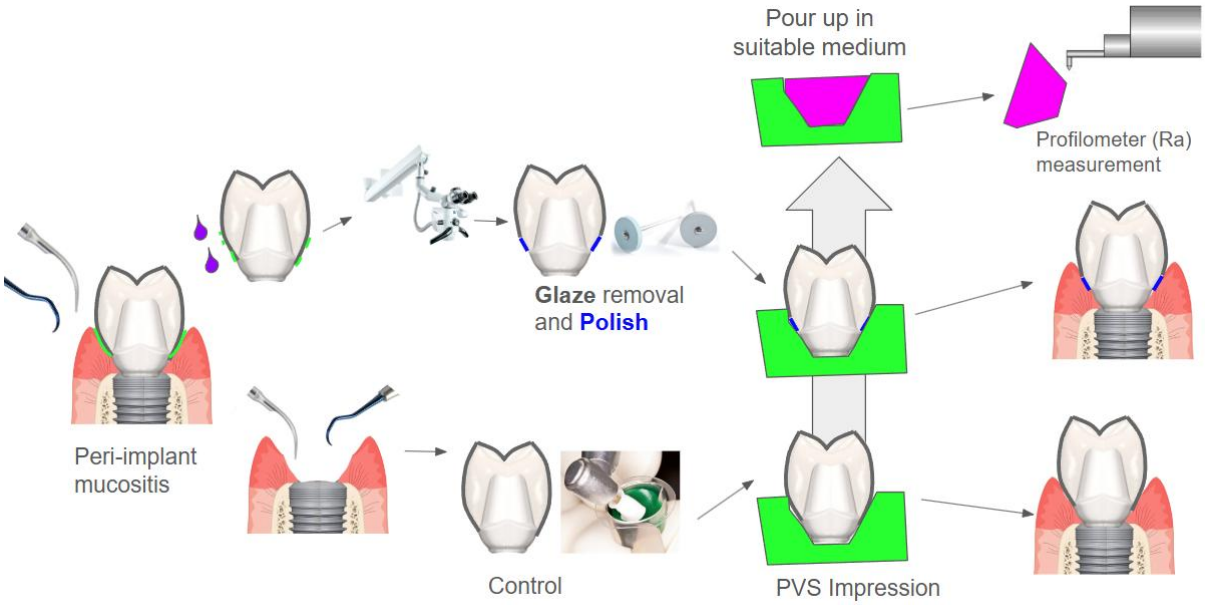

Figure 3: *In-Vivo* Arm Treatment Design. Following baseline data collection, non-surgical debridement without local anaesthetics was performed by the examiner (DS) using titanium curettes and titanium ultrasonic piezo tips. The implant crowns were removed for all participants by the second clinician (VH). While the suprastructure was removed, the exposed external surface of the implant fixture was gently debrided using titanium curettes and titanium ultrasonic piezo tips. All crowns underwent extra-oral debridement using a polishing cup and prophylaxis paste. The area was subsequently rinsed with sterile saline. The laboratory technician (JC) performed the glaze removal and polishing of the subgingival area for the treatment group, utilizing the protocol established during the in-vitro phase of the study. Following the intervention on the crown surface, a polyvinyl siloxane (PVS) impression was taken of the subgingival surface. Prior to re-insertion, the second clinician (VH) immersed the crown in 0.12% chlorhexidine for 5 minutes. The crown was then seated and re-torqued to the manufacturer's specifications.

Statistical Methods

To compare the Ra of the original discs to the 0.2µm threshold, a one-sample t-test was used. A paired-samples t-test was used to compare the Ra of the disc duplicates with their corresponding original discs and to assess the relative proportion of roughness between the two groups.

A one-sample t-test was also used to evaluate the probing force calibration relative to the gold-standard force of 0.2N. Intra-examiner reliability for PI, PD, and mBI was calculated using weighted Cohen's Kappa (κ) for each recorded site. An independent t-test was used to compare the mesial and distal emergence angles.

To evaluate the effectiveness of hand and powered instrumentation for biofilm removal, the primary outcome was the proportion of residual plaque in the subgingival region of the crown. A one-way ANOVA was used to compare residual plaque percentages across the four crown surfaces (mesial, buccal, distal, and lingual/palatal).

Regarding clinical response to the intervention, the primary outcome was the change in mBI. To assess changes across all clinical parameters, a paired-samples t-test was used to compare baseline data with 2-month post-treatment results. Statistical analyses were not performed for the 12-month data set due to the limited sample size available at that time point.

Results

In Vitro

Unless otherwise stated, all data are presented as mean ± standard deviation (SD). A paired-samples t-test revealed a statistically significant increase in surface roughness from the Original group to the Gypsum group ($p < 0.001$). The mean Ra value for the Gypsum group (Ra = 0.635 ± 0.037µm) was significantly higher than that of the Original group (Ra = 0.210 ± 0.061µm) (Table 1, Figure 4). The gypsum is approximately 3x rougher than the original discs (Table 1). The mean Ra value for the Acrylic group (Ra = 2.782 ± 0.623µm) was significantly higher than that of the Original group (Ra = 0.210 ± 0.061µm) (Table 1, Figure 4).

Table 1: The surface roughness of the discs and its gypsum and acrylic duplicate measured in Ra (µm).

Disc #	Original Disc Surface Roughness (Ra, µm)	Gypsum Duplicate Surface Roughness (Ra, µm)	Acrylic Duplicate Surface Roughness (Ra, µm)	Gypsum/Original
1	0.207	0.599	1.794	2.894
2	0.203	0.643	3.027	3.167
3	0.185	0.694	3.150	3.751
4	0.136	0.596	3.139	4.382
5	0.196	0.619	3.332	4.541
6	0.196	0.619	1.473	3.158
7	0.281	0.608	2.859	2.164
8	0.285	0.643	2.970	2.256
9	0.302	0.634	3.026	2.010
10	0.166	0.700	3.054	4.212
Mean ± SD	0.210 ± 0.061	0.635 ± 0.037	2.782 ± 0.623	3.263 ± 0.929

The mean Ra of the original discs is not significantly different from 0.2µm (p = 0.612) [Confidence Interval: 0.156, 0.244]. The gypsum duplicates are 3x rougher than the original discs (p = 0.394) [Confidence Interval: 2.335, 3.665].

Note: Ra = Arithmetic mean deviation of the surface profile, SD = standard deviation

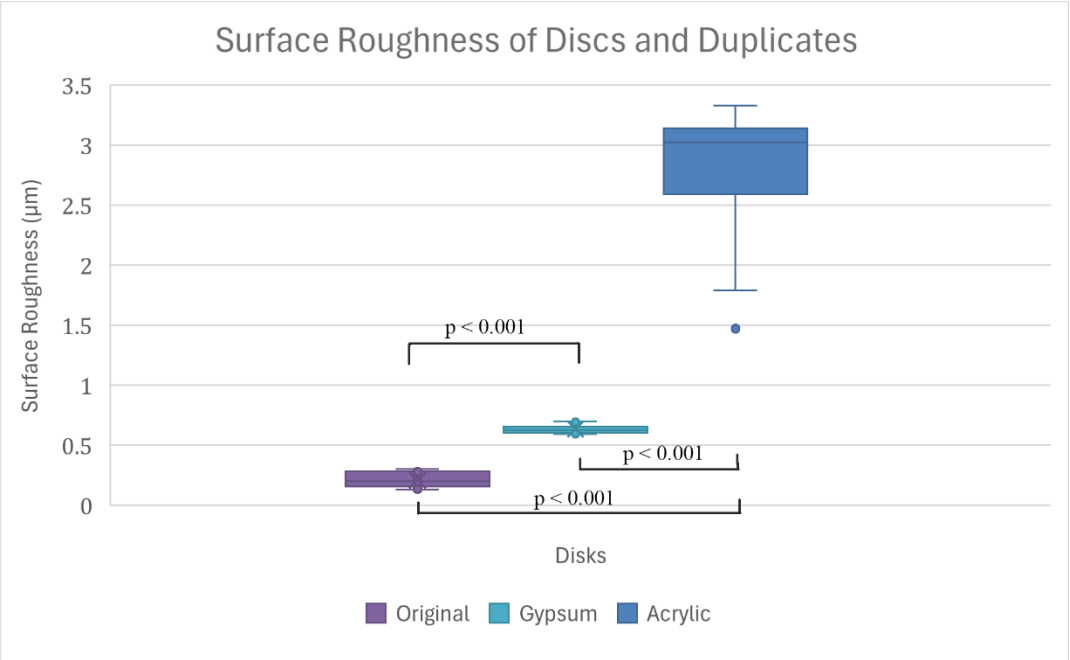

Figure 4: Surface Roughness of Discs and Duplicates measured in Ra (µm). The mean ± SD of the Ra of the original, gypsum and acrylic discs are 0.210 ± 0.061µm, 0.635 ± 0.037 µm, 2.782 ± 0.623 µm and respectively. The mean Ra of both the gypsum and acrylic duplicates is significantly higher than the original discs (p < 0.001). The mean Ra of the acrylic duplicates is significantly higher than the gypsum duplicates (p < 0.001).

Note: SD = standard deviation, The box represents the interquartile range, the centre line represents the median, and the whiskers represent the range.

Clinical Calibration

To ensure standardized clinical measurements, the examiner's probing force was calibrated to a target of 0.2N (20 g). The mean probing force recorded was 20.4 ± 5.28g, which was not significantly different from the 20g target (p = 0.81; Figure 5). These results confirm that the examiner was able to accurately and consistently replicate the required probing force throughout the study.

Intra-examiner reliability was assessed for 61 sites for PI, PD, and mBI (Table 2). The results demonstrated a high level of reproducibility for examiner DS. For PI, exact agreement was achieved with 100% exact agreement and a weighted Kappa (κ) of 1.0. PD showed a substantial weighted κ of 0.72. Although the exact agreement was 73.77%, the agreement within ±1mm reached 100%, confirming that any variations were within an acceptable clinical range. Finally, mBI demonstrated excellent reliability with 95% exact agreement and a weighted κ of 0.85. Overall, these findings indicate that the collection of the clinical parameters throughout the rest of the study were consistent and reliable.

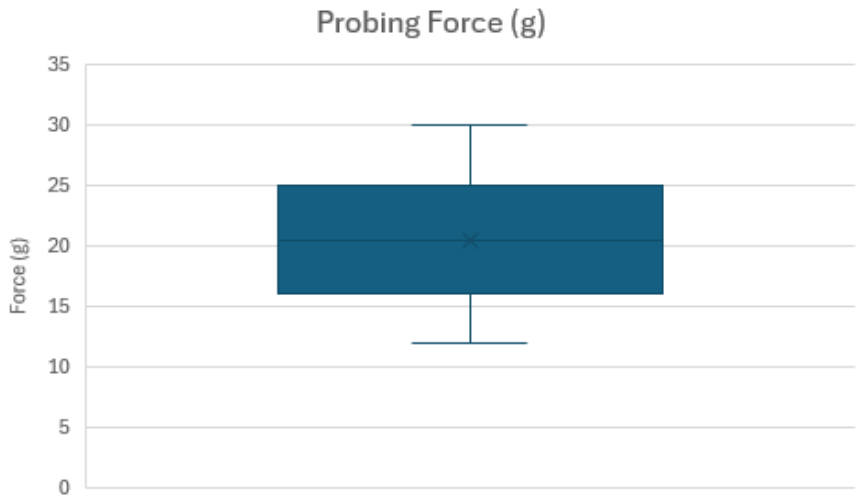

Figure 5: Probing Force Calibration. Intra-examiner calibration (N=10) yielded a mean probing force of 20.4 ± 5.3g (SD) which not statistically different from the target goal of 20g (equivalent to 0.2N) (p = 0.81).
Note: SD = standard deviation, The box represents the interquartile range, the centre line represents the median, and the whiskers represent the range.

Table 2: Intra-examiner reliability for PI, PD and mBI during clinical calibration performed intraorally.

Parameter	Number of sites	Exact Agreement (%)	Agreement ± 1mm	Weighted Kappa (κ)
PI	61	100.00	N/A	1.00
PD	61	73.77	100%	0.72
mBI	61	95.00	N/A	0.85

Note: PI: plaque index, PD: probing depth, mBI: modified Bleeding Index.

Clinical Results

A total of five participants (3 females, 2 males) with five implant-supported crowns were enrolled in the study. The mean age was 66.2 (range: 47-74 years old). All patients were non-smokers and did not report a history of diabetes. To maintain the double-blinded natural of the on-going trial, the group assignments for these initial participants remain unidentified.

Five potential cases were excluded from the study for various reasons. Two cases demonstrated resolution of peri-implant mucositis at the time of the scheduled intervention. Two crowns could not be retrieved despite successfully removing the prosthetic screw. One participant was on a course of antibiotics within two weeks of the intervention.

The clinical characteristics of the included crowns are summarized in Table 3. The sample consisted of one incisor, two premolars, and two molars, distributed across the maxilla (n = 3) and mandible (n = 2). The crowns had been in function for a mean of 5.6 years (range: 2–8 years). The average mesial and distal emergence angles were 19.0 ± 6.2° and 19.5 ± 6.0°, respectively. There was no statistically significant difference between the mesial and distal emergence angles (p = 0.90).

Following scaling without local anaesthetics, the residual plaque was quantified for each surface and for the crown overall (Table 4). The highest proportion of residual plaque was observed on the mesial surface (27.3 ± 6.8%) while the lowest was recorded on the distal surface (11.0 ± 7.9%). A one-way ANOVA revealed no statistically significant differences in residual plaque across the four surfaces (F

(3,12) = 2.9674, $p = 0.063$). Although a trend suggests that the mesial surface retains the highest surface area of plaque, this did not reach statistical significance.

Table 3: Prosthesis specifications for each sample.

Sample #	Site	Tooth Type	Buccal Profile	Interproximal Profile	Years in Function	Mesial Emergence Angle (°)	Distal Emergence Angle (°)
1	36	Molar	Straight	Concave	8	22.5	25.4
2	24	Premolar	Concave	Convex	6	24.2	14.3
3	15	Premolar	Concave	Concave	4	9.1	12.5
4	45	Molar	Convex	Convex	8	22.5	25.4
5	12	Incisor	Straight	Convex	2	16.8	19.9

The average years of function was 5.6 years. The average mesial and distal emergence angle with its standard deviation was 19.0 ± 6.2° and 19.5 ± 6.0°, respectively. The mesial and distal emergence angle are not statistically significantly different from each other ($p = 0.90$).

Notably, the overall residual plaque retained on the crown surfaces was significantly greater than 0% ($p < 0.001$), indicating that current scaling methods are ineffective at achieving complete biofilm removal in the subgingival region. Furthermore, the plaque front was seen extending apically to the implant-abutment interface (Figure 6).

Table 4: Detailed residual plaque on different prosthesis surface.

Sample #	Residual Plaque Mesial Surface (%)	Residual Plaque Buccal Surface (%)	Residual Plaque Distal Surface (%)	Residual Plaque Lingual/Palatal Surface	Average Residual Plaque per crown (%)
1	27.5	5.8	14.7	9.1	14.3
2	34.8	5.9	3.3	31.3	18.8
3	23.6	28.5	11.9	30.7	23.7
4	18.8	14.8	22.2	4.8	15.1
5	31.8	8.6	2.7	10.1	13.3
Average residual plaque per surface (%) ± SD	27.3 ± 6.8	12.7 ± 9.5	11.0 ± 7.9	17.2 ± 12.4	17.0 ± 10.9

The average residual plaque ± SD for all surfaces on all crowns combined is 17.0 ± 10.9%. Based on the one way-ANOVA test, there are no statistically significant differences in the residual plaque among the different surfaces (F (3, 12) = 2.97, $p = 0.063$). The one sample t-test for the overall residual plaque for all crowns combined showed that the residual plaque is statistically significantly larger than 0% ($p < 0.001$).
Note: SD = standard deviation

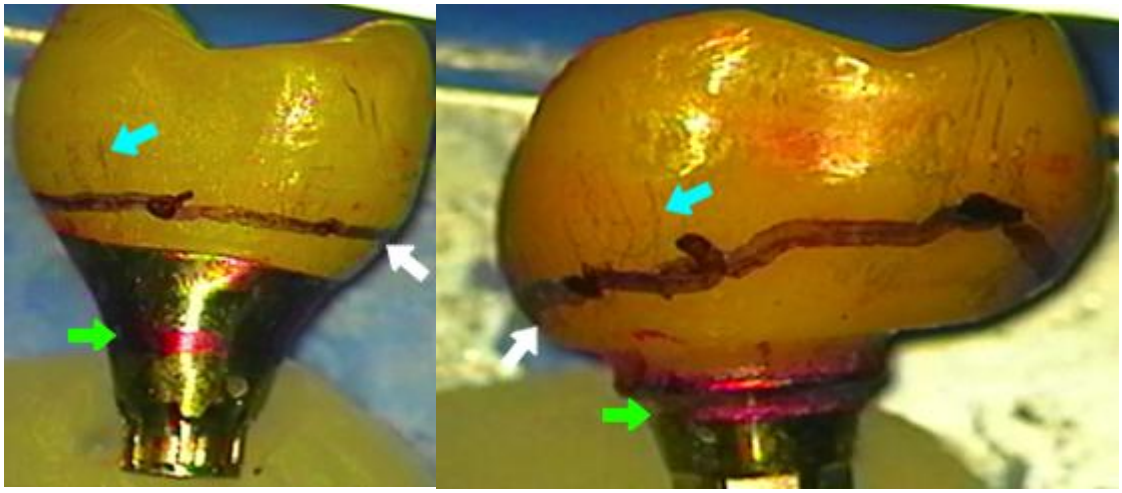

Figure 6: Extraoral photos of residual plaque on the removed crowns. The image on the left is a distal view of the #15 implant crown and the image on the right is distal view of the #45 implant crown. The images depict the disclosed residual plaque depicted by the pink interface areas. The black line (white arrow) is drawn based on the tissue height measurements transposed onto the crown. Black marks (blue arrow) on the crown can be seen from the debridement performed. For both implants, there is a patch of residual plaque extending to the implant-abutment interface (green arrow). For implant #45 (right side), the buccal cantilever is large and complicates access for probing and intra-oral debridement.

While this report does not include a comparative analysis of the specific intervention types, the longitudinal changes in clinical parameters following peri-implant mucositis treatment are illustrated in Figures 7 and 8 and Table 5. Individual crown data are presented in Figure 7 to demonstrate intra-case changes over time.

For PI, all included crowns exhibited a decrease following treatment that was sustained throughout the one-year follow-up period. Regarding PD, most crowns demonstrated an initial reduction with a trend to return toward baseline levels at the 12-month assessment. The mBI showed a significant short-term decrease for most cases. By the one-year follow-up, some crowns maintained these low levels while others rebounded to baseline values.

No consistent trends were observed for full-mouth parameters (PSR, FMPS, and FMBS). In the short term, some cases showed a reduction in these scores, while others demonstrated an increase, reflecting the variable nature of overall oral hygiene and periodontal condition among the participants.

When clinical parameters were analyzed as a moving average, clearer longitudinal trends emerged (Table 5, Figure 6). Both the PI and mBI demonstrated a decrease in the short term. While the mBI tended to return toward baseline levels in the long term, the PI exhibited a further decrease at the 12-month interval. Similarly, the FMPS decreased at two months and continued to decline over the one-year period. The FMBS showed a marginal increase in the short term but decreased considerably by the 12-month follow-up. The PD and PSR scores both decreased at two months but returned toward baseline levels in the long term.

Paired t-tests comparing baseline and 2-month post-treatment results revealed no statistically significant differences across the clinical parameters (Figure 8). However, both the PI ($p = 0.078$) and mBI ($p = 0.051$) demonstrated a strong trend toward reduction following the intervention. A marginal decrease in PD was also noted at two months ($p = 0.15$). Statistical analyses for the 12-month data set were not possible due to the limited sample size available at that time point.

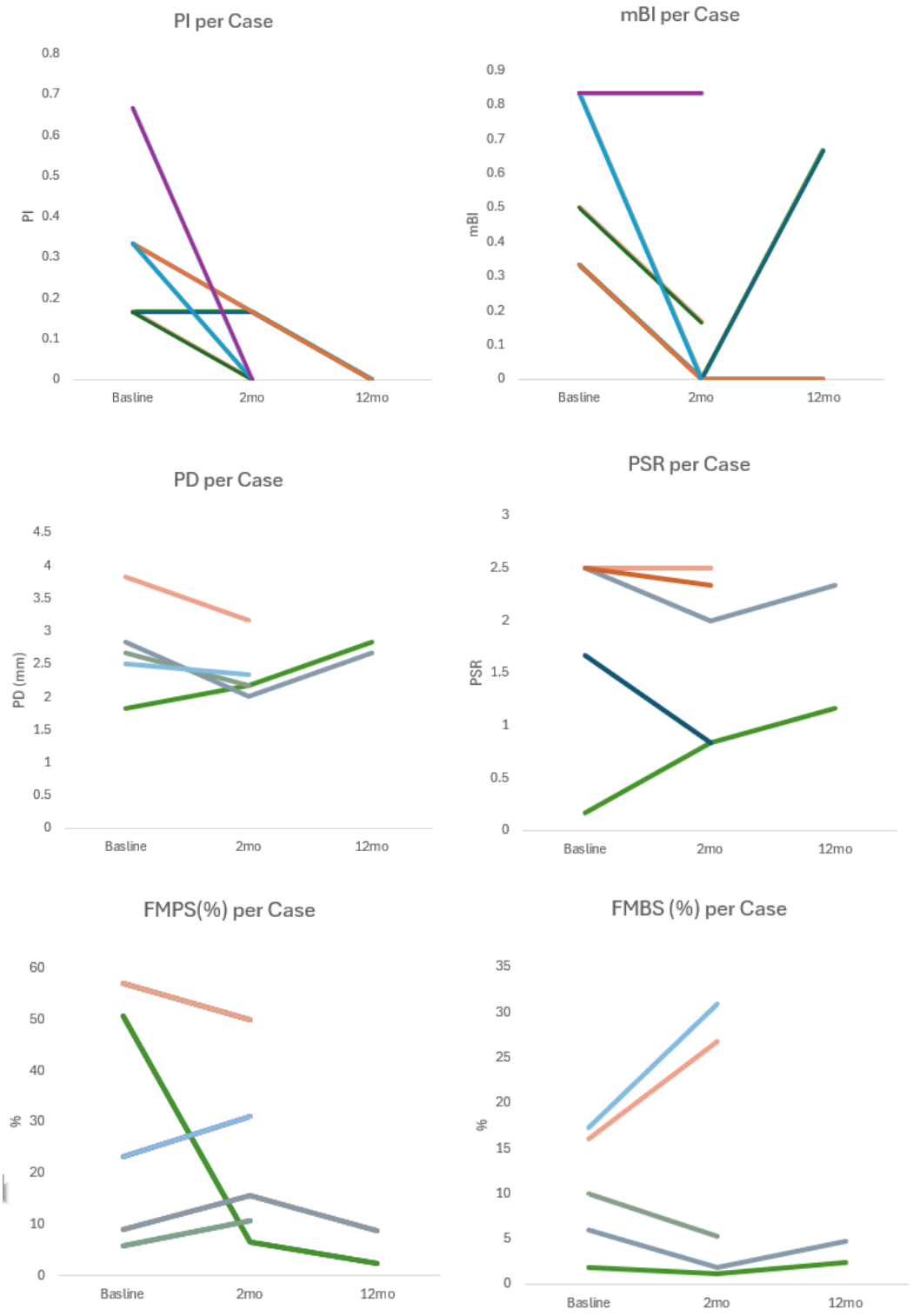

Figure 7: The changes in the clinical parameters (PI, mBI, PD, PSR, FMPS, FMBS) throughout the study for each case. Each coloured line represents the changes specific to each case over the subsequent examinations. As this is a continuing study, some cases are still pending their final examination.
Note: PI = plaque index, mBI = modified Bleeding Index, PD = Probing Depth, PSR = Periodontal Screening and Recording, FMPS = Full Mouth Plaque Score, FMBS = Full Mouth Bleeding Score. 2mo post = 2 months post-treatment, 12mo post = 12 months post-treatment

Table 5: The mean ± SD of the clinical parameters (PI, mBI, PD, PSR, FMPS, FMBS) throughout the study.

	Preop	2mo Post	12mo Post
PI	0.33 ± 0.18	0.07 ± 0.08	0.00 ± 0.00
mBI	0.57 ± 0.32	0.20 ± 0.32	0.33 ± 0.33
PD	2.73 ± 0.65	2.37 ± 0.41	2.75 ± 0.08
PSR	1.87 ± 0.91	1.70 ± 0.73	1.75 ± 0.58
FMPS	29.15 ± 21.12	22.77 ± 15.92	5.51 ± 3.13
FMBS	10.23 ± 5.87	13.21 ± 12.91	3.57 ± 1.19

Note: PI = plaque index, mBI = modified Bleeding Index, PD = Probing Depth, PSR = Periodontal Screening and Recording, FMPS = Full Mouth Plaque Score, FMBS = Full Mouth Bleeding Score. 2mo post = 2 months post-treatment, 12mo post = 12 months post-treatment, SD = Standard Deviation

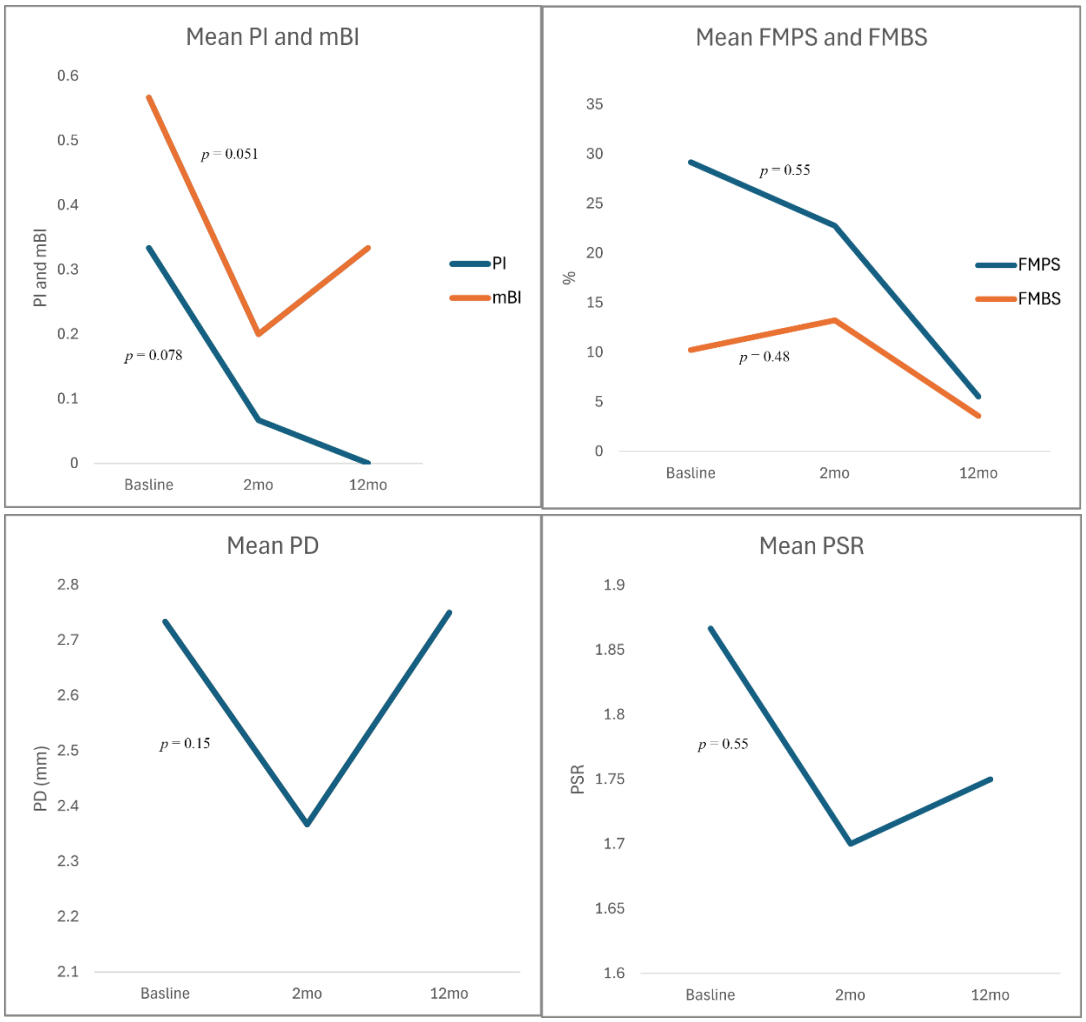

Figure 8: The moving average of clinical parameters (PI, mBI, PD, PSR, FMPS, FMBS) throughout the study. The results of the paired T-test comparing the baseline and 2 months post-treatment parameters are shown on the graphs. Despite none of the changes between baseline and 2 months post-treatment reporting any statistically significant differences, the PI and mBI both have a strong trend towards decreasing after the intervention (p = 0.078, p = 0.051, respectively). There may also be a marginal decrease in the PD after two months (p = 0.15). Statistical analyses could not be carried out for the 12 months post-treatment data set due to the limited number of samples. *Note: PI = plaque index, mBI = modified Bleeding Index, PD = Probing Depth, PSR = Periodontal Screening and Recording, FMPS = Full Mouth Plaque Score, FMBS = Full Mouth Bleeding Score. 2mo post = 2 months post-treatment, 12mo post = 12 months post-treatment*

Discussion

Protocol Validation

The baseline surface roughness (Ra) of the original zirconia discs in this study was not significantly different from 0.2µm. This value is widely regarded in the literature as the "threshold" surface roughness for bacterial colonization (Quirynen & Bollen, 1995). Achieving an Ra below 0.2µm is a primary target for dental materials because further reduction beyond this point does not result in a significant decrease in plaque accumulation. This concept is supported by Bollen et al. (1996) by which they demonstrated that comparing abutments with a surface roughness of 0.2µm versus 0.06µm had no major impact on supra- or subgingival microbial composition and quantity.

Conversely, increasing the surface roughness facilitates plaque accumulation by providing a larger surface area for initial bacterial attachment (Quirynen & Bollen, 1995). It also provides a protective niche, shielding bacteria from the shear forces generated by tongue movement, salivary flow, and routine oral hygiene measures (Quirynen & Bollen, 1995).

In the current study, polishing the zirconia discs with the Meisinger polishing system resulted in an Ra of 0.210± 0.061µm. When comparing these results to the existing literature, Ra values vary despite the use of identical polishing systems. For instance, Caglar et al. (2018) examined zirconia discs polished with the same Meisinger system with the three-step protocol and reported a mean Ra of 0.28 ± 0.11 µm while Mai et al. (2019) reported significantly lower values of 0.08 ± 0.03 µm.

Interestingly, Mai et al. (2019) found that simplifying the protocol to a two-step process (coarse and medium polishers) yielded a similar surface roughness (0.09 ± 0.08µm). The discrepancies in Ra across these studies may be attributed to confounding factors in the polishing process, such as operator experience, polishing force, and the disc speed (rotations per minute). Despite these variations, the

original discs utilized in our study successfully met the established clinical standard of 0.2μm for minimizing bacterial retention.

In the current study, the surface roughness of both the gypsum and acrylic duplicates was significantly higher than that of the original zirconia discs ($p < 0.001$), with the gypsum replicas being approximately three times rougher than the original surfaces. These findings align with established literature regarding the inherent limitations of dental stone in replicating highly polished surfaces.

Ravnholt (1994) observed that stone replicas of an unused glass slab (Ra = 0.0052μm) resulted in an Ra of 0.65μm, representing a surface nearly six times rougher than the original. This discrepancy in texture was attributed to the inherent irregular arrangement and the specific dimensions of the calcium sulfate dihydrate crystals within the gypsum (Ravnholt, 1994). In comparison to this study, the Ra of gypsum (0.635μm) closely mirrors Ra (0.65μm), suggesting that the crystalline structure of the dental stone imposes a predictable limit on surface smoothness.

In contrast, previous research suggests that acrylic resin can be an extremely accurate replication material, adding only 0.0138μ to the baseline surface roughness (Ravnholt, 1994). A primary difference between these protocols was the use of heat-cured acrylic in the earlier study versus the cold-cured (autopolymerizing) acrylic utilized here. Ravnholt (1994) employed a heat-curing process in 50°C water under 0.25MPa of pressure to mitigate bubble formation and prevent oxygen inhibition of the surface polymerization. Their protocol was significantly more standardized than the open-air, room-temperature curing used in the current study, which likely explains the increased roughness observed in our acrylic replicas. Given these findings, it is questionable if gypsum is an appropriate medium to replicate the surface roughness of such highly polished surfaces.

To prevent any potential damage to the patient's crowns, our replicas were fabricated using a polyvinyl siloxane (PVS) impression rather than being taken directly from the crown surface. Ravnholt (1994) established that the addition of a PVS intermediary has a negligible impact on final surface roughness,

contributing only 0.000-0.020μm. This confirms that our current protocol using PVS is adequate for capturing surface detail. However, our findings suggest that the acrylic duplication protocol requires refinement, possibly using a heat- and pressure-cured acrylic, before it can be considered a viable alternative to gypsum in this model.

Clinical Calibration

A critical component of the clinical assessment was the standardization of probing force, which averaged 20.4 ± 5.3g in this study. Maintaining a force of approximately 0.2N (equivalent to 20g) is vital for diagnostic accuracy around dental implants. Monje and Salvi (2024) advocates for a standardized probing force of 0.2N around implants in clinical studies to ensure consistency. Heavier forces tend to induce trauma-related bleeding, leading to false-positive bleeding scores, while lighter forces fail to have the probe tip to penetrate consistently within the connective tissue (Monje and Salvi, 2024). By achieving a mean force so close to the 0.2N target, the current study minimizes the risk of measurement error, providing more reliable data for PD and mBI.

The reliability of the clinical measurements was further confirmed through weighted Kappa (κ) analysis. For PD, the study achieved a substantial weighted κ of 0.72. While the exact agreement was 73.77%, the agreement within ±1mm reached 100%, confirming that any minor variations remained within an acceptable clinical range. This level of reliability is consistent with the literature, which report a range of κ values for PD, such as Ji et al. (2014) at 0.69, Iorio-Sicilianoa et al. (2024) at 0.808, and Menezes et al. (2016) at 0.821 to 0.848. While some authors like Clementini et al. (2023) have reported exceptionally high values ($\kappa = 0.98$), the results of the current study remain well within the "substantial" category for clinical research.

The mBI demonstrated even higher reliability, with a 95% exact agreement and a weighted κ of 0.85. This is classified as "excellent" or "almost perfect" agreement. These results mirror findings by de Tapia et al. (2019), who reported a nearly identical κ of 0.85 for mBI alongside a 0.90 for PD. Taken together,

these calibration metrics ensure that the longitudinal changes observed in peri-implant health throughout the study are reflective of true clinical trends rather than examiner variability.

Preliminary Clinical Results

Emergence Angle and Plaque Retention

In the current study, the average mesial and distal emergence angles were 19.0° and 19.5°, respectively. While these angles are statistically similar, a distinct trend emerged showing that the mesial surface retained the highest amount of residual plaque (27.3 ± 6.8%) compared to the distal surface (11.0 ± 7.9%). Recent literature suggests emergence angles ≥30° are associated with higher mBI scores and higher prevalence of peri-implantitis (Atieh et al., 2023). Furthermore, Wang (2025) further noted that concave or straight emergence profiles reduce the risk of peri-implant disease. Emerging evidence is suggesting that a taller abutment height (≥2 mm) might mitigate the risks of wide angles, while an abutment height of < 2mm combined with an angle ≥ 30° can increase peri-implantitis risk by fourfold (Misch et al., 2025).

The disproportionate plaque retention on the mesial surface, despite the favourable emergence angle, may be attributed to proximal contact changes. Greenstein et al. (2016) observed that open mesial contacts occur in 38–65% of cases within just two years of function. This phenomenon is likely driven by the anterior vector of occlusal forces, which causes natural teeth to drift mesially while the ankylosed implant remains stationary, creating a food trap that facilitates plaque accumulation (Greenstein et al., 2016).

Efficacy of Plaque Removal and the Plaque Front

The current study found that overall residual plaque remained significantly greater than 0% ($p < 0.001$) following mechanical debridement. This finding aligns with the *in- vitro* results reported by Tran et al. (2023), who subjected smooth titanium discs to common debridement protocols. Even with air

polishing, identified as the most effective method in that study, residual plaque coverage of 4%–5% persisted (Tran et al., 2023). If total biofilm elimination is unachievable under optimal laboratory conditions, it is unrealistic to expect 100% debridement efficacy in the complex *in-vivo* environment of an implant-supported restoration.

Despite this limitation, non-surgical therapy remains a cornerstone of clinical management. Suarez-Lopez Del Amo et al. (2016) and Renvert et al. (2008) concluded that repeated non-surgical treatment successfully manages peri-implant mucositis. While data specific to implants are limited, classic periodontal research suggests that small amounts of residual plaque create focal areas of inflammation that may remain subclinical (Waerhaug, 1978).

To our knowledge, this study is the first to document debridement efficacy specifically around the implant crown and abutment surfaces. Existing literature largely focuses on residual plaque on the implant fixture within simulated peri-implantitis models, rather than the prosthetic components involved in peri-implant mucositis (Munakata et al., 2022, Rahner et al., 2025, Wei et al., 2017).

While classic studies suggests that bacteria can colonize the microgap between the abutment and the implant, our study provides the first visual evidence that the plaque front can extend apically to the level of the implant-abutment junction in cases of peri-implant mucositis (Ericsson et al., 1995). In contrast to natural teeth, the plaque front is generally located 0.2mm coronal to the border of the junctional epithelium (Listgarten, 1976). Given anatomical studies demonstrating that the supracrestal attachment apparatus around implants typically span 3–4mm (Cochran et al., 1997; Herman et al., 2001), we can expect to find plaque at deeply subgingival despite shallow sulcular depths.

The depth of this plaque front has significant implications for clinical practice. Shi et al. (2020) demonstrated that the use of local anesthesia during scaling and root planning around natural teeth significantly improved pocket depth reduction and bleeding outcomes in sites with PD≥5mm. Given the limited access due to complex prosthetic contours and deep apical plaque front, the use of local

anesthesia may be essential. Our findings suggest that even in shallow pockets, providing local anesthesia during the debridement of peri-implant mucositis sites may lead to superior clinical outcomes by allowing clinicians to thoroughly instrument the entire depth of the contaminated surface.

Clinical Outcomes Following Intervention

Following the debridement intervention, both the PI and mBI demonstrated strong trends toward reduction ($p = 0.078$ and $p = 0.051$, respectively), accompanied by a marginal decrease in PD at the two-month follow-up. These trends are consistent with several control groups in existing literature using scaling and root planning (SRP). For instance, Menezes et al. (2016) observed PD reductions from 2.72mm to 2.37mm, and de Tapia et al. (2019) reported mBI improvements from 1.13 to 0.53. The proximity of our mBI *p*-value ($p = 0.051$) to the significance threshold suggests that the current lack of statistical significance is likely a function of the preliminary sample size rather than a lack of clinical effect. Given these documented trends and the consistency with established benchmarks, it is anticipated that these improvements will achieve statistical significance as the study progresses and the sample size increases.

Limitations

Several challenges were encountered during the execution of this research that impacted the enrollment and initial methodology. The most significant obstacle was identifying eligible participants within a university dental clinic setting. The inclusion criteria requiring persistent mucositis despite six months of prior treatment rendered many potential participants ineligible as the patient population in this setting often demonstrates inconsistent compliance or high attrition rates.

To address these recruitment barriers, outreach events were established to increase study awareness, and educational materials were distributed to local clinics to aid in participant identification. To date, however, no referrals have been received from private practices, possibly due to diagnostic inconsistencies or patient reluctance to transition care to a research setting. Additionally, logistical

concerns such as parking were identified as a deterrent. Consequently, the study now provides parking validation to reduce participant burden. Most significantly, the inclusion criteria are currently being expanded to encompass all cases of peri-implant mucositis, rather than only those classified as "persistent," to facilitate patient recruitment.

A specific technical challenge involved the accurate identification of the subgingival aspect of the crown. Initially, an aerosol indicator spray[16] was applied while the crowns were seated intraorally to demarcate the gingival margin. However, the application pressure forced the spray subgingivally. When combined with the plaque disclosing agent, the indicator darkened and masked the residual plaque deposits. To resolve this, once the crown was retrieved, the soft tissue depth was measured intraorally and subsequently transposed as a reference line on the crown extraorally. While the preliminary stages of this study presented several such obstacles, each methodological refinement has served to enhance the precision and overall quality of the investigation.

Conclusion

This study successfully established that the utilized polishing protocol produces a zirconia surface approximating the clinical "threshold roughness" of 0.2µm. However, laboratory duplication using gypsum and acrylic significantly increases surface roughness, which must be accounted for in *in-vitro* modelling. Clinically, the visual evidence that the plaque front can extend apically to the implant-abutment interface identifies a critical challenge for professional maintenance.

The presence of a deep plaque front suggests that clinicians should aim to debride down to the implant platform, rather than halting instrumentation at the first point of soft-tissue resistance. While mechanical debridement resulted in a trend toward improved peri-implant health, the persistent presence of residual plaque (averaging 17%) highlights the inherent difficulty of achieving total decontamination via

[16]Occlude® Aerosol Indicator Spray, Pascal Company Inc., Bellevue, Washington, USA

intraoral instrumentation alone. Ultimately, these results suggest that the effective non-surgical management of peri-implant mucositis may necessitate the routine use of local anaesthesia. This would allow clinicians to navigate complex prosthetic contours and reach the deep apical plaque front, thereby ensuring more predictable long-term clinical success.

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