CHANGES IN SURFACE CHARACTERISTICS OF MODERATELY ROUGHENED GRADE IV TITANIUM DISC FOLLOWING A STANDARDISED IMPLANTOPLASTY TECHNIQUE: AN IN-VITRO STUDY

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ABSTRACT

Aim: To analyze the changes in surface characteristics of moderately roughened grade IV titanium discs following a standardized implantoplasty protocol.

Materials and Method: Nine moderately roughened titanium discs (ø9.0 mm; 2-mm thickness) with a comparable surface to commercially available oral implants (Southern Implants (Pty) Ltd, Irene, South Africa) were used. One disc was used as a control sample while the remaining 8 discs were modified using a standardized technique. Each disc was divided into 4 sections of which each quadrant was instrumented in the same manner. Regular grit and super-fine grit diamond burs were used for 10s each, followed by brown and green silicone burs for 15s respectively. The surface characteristics of all samples were analysed using scanning electron microscopy (SEM), confocal laser scanning microscopy (CLSM), and energy dispersive x-ray spectroscopy (EDS).

Results: SEM analysis of the surfaces showed that as the instrumentation progressed from diamond burs to silicone burs, surface irregularities began to diminish. However, using silicone burs tended to increase the amount of surface debris and the roughness still remained significantly higher than the control sample. EDS identified some foreign elements originating from the silicone burs that were used.

Conclusion: The proposed standardized implantoplasty protocol did not decrease the roughness of the surface below that of the control disc. The clinical implications of foreign elements remaining on the titanium surfaces need further investigation.

DESCRIPTORS: Dental implants; Titanium; in vitro; peri-implantitis; microscopy; confocal; scanning; electron.


INTRODUCTION

Peri-implantitis is an irreversible inflammatory process involving the supporting tissues of a functioning oral implant, accompanied by a gradual marginal bone loss (Albrektsson & Isidor, 1994). Clinical studies have reported various proportions of implants and patients affected by peri-implantitis. One cross-sectional study involving 3413 oral implants in 662 subjects reported that 12.4% of implants displayed ongoing bone loss to a level exceeding or equal to 3 threads of an implant (Fransson et al., 2005) whereas another clinical study using the same type of oral implants reported approximately 4 times more incidence of peri-implantitis (Roos-Jansåker et al., 2006). This variation in the prevalence/incidence of peri-implantitis may be due to studies reporting with unstandardized definition of the disease (Zitzmann & Berglundh, 2008; Pesce et al., 2014).

Peri-implantitis, which is caused by bacterial adhesion
and subsequent biofilm formation on implant surfaces, it has been shown that the colonizing bacteria on the implant surface depended highly on the bacteria species such as motile rods, fusiform bacteria and spirochetes that are already present in the oral environment before implant placement (Mombelli, 2002). Another study showed that bacterial colonization occurred at 14 to 28 days of implant surface exposure to the oral environment (Koka et al., 1993) after which, an inflammatory response is induced which destabilizes the supporting structures of the implant and implant surface biocompatibility [Mouhyi et al., 2012; Tawse-Smith et al., 2014].

Current evidence suggests that peri-implantitis does not respond well to non-surgical therapy unlike the infection involving only the soft tissues surrounding an oral implant, known as peri-implant mucositis, can be resolved fairly predictably (Renvert et al., 2008; Romanos & Weitz, 2012). Therefore, surgical methods that include regenerative and resective procedures with surface decontamination protocols have been advocated for the management of this disease (Schwarz et al., 2013). In addition to this, a treatment modality involving implantoplasty has been partially evaluated [Okayasu & Wang, 2011] to decontaminate the exposed implant surfaces by mechanically removing implant threads using rotary instruments to achieve a smoother surface that can be maintained easily in respect to plaque adherence [Romeo et al., 2005; Suarez et al., 2013].

While there are several studies reporting on the prevalence of peri-implantitis, there is yet to be a consensus on the standardized treatment modality to treat the disease and this presents an ongoing challenge to clinicians when deciding on the correct treatment modality. A combination of resective surgery and implantoplasty has shown some promising results as indicated by a randomized controlled trial (Romeo et al., 2005); however, there is still a huge lack of clinical data evaluating this treatment option. The concept of implantoplasty appears to be clinically feasible; however, there must be a consensus on the type of burs or the sequence of burs to be used in order to achieve an ideal outcome [Louropoulou et al., 2012]. A recent in-vitro study that evaluated different shapes of carbide burs used in implantoplasty, showed that spherical-shaped carbide burs produced higher surface roughness values when compared to various carbide burs (Rimondini et al., 2000).

The aim of this in-vitro study was to analyze the changes in the surface characteristics of moderately roughened grade IV titanium discs following a standardized implantoplasty protocol.

**MATERIALS AND METHODS**

Titanium specimen

Nine moderately roughened titanium discs (ø9.0 mm; 2-mm thickness) with a comparable surface to commercially available oral implants (Southern Implants [Pty] Ltd, Irene, South Africa) were used. One disc was used as a control sample while the remaining 8 discs were modified using a standardized technique. Each disc was divided into 4 sections of which each quadrant (approximately 15.9 mm² surface area) was instrumented in the same manner.

Burs

Four types of burs were chosen according to their grit sizes:

- Regular grit and super-fine grit Shofu® diamond burs were used for 10s each, followed by Brownie® and Greenie® silicone burs for 15s respectively. Based on the findings of Meier et al. 2012, tapering-cylindrical Shofu® burs were chosen with each bur used at different pre-set timings (Fig 1).

Instrumentation protocol

The timed polishing protocols (TPPs) established were applied to two discs each (Table 1). The instrumentation was done using a testing apparatus that was previously used in another in-vitro study (Chang et al., 2011), and a similar device has been used by other researchers to demonstrate cutting efficiency (Siegel & von Fraunhofer 1996; 1999; 2000). Test discs were mounted on an acrylic base plate connected to a moveable arm that can be manipulated manually on a customized device. The hand piece was secured by an adjustable jig opposite the moveable arm (Fig 2A). The rotation frequency of the high-speed handpiece was measured using a calibration device (Handpiece Counter 2, Micron Corp., Tokyo, Japan) (Fig. 2B). The temperature of the irrigation solution (distilled water) from the handpiece was measured and standardized at 19°C at the start of the instrumentation. In order to simulate a constant pressure from the handpiece to the disc surface, 100g weights were attached below the head of the handpiece and the pressure was confirmed with a calibration device (Fig. 2C).

Each quadrant of the test disc was instrumented according to the chosen TPP (Fig 1, Fig. 2D) and repeated 8 times. Burs were used only once per quadrant. At the
Figure 1. Flow diagram of timed polishing protocols (TPPs) including descriptions of burs used in the implantoplasty

TPP 1
Regular-grit diamond bur (reference no. 107RD)
Instrumentation: 10 seconds

TPP 2
Superfine-grit diamond bur (reference no. SF107RD)
Instrumentation: 10 seconds

TPP 3
Brownie® silicone bur (reference no. PN0401)
Instrumentation: 15 seconds

TPP 4
Greenie® silicone bur (reference no. PN040)
Instrumentation: 15 seconds

Figure 2. Instrumentation protocol. A. Device used to mount the disc and hand piece to simulate brushing movements during instrumentation of the titanium surface,

B. Measuring the RPM of the high-speed hand piece with the Handpiece Counter 2

C. Pressure (g) acting on hand piece measured with calibration device

D. Instrumentation of the titanium disc.

Fig 2. Instrumentation protocol.
completion of the TTP, the titanium discs were removed with plastic tweezers without touching the instrumented surface and stored in the original packaging provided by the manufacturer prior to the microscopy analysis.

**Microscopy analysis**

The surface characteristics of all samples were initially analysed using scanning electron microscopy (SEM), confocal laser scanning microscopy (CLSM), and energy dispersive x-ray spectroscopy (EDS). In order to assess the surface morphology, SEM photomicrographs were acquired from all disc surfaces. An accelerating voltage of 5kV was selected for examination using a Field Emission SEM (JEOL 6700F Field Emission SEM, Tokyo, Japan).

Surface topographical data was collected using CLSM (Zeiss LSM 510, Carl Zeiss Microscopy GmbH, Jena, Germany). Using a PlanApochromat x20 / NA 0.6 objective, the confocal pinhole was adjusted to give an optical section depth of 3.0μm, operated in reflection mode with the gain adjusted to avoid pixel saturation. The resultant z sequence of images was analysed using plugins available for ImageJ (Rasband, W.S., U.S. National Institutes of Health, Bethesda, Maryland, USA, imagej.nih.gov/ij/, 1997-2012).

Selected areas of the disc were also analysed using EDS (JEOL 2300F Energy Dispersive x-ray analyser) at an accelerating voltage of 25kV. Surface composition was analysed in the backscattered electron mode (BSE). Each area was counted for 100 seconds.

**Statistical analysis**

The normality of data was assessed using histogram, stem and leaf plot, boxplot and measures of skewness and kurtosis. Independent samples t-test was used to determine the difference between control and each TTP in Ra and Sa changes. A statistical software package (IBM® SPSS® Statistics Version 20, IBM Corp., Armonk, NY, USA) was used to perform the statistical analysis. The significance for statistical analysis was set at $P < 0.05$.

**RESULTS**

**SEM and EDS analysis**

Scanning electron microscopy (SEM) examination of the control disc revealed a surface with generalized asperities. There were extensive randomly oriented irregularities, which were a typical feature of a titanium surface that have undergone modification process to achieve a moderately roughened surface (Fig. 3A & 3C). Elemental analysis by EDS indicated that surfaces had traces of aluminium residue from the ablation process, which correlated to the aluminium oxide grit used to blast the surface of the titanium disc during manufacturing (Fig 3C).
The instrumentation protocol of using only the regular-grit diamond bur (Shofu®) produced a surface that was rougher than the control sample due to the wave-like effect that the diamond bur created (Fig. 4). However, most of the

Fig 4. SEM photomicrographs of the titanium disc surface after TPP1 at A. x25, B. x250, C. x500, D. X1500 magnifications, and E. EDS results.
aluminium oxide elements were eliminated. These results were similarly seen in TPP2 and the wave-like features were lessened through further removal of surface layer using the super-fine-grit diamond burs (Fig. 5). After the instrumentation with...
Brownie® silicone burs, the surface imperfections were further diminished compared to TPP2 but there was a noticeable increase in surface debris including concavities or a “ditching” effect with shallow peripheries (Fig 6). Final instrumentation

![SEM photomicrographs of the titanium disc surface after TPP3 at A. x25, B. x250, C. x500, D. x1500 magnifications, and E. EDS results.](image-url)
with Greenie® burs showed a polished appearance and partial removal of debris that were left behind from the TPP3 (Fig 7). However, the concavities were still present. Both TPP3 and TPP4 introduced foreign elements onto the disc surface.
notably silicone, chlorine, iron and carbon elements (Figs. 6E & 7E). These elements originated from Brownie® and Greenie® silicone burs confirmed by the EDS analysis of unused samples of the four different burs (Table 1).

**Surface Roughness Analysis**

The titanium specimens were subjected to CLSM, which generated three-dimensional representations allowing subsequent analysis with ImageJ. The Ra values of each TPP were compared to the control through independent t-tests (Table 2). Each TPP did not decrease the roughness below the level of the control sample. There was a significant difference in roughness between the control and TPP1 (p-value <0.05), with TPP1 having higher Ra (mean = 6.093, SD = 1.365) than the control (mean = 2.125, SD = 0.351). The magnitude of the differences in the mean value (mean difference = -3.968, 95% CI: -4.730 TO -3.207) was large (effect size = 0.844). Although each TPP demonstrated a large effect size in the differences in the means when compared to the control, TPP2 and TPP4 had mean Ra values that were relatively similar. When comparing Sa data, the results were very similar in that none of the TPPs produced a smoother surface area than the control (Table 2). TPP2 was interpreted as the procedure that produced the lowest Ra and Sa values out of all four TPPs.

| TABLE 1. ELEMENTAL COMPOSITION OF UNUSED SAMPLES OF RG DIAMOND, SG DIAMOND, BROWNIE® AND GREENIE® BURS (SHADED ENTRIES INDICATE THAT ELEMENT IS PRESENT). |
|---|---|---|---|
| | RG diamond | SG diamond | Brownie® silicone | Greenie® silicone |
| Carbon | | | | |
| Chromium | | | | |
| Nickel | | | | |
| Silicone | | | | |
| Magnesium | | | | |
| Chlorine | | | | |
| Iron | | | | |
| Oxygen | | | | |
| Titanium | | | | |

| TABLE 2. MEAN SURFACE ROUGHNESS MEASUREMENTS OF CONTROL AND INSTRUMENTED TITANIUM DISCS |
|---|---|---|---|---|---|
| | TPP | Mean (SD) | Mean Difference | 95% Confidence Interval | Effect Size | p-value |
| Ra values (um) | | | | | | |
| Control | 2.125 (0.351) | - | - | - | - | - |
| TPP1 | 6.093 (1.365) | -3.968 | -4.730 | -3.207 | 0.844 | <0.001 |
| TPP2 | 3.145 (0.809) | -1.020 | -1.512 | -0.527 | 0.456 | <0.001 |
| TPP3 | 4.982 (1.267) | -2.856 | -3.568 | -2.144 | 0.762 | <0.001 |
| TPP4 | 3.734 (2.296) | -1.608 | -2.851 | -0.366 | 0.254 | <0.014 |
| Sa values (um) | | | | | | |
| Control | 1.550 (0.123) | - | - | - | - | - |
| TPP1 | 2.488 (0.401) | -0.938 | -1.242 | -0.634 | 0.650 | <0.001 |
| TPP2 | 1.951 (0.260) | -0.401 | -0.603 | -0.198 | 0.433 | <0.001 |
| TPP3 | 2.844 (0.619) | -1.294 | -1.633 | -0.955 | 0.747 | <0.001 |
| TPP4 | 2.383 (1.079) | -0.833 | -1.413 | -0.253 | 0.297 | <0.008 |

*Independent t-tests between control and each TPP.
N.B. For Ra Independent t-tests, all TPPs equal variances not assumed.
For Sa Independent t-tests, TPP1 and TPP2 have equal variances assumed. TPP3 and TPP4 have equal variances not assumed.
DISCUSSION

This in-vitro study examined the efficacy of proposed implantoplasty protocol using different types of burs according to a standardized sequence and duration to produce an ideal smoothness of moderately-roughened titanium surfaces.

To date, there is no standardized treatment protocol in the treatment of peri-implantitis although different mechanical treatment modalities such as implantoplasty have been proposed for surface decontamination. However, with the limited information on the specific types of burs and sequence of instrumentation to achieve an ideal smoothness of oral implant surface that is exposed to the oral cavity, it is still difficult to recommend an evidence-based treatment protocol.

Mechanically reducing the roughness of the implant surface using rotary instruments must achieve a smoothness parameter known as the “Ra threshold”, which is set at 0.2μm. This has been shown as the point of roughness above which facilitates biofilm formation and determines microbial composition (Bollen et al., 1996; Quirynen et al., 1996; Wim et al., 2006). By reducing the roughness of the exposed oral implant surface, the modified surface can be decontaminated and now physically deters the biofilm formation, thus preventing bacterial colonization and further plaque formation. This may also assist in the oral hygiene practice for the patients to maintain the area.

A recent consensus report on the clinical research in peri-implant disease identified the shortcomings of current clinical literature as it did not have a clear surgical design nor standardized method of decontaminating the implant surface (Sanz et al., 2012). It is also unclear whether the support of adjunct therapies such as systemic antibiotics or localized application of antimicrobials is indeed beneficial in disease resolution. The current understanding is that non-surgical therapy alone cannot successfully treat peri-implantitis and that some type of implant surface detoxification agent/techniques including implantoplasty must be considered when attempting to eliminate the further destruction of the supporting hard and soft tissues of the oral implants (Suarez et al., 2013).

This study focused on establishing a standardized method of mechanical decontamination of moderately roughened implant surfaces. The timed polishing protocols (TPPs) used in this study standardized the sequence of burs and followed the set time to be able to assess the efficacy of each bur on smoothing the implant surfaces and also the compounding effect of the instrumentation sequence. The changes in the surface characteristics when using only the regular-grit diamond bur was comparable to another study that showed wave-like structures appearing after the instrumentation (Barbour et al., 2007). Subsequently, when the modified surface was polished with a super-fine grit diamond bur, the surface roughness was decreased which was confirmed through the SEM analysis and was comparable to another recent in-vitro study (Meier et al., 2012).

The CLSM roughness measurements for both TPP1 and TPP2 resulted in significantly higher surface roughness compared to the untouched surface. The roughness measurements were significantly higher than the proposed 0.2 μm Ra threshold for biofilm formation contrasting to other study which used conical burs (Meier et al., 2012). A possible reason for this outcome may be attributed to the technical difficulties of instrumenting a small surface area (mm²), which resulted in multiple polishing strokes of the same area and creating deeper concavity.

Silicone polishers have been recommended for achieving the desired Ra value of 0.2μm (Matarasso et al., 1996; Romeo et al., 2005; Barbour et al., 2007; Meier et al., 2012). In contrast to this recommendation, the current study did not see a positive change to the surface roughness by using Brownie® and Greenie® silicone burs although the wave-like features on the implant surface were reduced. There were also further disadvantages of silicone debris being introduced to the instrumented surfaces. However, it must be taken into consideration that the titanium discs were not cleaned after the instrumentation.

The analysis of the instrumented surfaces using energy dispersive x-ray spectroscopy (EDS) showed that using only regular-grit diamond bur (TPP1) was sufficient to eliminate any aluminum oxide powder remnants that were originally used to modify the titanium surfaces. There were also no foreign elements remaining on the titanium discs when using either diamond burs (TPP1 and TPP2) unlike when polishing with silicone burs. Whether these foreign bodies would impact on the resolution of peri-implantitis as well as biocompatibility of the titanium implant surfaces for possible re-osseointegration must be investigated (Ruhling et al., 2001; Louropoulou et al., 2014). Another aspect of residual foreign bodies should also include assessing the possible consequence of the titanium implant particles that have been removed and still remaining in the surrounding hard and soft tissues. However, it is promising
that a short-term randomized controlled study which used the combined implantoplasty and surface decontamination methods showed that when a particular care was taken to remove any titanium deposits from the instrumented area, there was no detrimental result to the healing of the site (Schwarz et al., 2011).

In this study, irrigation was used while polishing the titanium discs with diamond burs. The concerns of overheating the implant during implantoplasty appear to be minor when irrigation is used, as a study has shown that only a minor change of 1.5°C in temperature occurs [Sharon et al., 2013]. Irrigation may also assist in removing any debris remaining on the oral implant surfaces.

Although this in-vitro study did not achieve a surface roughness parameter desirable for preventing biofilm formation, it is worth noting that a standardized implantoplasty technique was employed. A further improvement to the methodology can be suggested by using wider surface areas to allow longer strokes of instrumentation and avoid multiple cutting of the same area. Introduction of different types of burs or sequence of instrumentation may also improve the surface smoothness and using a titanium oral implant rather than a disc may be more appropriate to have results that would be more relevant to the clinical settings.

**CONCLUSIONS**

The proposed implantoplasty protocol did not achieve an ideal smoothness of the moderately roughened titanium surfaces. However, within the limitation of this study, it can be suggested that the diamond burs used in this study were successful in removing the external titanium surface layer and the surface irregularities were further improved by polishing with silicone burs.

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**Conflict of interest**

The authors declare that they have no conflict of interest.

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