FACTORS AFFECTING IMPLANT SURFACE ROUGHNESS AND PLATFORM ALTERATIONS AFTER IMPLANTOPLASTY. AN IN VITRO STUDY SIMULATING DIFFERENT CLINICAL SCENARIOS.

Burgueño-Barris, Genís[*]
Camps-Font, Octavi[§]
Figueiredo, Rui[‡]
Valmaseda-Castellón, Eduard[¶]

(*) DDS, Master of Oral Surgery and Implantology. Professor of the Master's degree program in Oral Surgery and Implantology, Faculty of Medicine and Health Sciences, University of Barcelona.
(§) DDS, Master of Oral Surgery and Implantology. Associate professor of Oral Surgery and Professor of the Master's degree program in Oral Surgery and Implantology, Faculty of Medicine and Health Sciences, University of Barcelona.
(‡) DDS, MS, PhD, Master of Oral Surgery and Implantology. Associate professor of Oral Surgery and Professor of the Master's degree program in Oral Surgery and Implantology, Faculty of Medicine and Health Sciences, University of Barcelona. Researcher at the IDIBELL institute.
(¶) DDS, MS, PhD. Master of Oral Surgery and Implantology. Professor of Oral Surgery. Director of the Master's degree program in Oral Surgery and Implantology, Faculty of Medicine and Health Sciences, University of Barcelona. Researcher at the IDIBELL institute.

‡ Corresponding author:
Dr. Rui Figueiredo
Faculty of Medicine and Health Sciences - University of Barcelona
Campus de Bellvitge; Facultat de Medicina i Ciències de la salut. Despatx de Cirugía e Implantología Bucal
C/ Feixa Llarga, s/n; Pavelló Govern, 2ª planta.
08907 L'Hospitalet de Llobregat; Barcelona (Spain).
Tel: +34 93 402 42 74
E-mail: ruibarbosa@ub.edu; Website: www.mastercirugiabucal.com

Short title: Roughness and platform alteration after implantoplasty

Key findings: Location and the presence of neighboring teeth and of a prosthesis affect the implantoplasty results.

Conflict of interest and sources of funding

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ABSTRACT

Purpose: The purpose of this study was to determine which clinical factors might affect the implantoplasty results concerning surface roughness, the presence of residual threads or platform alterations.

Materials and Methods: The implants (n = 60) were placed in 20 resin models (10 edentulous upper arch models and 10 partially dentate lower arch models) and 5mm peri-implant bone defects were created. These models were then placed in simulation mannequins. A single researcher performed the following procedures: implantoplasty of single-unit posterior mandibular implants with adjacent teeth; implantoplasty of single-unit posterior mandibular implants with non-removable restorations; implantoplasty of maxillary implants placed in the anterior zone with no adjacent teeth. The presence of residual threads, gaps in the implant-abutment interface or silicone debris were assessed with a scanning electron microscope (SEM) and the surface roughness (Sa and Sz) was analyzed with a confocal optical microscope. A descriptive and bivariate analysis of the data was conducted.

Results: The implantoplasty surfaces were significantly smoother than the original rough surface implants ($P < 0.05$). The surface roughness was significantly higher in posterior implants with neighboring teeth. Gaps in the implant-abutment interface were infrequent (6.67%; 95% CI: 2.62 to 15.93) and only appeared in the posterior zone ($P = 0.123$). The odds ratio for the presence of residual threads and silicone debris (posterior implants with adjacent teeth vs. anterior implants) was 7.1 (95% CI: 4.15 to 12.14; $P < 0.001$) and 5.53 (95% CI: 3.21 to 9.53; $P < 0.001$), respectively. When a prosthetic crown was present, residual threads were 7 times more likely to be found (OR= 7.0; 95% CI: 3.5 to 13.99; $P < 0.001$).

Conclusions: Implantoplasty leads to a significant reduction in the surface roughness of implants but is affected by several clinical variables. Obtaining a smooth surface seems to be more challenging in posterior implants with neighboring teeth and when the prosthetic crown cannot be removed. Furthermore, implantoplasty can sometimes cause gaps in the implant-abutment interface and accumulation of silicone debris, especially in areas with limited access.

Keywords: Implantoplasty, dental implants, surface roughness, peri-implantitis.

INTRODUCTION

Peri-implantitis is a chronic disease characterized by peri-implant soft tissue inflammation in conjunction with progressive peri-implant bone loss.(1,2) The risk of peri-implant diseases increases with age and could affect almost half of the implants after a 9-year period.(3) Several treatments for peri-implantitis have been described but the results are not always predictable.(4–7) Most authors recommend an initial non-surgical treatment followed by a surgical procedure.(8,9) Several surgical approaches are possible; they should be selected according to the bone defect anatomy, the esthetic involvement and the presence of keratinized mucosa, among other factors.(9–12)

Implantoplasty, which consists of removing the threads and polishing the exposed area of the implant, has been recommended to reduce the surface roughness of implants affected by peri-implantitis. The aim of the procedure is to detoxify the implant and to reduce biofilm adhesion and facilitate its removal.(13,14) Implantoplasty is usually indicated in resective or combined surgical approaches.(9,13–16)

Even though two recent systematic reviews (17,18) have stated that implantoplasty seems to be a safe procedure without significant biological or mechanical complications, other authors have expressed some concerns. The reduction of the implant's walls might lower its resistance to fracture, especially in cases involving narrow diameter implants with internal connections, unfavourable crown-to-implant ratios or advanced bone loss.(19–22) In addition, implantoplasty releases titanium particles that can remain firmly attached to the soft and hard tissues and may induce an inflammatory reaction.(23–26) Also, this technique might affect the platform area of the implant, compromising the correct seating of the abutment. This might lead to mechanical and biological complications due to the presence of gaps in the implant-abutment interface.

Several bur protocols have been described in the literature. One of the most suitable options seems to be the use of carbide tungsten burs followed by silicone polishers.(18,27) Several studies have obtained excellent surface roughness results with this protocol.(19,21,22,27) However, it should be noted that most of the studies were conducted in an ideal *in vitro* environment with excellent light, visibility and access conditions. Indeed, to the best of the authors' knowledge, only one study used an anatomic model (without soft tissues) placed in phantom heads.(28) However, it only analysed a particular clinical situation (single-unit implants placed in upper molars). Thus, there is no available data on whether surface roughness results might be affected by the position of the implant (anterior vs. posterior), by the presence of adjacent teeth or by the presence of a prosthetic crown. Therefore, the aim of the present *in vitro* study was to determine which clinical factors might affect the implantoplasty results concerning surface roughness, the presence of residual threads and platform alterations.

MATERIALS AND METHODS

Study Set-up

An in vitro study was conducted using 60 grade V dental implants with an external hexagonal connection (Avinent Coral HE® 3.3x10 mm. Avinent Implant System® S.L. Santpedor, Spain) and 20 custom-made models with soft tissues (BoneModels® S.L.U. Castellón, Spain) that simulated an edentulous maxilla (n = 10) and a partially edentulous lower mandible (n = 10). The dental implants employed had a moderately rough surface as a result of the sandblasting, acid-etching and anodizing techniques.

In the lower arch models, 4 dental implants were placed in the first molar and first premolar positions and standard 5 mm deep peri-implant subcrestal defects were created

(Figures 1A and 1B).

In the edentulous upper arch models, 2 narrow diameter implants were placed in the lateral incisors area, leaving 5 mm of the rough surface exposed in order to simulate a horizontal bone defect (Figure 1C).

Identical metal crowns (n = 10) were digitally designed, milled and placed on the implants in the lower left first premolar position (Figure 1A). A cover screw was placed in the remaining implants to protect their implant-abutment connection during the implantoplasty procedure. Before each instrumentation, the models were placed in their anatomical position in a phantom head simulator to recreate a clinical scenario.

Implantoplasty procedure

An experienced clinician (G.B.B.) performed all the implantoplasties using a turbine (GENTLEsilence LUX 8000B; KaVo Dental GmbH, Biberach an der Riß, Germany) under water irrigation, with 2.8X magnification (Galilean HD; ExamVision ApS, Samsø, Denmark) and adequate illumination (FocusTM LED 6000k; ExamVision ApS, Samsø, Denmark). The simplified 3-bur protocol described by Costa-Berenguer et al. (18,27) was followed: an oval-shape tungsten carbide bur (H379 314 023; Komet Dental, Lemgo, Germany) was used to remove the threads, followed by two silicon carbide polishers (9618 314 030 and 9608 314 030, Komet Dental, Lemgo, Germany) to polish the surface. The preparation time for each implant was recorded. Finally, reference points on the buccal, lingual, mesial and distal aspects were established before removing the fixtures with the implant driver. Identical polished titanium prosthetic abutments were then placed on each implant. After applying a 35 N·Cm torque, prosthetic screws (Avinent® Implant System, Santpedor, Spain) were used to retain the abutments.

Analysis of surface roughness

The surface roughness and topography of the dental implants were analyzed under an interferometric confocal microscope (Leica® 3DCM Wetzlar, Germany) with 20X magnification, placed totally perpendicular to the tangent of the surface. Areas of interest (4mm X 6mm) located 2.5 mm below the platform of each area (buccal, lingual, mesial, and distal) were observed. Ten upper jaw implants and 10 molar site implants were explored. An untreated implant and an untreated smooth prosthetic abutment of the same model were used as controls. The implants were randomly assigned. Images were processed with LeicaSCAN (Leica® Wetzlar, Germany) and LeicaMAP (Leica® Wetzlar, Germany) software. Surface roughness was defined by the following three-dimensional parameters:

- Sa (arithmetic mean height): difference in height of each point compared to the arithmetic mean of the surface.
- Sz (average maximal height): sum of the highest peak height value and the highest pit depth value within the defined area.

Assessment of platform deformation

An observer (G.B.B.) explored the implant-abutment and implant-crown interfaces with a scanning electron microscope (FEI ESEM Quanta-200, FELMI-ZFE® Graz, Austria). A total of 8 areas (buccal, lingual, mesial, distal, mesiobuccal, mesiolingual, distobuccal and distolingual) were assessed with 50x magnification. Accordingly, 8 images were obtained for each implant (n = 496) and, if the platform seemed affected, an additional image was taken with 100x magnification. The following parameters were recorded for each image:

- Maximal discrepancy (μm) between prosthetic abutment and implant platform. As the images were captured with a 10º angle, the real discrepancy was obtained after applying the following trigonometry formula: $Discrepancy = Measurement \times \left({}^{1}/_{\cos 10^{\circ}}\right)$.
- Presence of a gap between the abutment and the implant connection (maximal discrepancy of the gap (μm).
- Presence of residual threads or irregularities on the implant surface.
- Presence of silicone debris over the implant surface.

To test intraexaminer agreement and consistency, the assessment of 50 randomly selected images (50 measurements) was repeated after a 2-week interval. The intraclass correlation coefficient (ICC) was 0.98 (95% confidence interval (95% CI): 0.97 to 0.99; $P < 0.001$), showing excellent reliability and consistency.

Statistical analysis

The results of a previous study were used to calculate the sample size (27). Considering 4 groups (upper maxilla without adjacent teeth, lower molar with adjacent teeth, lower premolar with adjacent teeth and crown, and lower premolar with adjacent teeth and no crown) and 6 comparisons (at the mesiobuccal, buccal, distobuccal, mesiolingual, lingual and distolingual points), a 33% difference between the roughest and least rough surfaces was estimated. Ten implants per group were required if a surface roughness of 0.1 μm with a standard deviation (SD) of 0.02 μm (27) was expected, assuming a clinical change of 0.033 μm (33% of the total) with a statistical power of 80% and an alpha risk of 0.05. The implant characteristics were presented as absolute and relative frequencies for categorical outcomes. The groups were compared through bivariate analysis using Chi-square or Fisher's exact tests. The odds ratios (OR) with a 95% confidence interval were

calculated for each covariate.

The normality of the scale variables (roughness parameters and implant-abutment interface discrepancies) was explored through Shapiro-Wilk's test and visual analysis of the P-P and box plots. Where normality was rejected, the interquartile range (IQR) and median were calculated. Where the distribution was compatible with normality, the mean and standard deviation (SD) were used. Differences between groups of scale variables were explored using parametric tests (Student's *t* test for independent samples or one-way analysis of variance (ANOVA)) or nonparametric tests (Mann-Whitney U-test or Kruskal-Wallis test).

The statistical analysis was carried out with Stata14 software (StataCorp®, College Station, TX, USA) using Bonferroni's correction for multiplicity of contrasts. The assumptions underlying the statistical analysis were checked.

RESULTS

The median time employed in performing the implantoplasty was 6 min 40 s (IQR = 48 s). Implants located in molar regions with adjacent teeth (limited access) were associated with a significantly more time-consuming procedure, requiring approximately 10% of additional time ($P < 0.05$ for all pairwise comparisons) (Figure 2).

Table 1 summarizes the surface roughness results obtained for each position. The implantoplasty surfaces were significantly smoother than the untreated surfaces ($P < 0.001$) but rougher than the polished prosthetic abutment ($P < 0.001$) (Figure 3). The roughness parameters were influenced by the position of the implant ($P < 0.001$). Specifically, posterior fixtures had a significantly rougher surface than those in other areas [(Sa: MD = 0.16; 95%CI = 0.10 to 0.21) and (Sz: MD = 4.86; 95%CI = 3.42 to 6.29]). Conversely, both the Sa ($F(3, 75) = 0.23$; $P = 0.876$) and the Sz ($F(3, 75) = 0.58$;

P = 0.629) values were similar on all sides (i.e. buccal, lingual, mesial, and distal) where implantoplasty was performed. Moreover, neither Sa (P = 0.986) nor Sz (P = 0.906) were affected by the side (left or right) in which the implant was placed.

Table 2 and Figure 4 show the presence of residual threads, gaps in the implant-abutment interfaces or silicone debris in each situation analyzed. Residual threads (OR= 7.10; 95%CI: 4.15 to 12.14; P < 0.001) (Figure 4A) and silicone debris (OR= 5.53; 95%CI: 3.21 to 9.53; P < 0.001) (Figure 4B) were significantly more frequent in the molar area in comparison with the upper incisor sites. Four gaps (6.67%; Median: 362.68 µm; IQR: 49.32; Range: 342.00 to 408.29) (Figure 4C) in abutment-implant interfaces were identified in the posterior area (P = 0.123). The presence of a prosthetic crown brought a 7-fold rise in the risk of observing residual threads (OR=7.00; 95%CI: 3.50 to 13.99; P < 0.001). Silicon debris accumulation was also more frequent in implants with crowns, but this difference was not statistically significant (OR = 1.89; 95%CI: 1.00 to 3.60; P = 0.053).

Figure 5 (A and B) shows two radar charts of the distribution of the mean implant-abutment interface discrepancies in the 4 groups (i.e. anterior implants with no neighboring teeth *vs.* posterior implants with adjacent teeth and presence *vs.* absence of the prosthetic crown) for each implant location. All the implants subjected to implantoplasty exhibited some degree of discrepancy between the implant platform and the prosthetic abutment in at least one of the 8 areas assessed (Mean: 68 µm; SD = 57.93; Range: 0 to 408.29). When the prosthetic crown was present, the amount of discrepancy increased significantly (MD = 22.04 µm; 95%CI: 9.13 to 34.95; P = 0.002). On the other hand, the discrepancy results were similar (MD = 9.15 µm; 95%CI: -12.32 to 30.62; P = 0.394) when comparing anterior implants with no neighboring teeth with single-unit implants located in the posterior zone.

DISCUSSION

The present *in vitro* study aimed to determine whether clinical variables like implant location, the presence of neighboring teeth and the presence of a prosthesis might affect the outcome of implantoplasty. The present results have shown that these variables are indeed relevant and that worse surface roughness values were found in difficult access areas. However, all the implantoplasty samples had significantly smoother surfaces than the untreated implants (controls), which clearly indicates that implantoplasty can be performed even in unfavorable situations. In fact, the results were similar to those of most published studies (18,28–30). Still, it is important to stress that it was not possible to obtain an evenly polished surface in all situations.

One limitation of the present research is related to its *in vitro* nature, which always limits the external validity of the results. However, in this study, custom-made anatomical models placed in simulation mannequins were used, reducing this source of bias. In fact, most published papers on this topic have a considerably simpler set up, so reported roughnesses might be unrealistic in real patients.(19,21,22,27,30) Nevertheless, factors like bleeding, limited mouth opening and patients' anxiety, among others, could not be assessed. Thus, the present results are expected to be slightly worse in a clinical setting.

As already mentioned, one of the studies consulted employed custom-made anatomic models placed in a phantom head simulator to improve the generalization of the results.(28) However, the present study offers several important advantages. Firstly, the models had soft tissue. Secondly, the design assessed whether the presence of neighboring teeth and of a crown might affect the result. Finally, it analyzed the outcome variables of surface roughness, the presence of residual threads, the observation of gaps in the implant-

abutment interface and the presence of silicon debris. This clearly demonstrated that areas with more limited access had worse results for all the outcome variables. Indeed, gaps, residual threads and silicon debris were found much more frequently in the most challenging situation (posterior implants with adjacent teeth and with crowns).

According to some papers, implantoplasty slightly reduces the resistance to fracture of dental implants.(27,31) One possible explanation for this could be related to the discrepancies detected between the platforms and the abutments, which might affect the mechanical properties of the implant-abutment complex. In addition, a gap was observed in some locations, despite protecting the connection with a cover screw during the implantoplasty procedure. Tissue level implants or implants with a polished collar would probably be less likely to suffer this complication. The discrepancy could also cause inflammation and marginal bone loss due to bacterial leakage,(32) an issue that might be specially relevant when a combined surgical treatment is used since the gap could be in a critical area, very close to the peri-implant bone. However, this discrepancy would not be as clinically significant when resective approaches are employed, since the gap often lies above the mucosal margin. Future research is necessary to analyze the clinical repercussions of these discrepancies.

The presence of prosthetic crowns made implantoplasty less effective, with more gaps and residual threads and worse surface roughness values. Therefore, implantoplasty outcomes might be better in implants with screw-retained restorations that can be easily removed.

Other in vitro studies have reported slightly smoother surfaces after implantoplasty than those measured in these results. For example, using the same bur protocol, Costa-Berenguer et al. (27) and Behesti Maal et al. (29) reached Sa = 0.1 ± 0.02 μm and 0.41 ± 0.13 μm respectively. Ramel et al. (30) employed a different bur protocol (3 diamond

burs + 2 silicone polishers) and achieved a similar result (Ra = 0.32 ± 0.14 μm). The results of the present study are likely to be more realistic due to the study design.

Finally, implantoplasty generates titanium debris, which induces inflammatory reactions of the peri-implant soft tissue and bone.(23–26) In addition, silicon polishers can also release debris that stays on the implant surface. In this study, silicone debris was found at one third of the locations, usually attached to the platform zone. Posterior implants with neighboring teeth and with crowns seem to have a higher risk of accumulating silicon particles which, in turn, might induce an undesirable inflammatory reaction.

CONCLUSIONS

Implantoplasty significantly reduces the surface roughness of implants but this is affected by several clinical variables. Obtaining a smooth surface seems to be more challenging in posterior implants with neighboring teeth and when a prosthetic crown cannot be removed. Furthermore, on some occasions implantoplasty can cause gaps in the implant-abutment interface and accumulation of silicone debris, especially in areas with limited access. Further clinical and *in vitro* studies should be conducted to assess the results of implantoplasty for the treatment of peri-implantitis.

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FIGURES AND TABLES LEGENDS

Figure 1: Custom-made anatomic model. A: Lateral view of an implant with a prosthetic crown in the posterior area of the mandibular anatomic model. B: Lateral view of an implant with a standard bone defect in the posterior area of the mandibular anatomic model. C: View of the anterior implants placed in an edentulous maxilla.

Figure 2: Box-plot comparing the time taken to perform the implantoplasty in each group. Implants located in the anterior area of an edentulous maxilla were classified as a favorable clinical situation whereas implants located in the posterior mandible with adjacent teeth were classified as having limited access.

Figure 3: Image obtained with an interferometric confocal microscope assessing implant roughness after implantoplasty. A: Implant after implantoplasty. B: Untreated implant surface (control). C: Polished prosthetic abutment (control).

Figure 4: Images obtained through a scanning electron microscope. A: Presence of residual threads after implantoplasty. B: Presence of silicone debris after implantoplasty. C: Presence of an implant-abutment gap after implantoplasty.

Figure 5: Radar chart evaluating the mean implant-abutment discrepancy after implantoplasty for each of the areas assessed. A: Comparison between anterior implants with no neighboring teeth (favorable access) and posterior implants with adjacent teeth (limited access). B: Comparison between implants with and without prosthetic crowns.

Table 1: Surface roughness after implantoplasty, by area (anterior or posterior) and group

Table 2: Risk of residual threads, gaps in the implant-abutment interface and silicone debris, by location and presence or absence of a prosthetic crown

TABLES

Table 1: Surface roughness after implantoplasty, by area (anterior or posterior) and group

Clinical variables	Sa (µm)			Sz (µm)		
	Mean (SD)	MD (95% CI)	P	Mean (SD)	MD (95% CI)	P
Favorable access (anterior implants without adjacent teeth)	0.53 (0.10)	-0.16 (-0.21 to -0.10)	< 0.001*	8.98 (1.40)	-4.86 (-6.29 to -3.43)	< 0.001*
Limited access (posterior implants with adjacent teeth)	0.68 (0.13)			13.84 (4.33)		
Implantoplasty samples (Total)	0.60 (0.14)	NA	< 0.001†	11.41 (4.03)	NA	< 0.001†
Untreated implant surface	1.83 (0.10)			37.78 (0.35)		
Polished prosthetic abutment	0.24 (0.01)			4.46 (0.15)		

MD: Mean difference; SD: Standard deviation; 95% CI: 95% Confidence interval

* independent *t* test, P < 0.001; † Kruskal-Wallis test with Bonferroni correction

Table 2: Risk of residual threads, gaps in the implant-abutment interface and silicone debris after implantoplasty, by location and presence or absence of a prosthetic crown

	Residual threads	**Implant-Abutment gap**	**Silicone debris**
Posterior implants with adjacent teeth	87/160 (54.4%)	4/160 (2.5%)	75/160 (46.9%)
Anterior implants without adjacent teeth	23/160 (14.4%)	0/160 (0%)	22/160 (13.8%)
OR (95%CI)	7.10 (4.15 to 12.14)*	NA	5.53 (3.21 to 9.53)*
P	**<0.001***	**0.123†**	**<0.001***
With crown	56/80 (70.0%)	0/80 (0%)	37/80 (46.3%)
Without crown	20/80 (25.0%)	0/80 (0%)	25/80 (31.3%)
OR (95%CI)	7.00 (3.50 to 13.99)*	NA	1.89 (1.00 to 3.60)
P	**<0.001***	**NA**	**0.053**
TOTAL	186/480 (38.8%)	4/480 (0.8%)	159/480 (33.1%)

*Statistically significant differences; †Fisher exact test; NA: Not applicable
Eight locations (mesial, mesiobuccal, buccal, distobuccal, distal, distolingual, lingual and mesiolingual) were assessed on each implant.

FIGURES

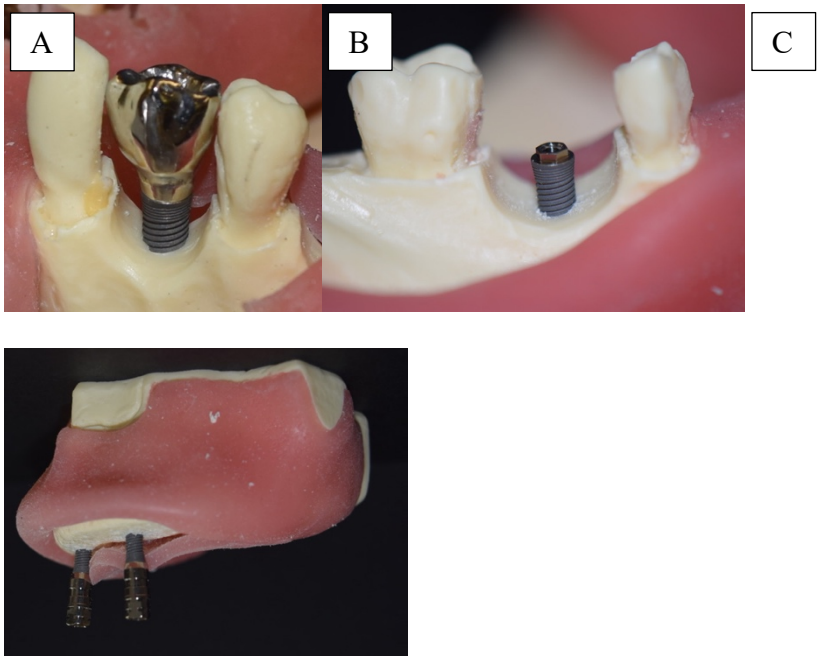

Figure 1: Custom-made anatomic model. A: Lateral view of an implant with a prosthetic crown in the posterior area of the mandibular anatomic model. B: Lateral view of an implant with a standard bone defect in the posterior area of the mandibular anatomic model. C: View of the anterior implants placed in an edentulous maxilla.

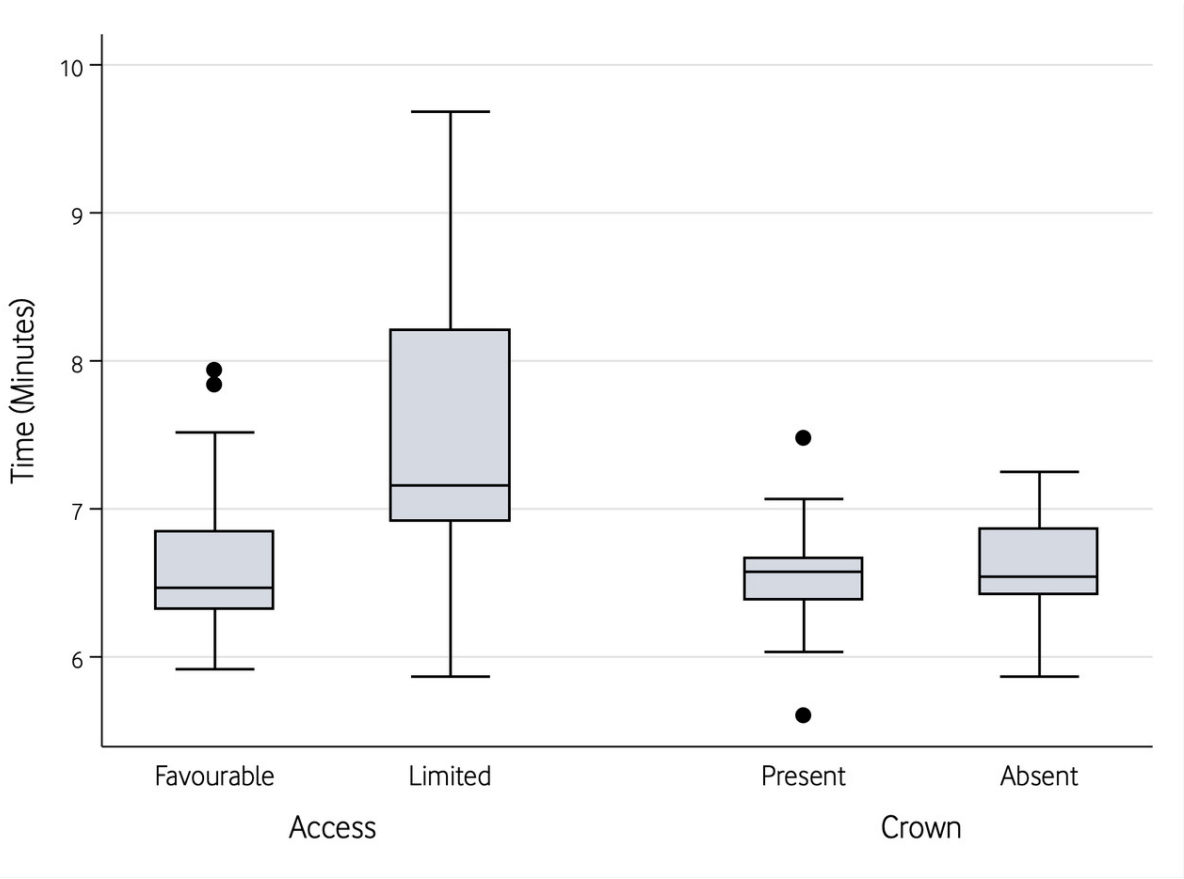

Figure 2: Box-plot comparing the time taken to perform the implantoplasty in each group. Implants located in the anterior area of an edentulous maxilla were classified as a favorable clinical situation whereas implants located in the posterior mandible with adjacent teeth were classified as having limited access.

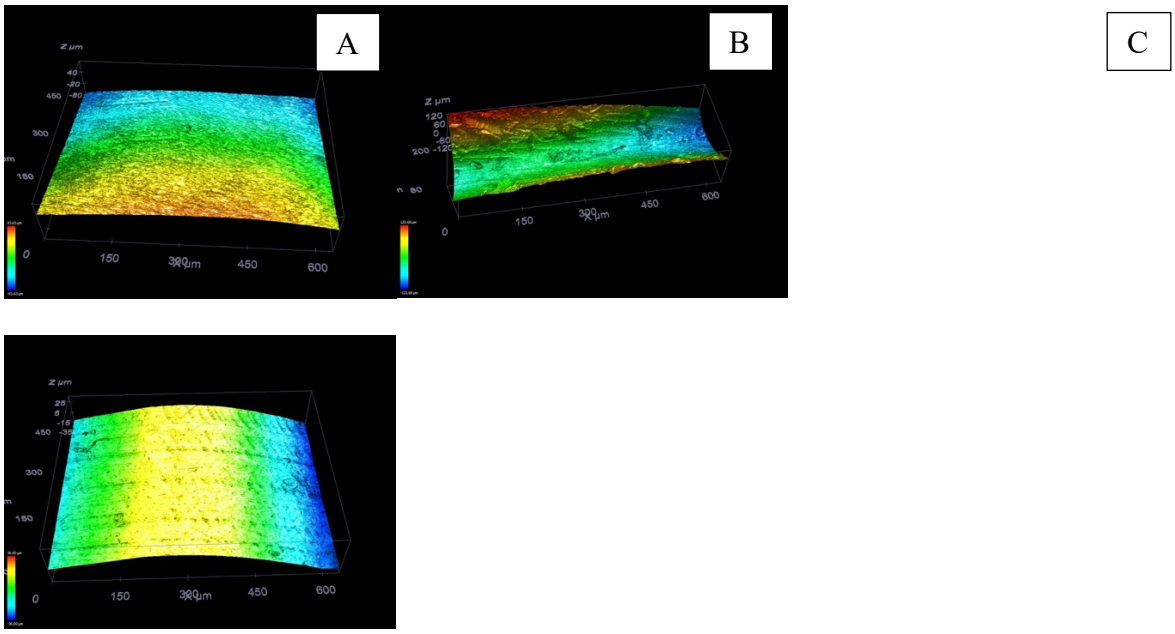

Figure 3: Image obtained with an interferometric confocal microscope assessing implant roughness after implantoplasty. A: Implant after implantoplasty. B: Untreated implant surface (control). C: Polished prosthetic abutment (control).

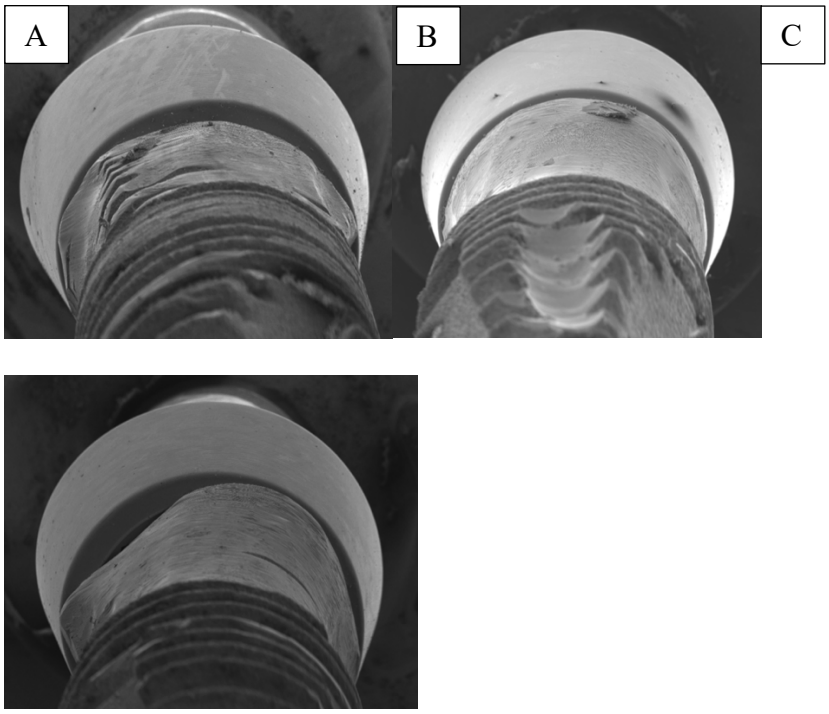

Figure 4: Images obtained through a scanning electron microscope. A: Presence of residual threads after implantoplasty. B: Presence of silicone debris after implantoplasty. C: Presence of an implant-abutment gap after implantoplasty.

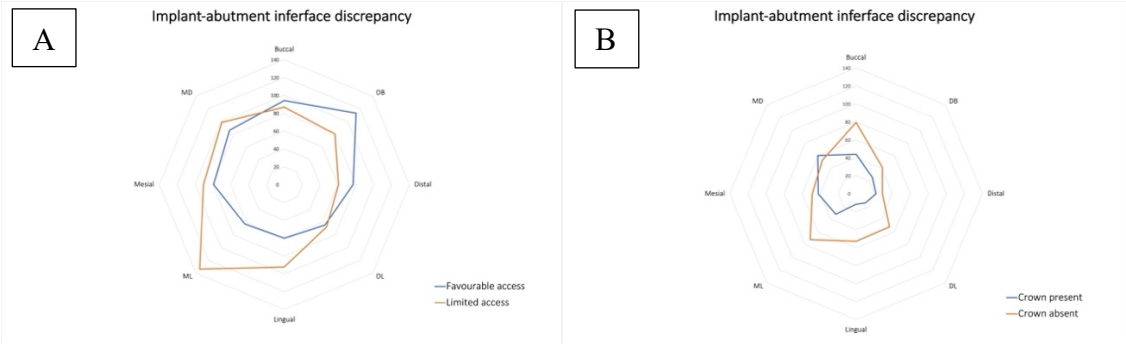

Figure 5: Radar chart evaluating the mean implant-abutment discrepancy after implantoplasty for each of the areas assessed. A: Comparison between anterior implants with no neighboring teeth (favorable access) and posterior implants with adjacent teeth (limited access). B: Comparison between implants with and without prosthetic crowns.