The Influence of Implantoplasty on Surface Roughness, Biofilm Formation, and Biocompatibility of Titanium Implants: A Systematic Review

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Short title: Implantoplasty: A systematic review.

Key findings: Implantoplasty seems to improve the surgical treatment of peri-implantitis.
Conflict of interest and sources of funding

The authors declare that they have no conflicts of interest in relation to this study. The authors declare the following interests outside the presented work:

Dr. Genís Burgueño-Barris reports grants and non-financial support from Avinent (Santpedor, Spain) and personal fees from Septodont (Ciudad, France) and Araguaney Dental (Barcelona, Spain).

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Dr. Eduard Valmaseda-Castellón reports personal fees and non-financial support from MozoGrau (Valladolid, Spain) and from Avinent (Santpedor, Spain), personal fees from BioHorizons Ibérica (Madrid, Spain), Inibsa Dental (Lliça de Vall, Spain) and Dentsply implants Iberia (Barcelona, Spain) outside the submitted work.

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ABSTRACT

**Purpose:** A review was done to evaluate the effect of implantoplasty on surface roughness, biofilm formation, and biocompatibility of dental implants. **Materials and Methods:** Electronic searches were done in PubMed (OVID), Scopus, Web of Science, and The Cochrane Library to identify all relevant articles published until April 2020. All publications evaluating changes in implant surfaces after implantoplasty were included. The primary outcome variable was roughness of the implant surface. Secondary outcome variables were biofilm elimination and regrowth, changes in surface elements, and cell viability. **Results:** A total of 11 in vitro studies and two in vivo publications were included. Implantoplasty reduced surface roughness of the implant. The final outcome depended on the bur protocol, with tungsten carbide burs providing the smoothest surfaces, followed by silicone polishers. Implantoplasty did not affect cell viability, and roughness was inversely correlated to human gingival fibroblast growth. The technique also proved effective in removing biofilm and preventing its regrowth. **Conclusion:** Implantoplasty reduces the surface roughness of dental implants, which in turn inhibits biofilm formation without affecting the biocompatibility of titanium implants. Since most of the included studies were done in an in vitro setting, further clinical trials are necessary to confirm these outcomes. Int J Oral Maxillofac Implants 2021. doi: 10.11607/jomi.8785

**Keywords:** Implantoplasty, surface roughness, biofilm, peri-implantitis, systematic review.

INTRODUCTION

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Peri-implantitis is a chronic disease characterized by peri-implant soft tissue inflammation (bleeding on probing, and/or suppuration) in conjunction with progressive peri-implant bone loss (1). The management of peri-implantitis is complex and usually involves sequential treatment: a first stage of non-surgical cleaning, followed by a surgical procedure (2,3). Several surgical techniques have been described. In this regard, clinicians should choose the most appropriate approach taking into account variables such as bone defect anatomy, esthetics, and the presence or absence of keratinized mucosa (3–7). Some authors recommend to smoothen the supracrestal non-osseointegrated portion of the implant surface in order to reduce biofilm growth (8,9). This technique, known as implantoplasty (IP), is mainly indicated in resective or in combined surgical approaches (8–12).

The composition and development of biofilms is influenced by surface properties such as chemical composition, surface free energy and topography. Accordingly, surface roughness and other physicochemical features render dental implants susceptible to bacterial adhesion and proliferation (13). After 14 days of exposure to the oral cavity, rough implant surfaces are already recovered by a mature biofilm (14). These findings seem to justify the need to modify the surface of dental implants once they experience bone loss.

However, some reports have expressed concerns regarding IP. On one hand, the reduction of the implant diameter could potentially decrease its strength, which might be especially critical in the case of narrow implants (15,16) and internal connections (17). On the other hand, IP generates titanium debris, which is difficult to remove from hard and soft tissues, and can induce an inflammatory reaction (18,19). Last but not least, polishing the implant surface can modify its physicochemical properties and affect cell attachment and therefore biocompatibility (20).

Many IP protocols have been described in the literature. The implant threads are usually removed using diamond burs or carbide drills, and the surface is polished using Arkansas
stone or silicon polishers to obtain a smooth and shiny surface (8–12,21–23). There is no universally accepted protocol, however (21–23).

The present systematic review was carried out to determine the effect of IP upon surface roughness as primary outcome. Secondary outcomes were biofilm growth and the biocompatibility of titanium dental implants.

**MATERIALS AND METHODS**

The present systematic review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (24).

The inclusion criteria were: clinical or preclinical studies using IP for the treatment of peri-implantitis. We also included *in vitro* studies assessing the proprieties of the implant surface.

The primary outcome measure was:

- Surface roughness, defined using roughness parameters: Ra (mean of the absolute values of the modified roughness profile, based on the central line to a reference route) and Rz (arithmetic mean of the differences between 5 highest and 5 lowest points of a profile within a sample route on the measured surface) or three-dimensional (3D) measurements: Sa (arithmetic mean height) and Sz (average maximum height).

The secondary outcome measures were:

- Biocompatibility: assessed through cell viability assays (quantification of adenosine triphosphate metabolite and/or alkaline phosphatase activity).

- Chemical composition of the implant surface: percentages of chemical elements included in the composition of the implant surface. Measurements were made using energy-dispersive X-ray spectroscopy.
- Biofilm removal: assessed with scanning electron microscopy (SEM) to determine the remaining biofilm (percentage of the surface or biofilm width) on the implant surface.
- Biofilm regrowth: bacterial growth over implant surfaces after IP. Measurements were made using SEM or spectrophotometry to determine biofilm thickness.

An electronic search was made of the PubMed (OVID), Scopus, Web of Science and The Cochrane Library (Wiley) databases up until 15 April 2020, without year restrictions. Only articles in English were reviewed. The following search term was applied implantoplasty OR ((peri-implant OR periimplant) AND "implant surface modification" OR “implant surface decontamination” OR “implant surface debridement”). The search was completed by manual screening of the references cited in the selected papers.

Two examiners (G.B.B. and O.C.F.) independently selected the studies in accordance with the inclusion criteria and extracted all data. Initially, duplicates or irrelevant studies (based on the title) were excluded, and the abstracts were examined. Then, the full texts of all the remaining papers were assessed. Disagreements were solved by consensus. The authors were contacted when necessary for clarification of missing information.

RESULTS
The initial electronic search yielded 226 studies, and one additional paper (25) was included after manual searching through cited references. After duplicate removal and evaluation of both the title and abstract, 14 potential papers were finally assessed for full-text analysis. One of these papers was rejected since the roughness determinations did not include either Sa or Ra measurements (26). Thus, 13 articles were finally selected for analysis (Figure 1) (21-23,25,27-35).
Eleven of the publications were *in vitro* studies (21–23,27–33), while the other two were *in vivo* studies which analyzed biofilm in implants that had been retrieved from humans (34,35). The data of all the studies were summarized in tables according to the outcome measure: surface roughness assessment (Table 1); biofilm formation (Table 2); and biocompatibility assessment (Table 3). In one study (28), some data could not be retrieved from the manuscript, and this information was moreover not supplied by the authors (two e-mails were sent to the corresponding author).

All IP procedures reduced the surface roughness of the implants (21,23,25,27,32), except in one study (22). However, roughness was greater than that of a machined surface (21,23,25). The smoothest surface in the *in vitro* studies was obtained using tungsten carbide drills and two different grid silicone polishers (Brownie® and Greenie®)(23,27).

Implantoplasty did not affect cell viability (31,33). Gingival fibroblasts exhibited adenosine triphosphate activity, and osteoblasts showed alkaline phosphatase activity on incubated surfaces after implantoplasty (31,33). Besides, smoother surfaces (with lower Sa) enhanced human gingival fibroblasts growth and reduced the cytokine levels (23). Surfaces after IP had a different proportion of chemical elements in comparison to machined surfaces (titanium, aluminum or nitrogen) or moderately rough surfaces (titanium, oxygen, carbon, aluminum or sodium) (31,33).

Implantoplasty exhibited an anti-biofilm effect and seemed to reduce biofilm regrowth (32,34,35). On the other hand, the evidence is inconsistent regarding the disinfection efficacy of IP when compared to other treatment strategies. El Chaar et al. (35) concluded that IP was the only therapy to achieve complete biofilm removal. However, another *in vitro* study found biofilm removal and regrowth to be comparable among IP, air-powder abrasive systems and Ti Brush® (32).
DISCUSSION

The aim of the present review was to assess the implant surface properties after IP, taking into account surface roughness, biofilm formation and biocompatibility. Based on the findings of the systematic review, it can be assumed that IP produces a smoother surface in comparison with unmodified moderately rough surfaced implants (21,23,25,27,32). Also, IP appears to reduce biofilm formation and regrowth, without significantly modifying the biocompatibility of the implants (23,31–35).

The degree of surface roughness directly depends upon the IP protocol used. According to the analyzed papers, tungsten carbide burs followed by two silicon carbide polishers seem to provide the smoothest surfaces (23,27). Nevertheless, other options, such as the use of three diamond drills (106, 40 and 15 µm) followed by an Arkansas stone, have also exhibited good results (21,29). The selection of the final burs seems to be a key factor. Indeed, de Souza Júnior et al. (22) obtained disappointing results probably because they did not include a final polishing step in their protocol. Comparison between the different polishing options seems to result in the recommended use of two silicon carbide polishers (21,23,27). However, in most in vitro studies, IP was performed under ideal conditions. In fact, only one paper used a model (without soft tissues) placed in a phantom head to simulate the clinical scenario (29). Thus, the in vitro roughness values (Table 1) might prove very difficult to achieve in clinical practice, especially in areas of difficult access or when the restoration cannot be removed. Future studies therefore should focus on improving the external validity of the results.

Exposed dental implant surfaces seem to favor the development of oral biofilms (14,36). Furthermore, biofilm is attached to the rough surface, so standard decontamination methods used in teeth might fail to remove the microbiota (35,37). Implantoplasty removed biofilm better than other treatments (35), and significantly reduced initial biofilm attachment, in comparison with mechanical debridement (32,34). It is important to stress that the 2 in vivo
studies included in the present review (34,35) used failed dental implants and this might limit the generalization of the data. On the other hand, two reports (32,34) obtained similar results regarding biofilm elimination and regrowth using IP and chemical decontamination (34), Ti Brush (32) or an air-powder abrasive system (32). Thus, IP seems to accomplish its main goal of reducing biofilm formation after surgical treatment. It is clear that further studies are needed, since other options, such as air-powder abrasive systems could have similar efficacy without increasing the risk of mechanical or biological complications (32). Another alternative is the use of electrolytic cleaning systems which seem to eliminate biofilm better than air-powder systems (38,39), though further research is needed to assess the impact of the use of such cleaning devices.

The effect of grinding and smoothing the implant superficial layer may affect its biocompatibility. Schwarz et al. (33) assessed cell viability measuring adenosine triphosphate activity in gingival fibroblasts (33), while Toma et al. (31) assessed alkaline phosphatase activity in osteoblast like Saos-2 cells (31). These studies suggest that both fibroblasts and osteoblasts can grow on implant surfaces after IP. The chemical elemental composition of implants after IP is also similar to that of machined surfaces (31,33). Furthermore, smoother surfaces seem to enhance the initial growth of human gingival fibroblasts and reduce the presence of cytokines (23).

The main limitation of the present review was the lack of clinical articles, since there were only two in vivo studies, with very limited samples and a short follow-up time. A recent review published on the same subject but with a different approach since it was not centered on the surface properties of implants after IP, stated that this procedure does not seem to be linked with any significant mechanical or biological complication (40). However, IP has been associated with implant fracture (15,16), while titanium particles become embedded in the hard and soft peri-implant tissues during surgery (18,41). These particles are difficult to
remove, and there might be a relationship among bio-corrosion, implant particles and biological complications (18). Moreover, two papers have concluded that titanium particles in the surrounding tissues are a common finding in implants with peri-implantitis (18,41). Thus, it is clear that further clinical research with longer follow-up periods is needed before IP can be systematically recommended.

**Conclusions**

Implantoplasty significantly reduces the surface roughness of dental implants. This allows the reduction of biofilm formation without apparently compromising the biocompatibility of titanium surfaces. The use of carbide tungsten cutters followed by silicone polishers seems to provide the best outcomes in terms of the reduction of surface roughness. However, since most of the included studies were made in an *in vitro* setting, further clinical trials are necessary to confirm these outcomes.
REFERENCES


22. De Souza Júnior JM, De Souza JGO, Neto ALP, Iaculli F, Piatelli A, Bianchini MA. Analysis of effectiveness of different rotational instruments in implantoplasty: An in


Figure 1: PRISMA search flow-chart.
<table>
<thead>
<tr>
<th>Studies (Year)</th>
<th>Study type</th>
<th>Sample</th>
<th>Implantoplasty protocol and study groups</th>
<th>Surface roughness results</th>
<th>Main outcomes</th>
</tr>
</thead>
</table>
| Beheshti Maal et al. (2020) (23) | In vitro  | 48 titanium grade IV disks 36 tests disks with moderately rough sandblasted and acid-etched surface 6 control sandblasted and acid-etched (CR) 6 control polished (CP) | G1: 3 Diamond burs: 105µm, 40µm, 8µm  
G2: 3 Diamond burs: 105µm, 40µm, 8µm + Arkansas stone  
G3: 3 Diamond burs: 105µm, 40µm, 8µm + 2 Silicone polishers: Brownie® and Greenie®  
G4: 2 Carbide cutting burs  
G5: 2 Carbide cutting burs + Arkansas stone  
G6: 2 Carbide cutting burs + 2 Silicone polishers: Brownie® and Greenie®  
CR: control moderately rough  
CP: control polished | Sa  
CP: 0.05 ± 0.02 µm  
CR: 1.74 ± 0.15 µm  
G1: 1.74 ± 0.62 µm  
G2: 0.69 ± 0.48 µm  
G3: 0.42 ± 0.09 µm  
G4: 0.74 ± 0.28 µm  
G5: 0.54 ± 0.07 µm  
G6: 0.41 ± 0.13 µm  
Sz:  
CP: 2.37 ± 1.92 µm  
CR: 17.92 ± 1.34 µm  
G1: 14.98 ± 3.46 µm  
G2: 7.06 ± 3.26 µm  
G3: 6.73 ± 2.38 µm  
G4: 12.16 ± 6.65 µm  
G5: 13.96 ± 2.53 µm  
G6: 6.08 ± 2.78 µm | Carbide cutting burs achieved smoother surfaces than diamond burs.  
Silicone polishers (Brownie® and Greenie®) yielded better results than the use of Arkansas stone. |
Sandblasted and acid-etched | Experienced professional. Tungsten carbide burs; silicon carbide polishers: brownie and greenie.  
T: Implantoplasty  
C: Control moderately rough | Sa  
T: 0.1 ± 0.02 µm*  
C: 0.76 ± 0.08 µm  
Sz  
T: 3.67 ± 1.28 µm*  
C: 10.92 ± 0.94 µm | A smooth surface can be obtained with tungsten burs and silicon polishers. |
<p>| de Souza Júnior | In vitro  | 36 implants | Experienced professional | Ra | All test groups had similar results in |</p>
<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>Design</th>
<th>Number</th>
<th>Surface Description</th>
<th>Professional Experience</th>
<th>Data Available</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>et al. (2016) (22)</td>
<td>In vitro</td>
<td>22 implants</td>
<td>Implant surface: Dual acid-etched with controlled standardized pressure: G1: diamond G2: tungsten G3: multilaminar C: control machined surface</td>
<td></td>
<td>G1: 4.12 (\mu m) G2: 4.88 (\mu m) G3: 5.01 (\mu m) C: 1.92 (\mu m^*)</td>
<td>terms of surface roughness, but less temperature increase was registered when tungsten burs were used.</td>
</tr>
<tr>
<td>Meier et al. (2012) (28)</td>
<td>In vitro</td>
<td>22 implants</td>
<td>Implant surface: Moderately rough Sandblasted and acid-etched Experienc</td>
<td>Experienced professional. 11 groups: 10 carbide cutters (different form) 1 diamond bur</td>
<td>No available data</td>
<td>Conical shaped tungsten burs provided the smoothest surface. The poorest results were obtained using a no. 6 round tungsten bur. Burs without notches yielded better results.</td>
</tr>
</tbody>
</table>
| Ramel et al. (2016) (21) | In vitro | 42 implants | Implant surface: Moderately rough Sandblasted and acid-etched Expe | Experienced professional. G1: 3 Diamond burs: 106,40,15 \(\mu m\) + 2 silicon polishers: Brownie\(^*\) and Greenie\(^*\) G2: 3 Diamond burs: 106,40,15 \(\mu m\) + Arkansas G3: 3 Diamond burs: 106,40,4 \(\mu m\) G4: 3 Diamond burs: 106,40,4 \(\mu m\) + 1 Silicon polisher: Greenie\(^*\) G5: 5 Diamond burs: 106,40,15, 8,4 \(\mu m\) G6: 5 Diamond burs: 106,40,15, 8,4 \(\mu m\) + 1 Silicon polisher: Greenie\(^*\) CP: control polished CR: control moderately rough | Ra G1: 0.32 ± 0.14 \(\mu m\) G2: 0.39 ± 0.13 \(\mu m\) G3: 0.71 ± 0.22 \(\mu m\) G4: 0.59 ± 0.19 \(\mu m\) G5: 0.98 ± 0.30 \(\mu m\) G6: 0.75 ± 0.26 \(\mu m\) CP: 0.1 ± 0.01 \(\mu m\) CR: 1.94 ± 0.47 \(\mu m\) Rz G1: 2.31 ± 0.95 \(\mu m\) G2: 3.19 ± 1.17 \(\mu m\) G3: 5.39 ± 1.84 \(\mu m\) G4: 4.35 ± 1.37 \(\mu m\) G5: 6.86 ± 2.20 \(\mu m\) G6: 5.21 ± 1.77 \(\mu m\) CP: 0.81 ± 0.19 \(\mu m\) CR: 13.15 ± 3.09 \(\mu m\) | A protocol that included 3 diamond burs and an Arkansas stone showed a good outcome taking into account surface roughness, treatment duration and final debris. A protocol with 3 diamond burs and 2 silicon polishers yielded the smoothest surface.
<table>
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<tbody>
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<td></td>
<td></td>
<td></td>
<td>G1: 1.18 ± 0.39 µm G2: 0.90 ± 0.19 µm G3: 1.10 ± 0.53 µm G4: 0.93 ± 0.52 µm G5: 1.26 ± 0.42 µm G6: 1.03 ± 0.29 µm G7: 1.02 ± 0.15 µm G8: 1.00 ± 0.19 µm G9: 1.11 ± 0.29 µm G10: 1.16 ± 0.26 µm G11: 1.34 ± 0.59 µm G12: 1.37 ± 0.48 µm G13: 1.04 ± 0.14 µm G14: 1.21 ± 0.40 µm G15: 1.60 ± 0.41 µm CP: 0.60 ± 0.20 µm CR: 3.20 ± 0.37 µm</td>
<td>Rz</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>G1: 6.01 ± 1.69 µm G2: 4.48 ± 0.89 µm G3: 4.99 ± 1.60 µm G4: 3.34 ± 2.07 µm G5: 4.64 ± 1.35 µm G6: 3.99 ± 1.00 µm G7: 5.21 ± 0.69 µm G8: 4.46 ± 0.91 µm G9: 4.43 ± 1.28 µm</td>
<td>All surface procedures produced smoother surfaces than in the control group (titanium plasma-sprayed surface). The most effective protocol was that using 30 µm plus 15 µm diamond burs.</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Materials Used</td>
<td>Surface Roughness (μm)</td>
<td>Comments</td>
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<td>------------------------------</td>
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</tbody>
</table>
| Sahrmann et al. (2019) (29)  | In vitro        | 30 titanium implants placed in phantom head simulators                           | G1: 3 Diamond burs: 106, 40 μm + Arkansas stone  
G2: Silicate carbide stone + Arkansas stone + 2 silicon polishers: Brownie® and Greenie® | Ra  
G1: 0.76 ± 0.14 μm  
G2: 0.38 ± 0.15 μm*  
Rz  
G1: 4.12 ± 0.72 μm  
G2: 1.87 ± 0.69 μm*  
CP: 2.97 ± 1.11 μm  
CR: 16.25 ± 1.40 μm | The use of silicon carbide + Arkansas stones + silicone polishers seemed to be better option in comparison with the combination of 3 diamond burs and Arkansas stones. |
| Tawse-Smith et al. (2016) (30)| In vitro       | 40 titanium disks (20 with machined surface and 20 with rough surface)          | Implantoplasty experimental design – custom made device:  
Diamond regular grit, diamond super-fine grit, and 2 silicone polishers: Brownie® and Greenie®  
G1: machined  
G2: moderately rough | Machined disk (G1):  
Before implantoplasty: 4.00 ± 0.52 μm  
After implantoplasty: 3.09 ± 0.29 μm  
Rough disk (G2):  
Before implantoplasty: 4.50 ± 0.4 μm  
After implantoplasty: 2.02 ± 0.73 μm | This implantoplasty protocol did not yield the expected outcome, although surface roughness was reduced in both groups. |
| Toma et al. (2018) (32)      | In vitro       | 250 titanium moderately rough disks colonized with S. gordonii                  | Experienced professional:  
G1: Plastic curette  
G2: Air powder abrasive system  
G3: Ti Brush® | Ra  
G1: 1.61 ± 0.17 μm  
G2: 1.31 ± 0.14 μm  
G3: 1.22 ± 0.31 μm  
G4: 0.98 ± 0.12 μm*  
CP: 4.88 ± 0.83 μm  
CR: 16.25 ± 1.40 μm | Implantoplasty reduced surface roughness better than the other treatments |
<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
<th>Rz Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G4: Implantoplasty (diamond bur)</td>
<td>Control moderately rough</td>
<td>1.65±0.107 µm</td>
</tr>
<tr>
<td>C: Control</td>
<td></td>
<td></td>
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<tr>
<td>G1: 9.98 ± 0.24 µm</td>
<td></td>
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<tr>
<td>G2: 9.22 ± 0.27 µm</td>
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<td>G3: 8.76 ± 0.15 µm</td>
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<tr>
<td>G4: 7.26 ± 0.022 µm*</td>
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<td></td>
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<tr>
<td>C: 9.79 ± 0.34 µm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Data of studies that assessed the effect of implantoplasty upon surface roughness. * Statistically significant differences. G: Group. T: Test group. C: Control group; CP: control group with machined or polished surface. CR: control group with rough surface.
<table>
<thead>
<tr>
<th>Studies (Year)</th>
<th>Study type</th>
<th>Sample</th>
<th>Implantoplasty protocol and study groups</th>
<th>Anti-biofilm therapy</th>
<th>Biofilm regrowth</th>
<th>Main outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geremias et al. (2017) (34)</td>
<td>In vivo</td>
<td>3 implants with peri-implantitis removed 4 months after surgical peri-implant treatment (open flap debridement; open flap debridement + chemical decontamination; and implantoplasty) Moderately rough, sandblasted and acid-etched contaminated implants</td>
<td>Experienced professional. G1: mechanical debridement (plastic curettes) G2: mechanical debridement + chemical decontamination (citric acid) G3: Implantoplasty: diamond burs and Arkansas stones</td>
<td>-</td>
<td>S. Mutans planktonic growth assessed by spectrophotometry and SEM G1: 0.210 ± 0.031 nm* G2: 0.165 ± 0.006 nm G3: 0.158 ± 0.017 nm</td>
<td>Implantoplasty and chemical decontamination inhibit biofilm regrowth in comparison with mechanical debridement.</td>
</tr>
</tbody>
</table>
Toma et al. (2018) (32)

| In vitro | 250 titanium moderately rough disks colonized with *S. gordonii* | Experienced professional. G1: plastic curette  
G2: Air powder abrasive system  
G3: Ti Brush®  
G4: Implantoplasty (diamond bur)  
C: Control moderately rough | No significant differences in control vs plastic curettes. Significant differences in control and plastic curettes vs air-powder abrasive system, Ti Brush® and implantoplasty | No significant differences between control and plastic curettes. Significant differences control-G1 vs G2, G3, control and plastic curettes vs air-powder abrasive system, Ti Brush® and implantoplasty | Implantoplasty allowed more effective biofilm removal and less regrowth than plastic curettes and the control group. Implantoplasty, air-powder abrasive systems and Ti Brush® seemed to be equally effective. |

Table 2: Studies that analyzed the effect of implantoplasty upon biofilm formation. * Statistically significant differences; G: Group; C: Control; SEM: Scanning electron microscopy.
<table>
<thead>
<tr>
<th>Studies (Year)</th>
<th>Study type</th>
<th>Sample</th>
<th>Implantoplasty protocol and study groups</th>
<th>Biocompatibility: cell viability</th>
<th>Implant surface chemical composition</th>
<th>Main outcomes</th>
</tr>
</thead>
</table>
| Behesti Maal et al.    | In vitro   | 48 titanium grade IV disks 36 tests disks with rough surface by cathodic anodization 6 control Sandblasted and acid-etched (CR) 6 control polished (CP) | G1: 3 Diamond burs: 105µm, 40µm, 8µm  
G2: 3 Diamond burs: 105µm, 40µm, 8µm + Arkansas stone  
G3: 3 Diamond burs: 105µm, 40µm, 8µm + 2 Silicone polishers: Brownie® and Greenie®  
G4: 2 Carbine cutting burs  
G5: 2 Carbine cutting burs + Arkansas stone  
G6: 2 Carbine cutting burs + 2 Silicone polishers: Brownie® and Greenie®  
CR: control moderately rough  
CP: control polished | Human gingival fibroblasts (HGF) from donors. Higher increase in HGF in all tested surfaces in comparison with moderately rough surfaces (at 15 and 30 days)  
Significantly negative correlation between Sa and number of fibroblasts at days 3, 15 and 30.  
Less cytokines (VEGF, IL-6, MCP1, MCP3 and IP-10) and fibronectin in surfaces after implantoplasty in comparison with moderately rough surface after 30 days | - | Surface roughness after implantoplasty influenced the initial growth of human gingival fibroblasts and the presence of cytokines. Smoother surfaces enhanced human gingival fibroblast growth and reduced the cytokine levels. Sa values were inversely correlated to human gingival fibroblast growth. |
| Schwarz et al.         | In vitro   | 40 moderately rough, sandblasted and acid-etched implants              | Experienced professional. Diamond burs and Arkansas stones | Undisturbed cell viability: gingival fibroblasts had adenosine triphosphate activity after 6 days of incubation. | Implantoplasty vs machined comparable percentages of C, O, Na, Cl, K, Si but differences in N, Ti and Al. | Implantoplasty did not affect cell viability. Chemical elemental composition of implant surface after |
Implantoplasty vs moderately rough different percentages of C, O, Na, Ti and Al

<table>
<thead>
<tr>
<th>Study</th>
<th>Model</th>
<th>Surface Description</th>
<th>Tissue/Cell Type</th>
<th>Biocompatibility Effects</th>
<th>Implanted surface biocompatibility</th>
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Table 3: Data of studies that assessed the effect of implantoplasty upon biocompatibility. * Statistically significant differences; CP: control polished; CR: control rough; G: Group; HGF: Human gingival fibroblasts; VEGF: vascular endothelial growth factor; IL-6: interleukin 6; MCP1: monocyte chemotactic protein-1; MCP3: monocyte chemotactic protein-3; IP-10: interferon gamma-induced protein 10; C: Carbon; O: Oxygen; Na: Sodium; Cl: Chlorine; K: Potassium; Si: Silicon; N: Nitrogen; Ti: Titanium; Al: Aluminum.
<table>
<thead>
<tr>
<th>Studies (Year)</th>
<th>Study type</th>
<th>Sample</th>
<th>Implantoplasty protocol and study groups</th>
<th>Surface roughness results</th>
<th>Main outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beheshti Maal et al. (2020) (23)</td>
<td>In vitro</td>
<td>48 titanium grade IV disks 36 tests disks with moderately rough sandblasted and acid-etched surface 6 control sandblasted and acid-etched (CR) 6 control polished (CP)</td>
<td>G1: 3 Diamond burs: 105μm, 40μm, 8μm G2: 3 Diamond burs: 105μm, 40μm, 8μm + Arkansas stone G3: 3 Diamond burs: 105μm, 40μm, 8μm + 2 Silicone polishers: Brownie® and Greenie® G4: 2 Carbide cutting burs G5: 2 Carbide cutting burs + Arkansas stone G6: 2 Carbide cutting burs + 2 Silicone polishers: Brownie® and Greenie®</td>
<td>Sa CP: 0.05 ± 0.02 μm CR: 1.74 ± 0.15 μm G1: 1.74 ± 0.62 μm G2: 0.69 ± 0.48 μm G3: 0.42 ± 0.09 μm G4: 0.74 ± 0.28 μm G5: 0.54 ± 0.07 μm G6: 0.41 ± 0.13 μm Sz: CP: 2.37 ± 1.92 μm CR: 17.92 ± 1.34 μm G1: 14.98 ± 3.46 μm G2: 7.06 ± 3.26 μm G3: 6.73 ± 2.38 μm G4: 12.16 ± 6.65 μm G5: 13.96 ± 2.53 μm G6: 6.08 ± 2.78 μm</td>
<td>Carbide cutting burs achieved smoother surfaces than diamond burs. Silicone polishers (Brownie® and Greenie®) yielded better results than the use of Arkansas stone.</td>
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<tr>
<td>Costa-Berenguer et al. (2018) (27)</td>
<td>In vitro</td>
<td>20 implants Implant surface: Moderately rough Sandblasted and acid-etched</td>
<td>Experienced professional. Tungsten carbide burs; silicon carbide polishers: brownie and greenie. T: Implantoplasty C: Control moderately rough</td>
<td>Sa T: 0.1 ± 0.02 μm* C: 0.76 ± 0.08 μm Sz T: 3.67 ± 1.28 μm* C: 10.92 ± 0.94 μm</td>
<td>A smooth surface can be obtained with tungsten burs and silicon polishers.</td>
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<td>de Souza Júnior</td>
<td>In vitro</td>
<td>36 implants</td>
<td>Experienced professional</td>
<td>Ra</td>
<td>All test groups had similar results in</td>
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<tr>
<td>Study (Year)</td>
<td>Design</td>
<td>Implant Surface</td>
<td>Processing and Technique</td>
<td>Surface Roughness Measurements</td>
<td>Findings</td>
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| et al. (2016) (22)   | In vitro   | Implant surface: Dual acid-etched | with controlled standardized pressure:  
G1: diamond  
G2: tungsten  
G3: multilaminar  
C: control machined surface | G1: 4.12 µm  
G2: 4.88 µm  
G3: 5.01 µm  
C: 1.92 µm* | terms of surface roughness, but less temperature increase was registered when tungsten burs were used. |
11 groups:  
10 carbide cutters (different form)  
1 diamond bur | No available data | Conical shaped tungsten burs provided the smoothest surface.  
The poorest results were obtained using a no. 6 round tungsten bur.  
Burs without notches yielded better results. |
| Ramel et al. (2016) (21) | In vitro   | 42 implants                      | Experienced professional.  
G1: 3 Diamond burs: 106,40,15 µm + 2 silicon polishers: Brownie® and Greenie®  
G2: 3 Diamond burs: 106,40,15 µm + Arkansas  
G3: 3 Diamond burs: 106,40,4 µm  
G4: 3 Diamond burs: 106,40,4 µm + 1 Silicon polisher: Greenie®  
G5: 5 Diamond burs: 106,40,15, 8,4 µm  
G6: 5 Diamond burs: 106,40,15, 8,4 µm + 1 Silicon polisher: Greenie®  
CP: control polished  
CR: control moderately rough | Ra  
G1: 0.32 ± 0.14 µm  
G2: 0.39 ± 0.13 µm  
G3: 0.71 ± 0.22 µm  
G4: 0.59 ± 0.19 µm  
G5: 0.98 ± 0.30 µm  
G6: 0.75 ± 0.26 µm  
CP: 0.1 ± 0.01 µm  
CR: 1.94 ± 0.47 µm  
Rz  
G1: 2.31 ± 0.95 µm  
G2: 3.19 ± 1.17 µm  
G3: 5.39 ± 1.84 µm  
G4: 4.35 ± 1.37 µm  
G5: 6.86 ± 2.20 µm  
G6: 5.21 ± 1.77 µm  
CP: 0.81 ± 0.19 µm  
CR: 13.15 ± 3.09 µm | A protocol that included 3 diamond burs and an Arkansas stone showed a good outcome taking into account surface roughness, treatment duration and final debris.  
A protocol with 3 diamond burs and 2 silicon polishers yielded the smoothest surface. |
| Rimondini et al. (2000) (25) | In vitro | 22 titanium implants plasma-sprayed coated 2 titanium machined cylinders | G1: Carbide 6 tapered round<br>G2: Carbide 6 large transversal cuts<br>G3: Carbide 6 fine transversal cuts<br>G4: Carbide 8 bladed<br>G5: Carbide 16 bladed<br>G6: Carbide 30 bladed<br>G7: Diamond 30 µm<br>G8: Diamond 15 µm<br>G9: Diamond 8 µm<br>G10: Carbide 8+16 bladed<br>G11: Carbide 8+16+30 bladed<br>G12: Carbide 16+30 bladed<br>G13: Diamond 30+15 µm<br>G14: Diamond 30+15+8 µm<br>G15: Diamond 15+8 µm<br>CP: Control polished<br>CR: Control rough | Ra<br>G1: 1.18 ± 0.39 µm<br>G2: 0.90 ± 0.19 µm<br>G3: 1.10 ± 0.53 µm<br>G4: 0.93 ± 0.52 µm<br>G5: 1.26 ± 0.42 µm<br>G6: 1.03 ± 0.29 µm<br>G7: 1.02 ± 0.15 µm<br>G8: 1.00 ± 0.19 µm<br>G9: 1.11 ± 0.29 µm<br>G10: 1.16 ± 0.26 µm<br>G11: 1.34 ± 0.59 µm<br>G12: 1.37 ± 0.48 µm<br>G13: 1.04 ± 0.14 µm<br>G14: 1.21 ± 0.40 µm<br>G15: 1.60 ± 0.41 µm<br>CP: 0.60 ± 0.20 µm<br>CR: 3.20 ± 0.37 µm | All surface procedures produced smoother surfaces than in the control group (titanium plasma-sprayed surface).<br>The most effective protocol was that using 30 µm plus 15 µm diamond burs.

<p>| | | | | Rz&lt;br&gt;G1: 6.01 ± 1.69 µm&lt;br&gt;G2: 4.48 ± 0.89 µm&lt;br&gt;G3: 4.99 ± 1.60 µm&lt;br&gt;G4: 3.34 ± 2.07 µm&lt;br&gt;G5: 4.64 ± 1.35 µm&lt;br&gt;G6: 3.99 ± 1.00 µm&lt;br&gt;G7: 5.21 ± 0.69 µm&lt;br&gt;G8: 4.46 ± 0.91 µm&lt;br&gt;G9: 4.43 ± 1.28 µm |</p>
<table>
<thead>
<tr>
<th>Study</th>
<th>Environment</th>
<th>Description</th>
<th>Surface roughness before implantoplasty</th>
<th>Surface roughness after implantoplasty</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Sahrmann et al. (2019) (29)</td>
<td>In vitro</td>
<td>30 titanium implants placed in phantom head simulators</td>
<td>G1: 3 Diamond burs; 106, 40 µm + Arkansas stone</td>
<td>G10: 4.04 ± 0.83 µm</td>
<td>The use of silicon carbide + Arkansas stones + silicone polishers seemed to be better option in comparison with the combination of 3 diamond burs and Arkansas stones.</td>
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<td>G2: Silicate carbide stone + Arkansas stone + 2 silicon polishers: Brownie® and Greenie®</td>
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<td>G11: 4.12 ± 1.32 µm</td>
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<td>G12: 4.33 ± 1.28 µm</td>
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<td>G13: 4.86 ± 0.57 µm</td>
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<td>G14: 5.84 ± 1.17 µm</td>
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<td>G15: 7.65 ± 2.04 µm</td>
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<td>CR: 2.97 ± 1.11 µm</td>
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<td>CP: 2.97 ± 1.11 µm</td>
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<tr>
<td>Tawse-Smith et al. (2016) (30)</td>
<td>In vitro</td>
<td>40 titanium disks (20 with machined surface and 20 with rough surface)</td>
<td>G1: machined</td>
<td>Machined disk (G1): 4.00 ± 0.52 µm</td>
<td>This implantoplasty protocol did not yield the expected outcome, although surface roughness was reduced in both groups.</td>
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<tr>
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<td>Implantoplasty experimental design – custom made device:</td>
<td>G2: moderately rough</td>
<td>After implantoplasty: 3.09 ± 0.29 µm</td>
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<td>Diamond regular grit, diamond super-fine grit, and 2 silicone polishers: Brownie® and Greenie®</td>
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<td>G1: Plastic curette</td>
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<td>G2: Air powder abrasive system</td>
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<td>G3: Ti Brush®</td>
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<tr>
<td>Toma et al. (2018) (32)</td>
<td>In vitro</td>
<td>250 titanium moderately rough disks colonized with S. gordonii</td>
<td>Experienced professional:</td>
<td>Ra</td>
<td>Implantoplasty reduced surface roughness better than the other treatments.</td>
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<td>G1: Plastic curette</td>
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<td>G1: 1.61 ± 0.17 µm</td>
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<td></td>
<td>G2: Air powder abrasive system</td>
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<td>G2: 1.31 ± 0.14 µm</td>
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<td>G3: Ti Brush®</td>
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<td>G3: 1.22 ± 0.31 µm</td>
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<td>G4: 0.98 ± 0.12 µm*</td>
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Table 1: Data of studies that assessed the effect of implantoplasty upon surface roughness. * Statistically significant differences. G: Group. T: Test group. C: Control group; CP: control group with machined or polished surface. CR: control group with rough surface.
<table>
<thead>
<tr>
<th>Studies (Year)</th>
<th>Study type</th>
<th>Sample</th>
<th>Implantoplasty protocol and study groups</th>
<th>Anti-biofilm therapy</th>
<th>Biofilm regrowth</th>
<th>Main outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geremias et al. (2017) (34)</td>
<td>In vivo</td>
<td>3 implants with peri-implantitis removed 4 months after surgical peri-implant treatment (open flap debridement; open flap debridement + chemical decontamination; and implantoplasty) Moderately rough, sandblasted and acid-etched contaminated implants</td>
<td>Experienced professional. G1: mechanical debridement (plastic curettes) G2: mechanical debridement + chemical decontamination (citric acid) G3: Implantoplasty: diamond burs and Arkansas stones</td>
<td>-</td>
<td>S. Mutans planktonic growth assessed by spectrophotometry and SEM G1: 0.210 ± 0.031 nm* G2: 0.165 ± 0.006 nm G3: 0.158 ± 0.017 nm</td>
<td>Implantoplasty and chemical decontamination inhibit biofilm regrowth in comparison with mechanical debridement.</td>
</tr>
<tr>
<td>Toma et al. (2018) (32)</td>
<td>In vitro</td>
<td>250 titanium moderately rough disks colonized with <em>S. gordonii</em></td>
<td>Experienced professional. G1: plastic curette G2: Air powder abrasive system G3: Ti Brush® G4: Implantoplasty (diamond bur) C: Control moderately rough</td>
<td>No significant differences in control vs plastic curettes. Significant differences in control and plastic curettes vs air-powder abrasive system, Ti Brush® and implantoplasty</td>
<td>No significant differences between control and plastic curettes. Significant differences control-G1 vs G2, G3, control and plastic curettes vs air-powder abrasive system, Ti Brush® and implantoplasty</td>
<td>Implantoplasty allowed more effective biofilm removal and less regrowth than plastic curettes and the control group. Implantoplasty, air-powder abrasive systems and Ti Brush® seemed to be equally effective.</td>
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Table 2: Studies that analyzed the effect of implantoplasty upon biofilm formation. * Statistically significant differences; G: Group; C: Control; SEM: Scanning electron microscopy.
<table>
<thead>
<tr>
<th>Studies (Year)</th>
<th>Study type</th>
<th>Sample</th>
<th>Implantoplasty protocol and study groups</th>
<th>Biocompatibility: cell viability</th>
<th>Implant surface chemical composition</th>
<th>Main outcomes</th>
</tr>
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</table>
| Behesti Maal et al. (2020) (23) | In vitro | 48 titanium grade IV disks 36 tests disks with rough surface by cathodic anodization 6 control Sandblasted and acid-etched (CR) 6 control polished (CP) | G1: 3 Diamond burs: 105µm, 40µm, 8µm  
G2: 3 Diamond burs: 105µm, 40µm, 8µm + Arkansas stone  
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G5: 2 Carbide cutting burs + Arkansas stone  
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Implantoplasty vs moderately rough different percentages of C, O, Na, Ti and Al


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Table 3: Data of studies that assessed the effect of implantoplasty upon biocompatibility. * Statistically significant differences; CP: control polished; CR: control rough; G: Group; HGF: Human gingival fibroblasts; VEGF: vascular endothelial growth factor; IL-6: interleukin 6; MCP1: monocyte chemotactic protein-1; MCP3: monocyte chemotactic protein-3; IP-10: interferon gamma-induced protein 10; C: Carbon; O: Oxygen; Na: Sodium; Cl: Chlorine; K: Potassium; Si: Silicon; N: Nitrogen; Ti: Titanium; Al: Aluminum.