The Effect of a Polishing Protocol on the Surface Roughness of Zirconium Oxide

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Purpose: To evaluate the surface roughness values of zirconium oxide samples that were gradually polished using a commercially available polishing system and polishing paste. Materials and Methods: A total of 50 rectangular specimens of predetermined size (10 × 10 × 3 mm) were sintered from zirconium oxide. Samples were randomly assigned to one of five groups (n = 10 each): control, coarse (Co), fine (F), super fine (SF), or polishing paste (PP). In the control group, no polishing was done; in the Co group, a coarse polisher was used; and the specimens in the remaining three groups underwent additional processing with a fine rubber abrasive. For SF and PP samples, subsequent treatment with a super fine polisher was applied. Finally, for the PP group, a goat-hair brush with diamond polishing paste was used. An optical profilometer was used to evaluate roughness average (Ra) in micrometers (µm). ANOVA and Games-Howell post hoc tests were utilized to detect differences between groups. The significance level was set to α = .05. Results: Surface roughness gradually decreased with further polishing throughout the groups: control Ra = 0.525 ± 0.099 µm; Co Ra = 0.252 ± 0.038 µm; F Ra = 0.196 ± 0.035 µm; SF Ra = 0.114 ± 0.031 µm; and PP Ra = 0.054 ± 0.020 µm. Statistically significant differences were detected among all groups (P < .05). Conclusion: A surface roughness of 0.054 µm can be achieved if a full zirconia polishing protocol is used. Zirconium oxide can be polished to various surface roughnesses using commercially available polishing products. Int J Prosthodont 2020;33:217–223. doi: 10.11607/ijp.6686

Development of an effective transmucosal barrier between the oral environment and the dental implant is one of the most important parts of implant therapy. It is widely considered that if this seal is not adequate, plaque penetration, which results in the progression of peri-implant diseases, could pose a considerable risk to treatment success. It might be suggested that the development of this biologic protection depends not only on the quality of the soft peri-implant tissues, but also on how the implant is restored—in fact, the prosthetic abutment, which extends subgingivally, is the area where epithelial cells align to create an attachment via hemidesmosomes. Therefore, abutment material may play an important role in this process, and the tissues might react differently to materials such as titanium, zirconia, glazed porcelain, and lithium disilicate ceramics. There are different opinions on optimal material choice; however, it cannot be denied that zirconia as a material offers substantial advantages over other choices due to lower adhesion of bacteria, less inflammatory response in soft tissues, and, of course, esthetics. Furthermore, van Brakel...
et al have shown significantly reduced probing depths around zirconia abutments compared to titanium parts in a cohort of 20 patients. In addition, a recent systematic review confirmed less increase in plaque accumulation and bleeding on probing over time for zirconia abutments compared to titanium.

Interestingly enough, it is suggested that the response of the soft tissues might depend not only on the type of the material, but on the polishing status of the material's surface as well.

The smoothness of the zirconia surface and its importance to peri-implant tissues has been debated in recent years. There are several opinions regarding what kind of zirconia surface should be provided to soft peri-implant tissues: polished, roughened, or ultra-polished. Linkevicius suggested in a case series with a 3-year follow-up that a screw-retained restoration with an ultra-polished zirconia surface evoked a positive reaction of peri-implant tissues. Additional evidence in favor of zirconia comes from a study by Bolten et al, in which ultra-polished zirconia abutments (roughness average [Ra] = 0.06 mm) showed lower probing depths compared to titanium abutments with a standard machined surface (Ra = 0.2 mm). Although lower probing depths do not necessarily mean healthier peri-implant tissues, the question remains: How is the needed smoothness of zirconia achieved in a dental laboratory?

Custom zirconia abutments must undergo various preparations before being delivered to the implant. There are various commercially available ceramic polishers for smoothing the surface of the restoration; however, the end point of polishing is usually defined subjectively by the dental technician, and the actual roughness remains unknown. Happe et al developed a polishing protocol that allowed smoothing of the surfaces of zirconia specimens ranging from 0.29 to 0.07 mm in a controlled way. Polishing machines were used in the study to give more control to the process, meaning that the real smoothness of zirconia in everyday clinical situations may be different with the involvement of laboratory technicians. In addition, more information about the polishing abilities of other brands of zirconia or the polishing armamentarium than presented in previous studies is needed.

Therefore, the aim of this experiment was to evaluate the surface roughness values of zirconia samples that underwent gradual polishing by an experienced dental technician using tools from a commercially available polishing system and polishing paste.

**MATERIALS AND METHODS**

A total of 50 rectangular specimens of predetermined size (10 × 10 × 3 mm) were sintered from zirconium oxide (Lava Classic, 3M ESPE) according to the manufacturer's instructions. Samples were randomly assigned to one of five groups (n = 10 each): control, coarse (Co), fine (F), super fine (SF), and polishing paste (PP). In the control group, no polishing was done and the samples were left as sintered. Other specimens were processed using a diamond-impregnated polishing system (NTI CeraGlaze, NTI-Kahla) (Table 1) and soft goat-hair brush (P1259, NTI-Kahla) with diamond polishing paste (Zirkopol, Feguramed).

All polishing procedures were carried out under a microscope (EyeMag Pro; ZEISS) at ×3.2 magnification. A coarse polisher (NTI CeraGlaze P301, NTI-Kahla) was used for 2 minutes at 16,000 rpm to prepare all samples expect for those in the control group. No further polishing was done in the Co group, but specimens in the remaining three groups underwent additional processing with a fine polisher (NTI CeraGlaze P3001, NTI-Kahla) for 1 minute at 12,000 rpm. No further processing was done in the F group. For the SF and PP samples, a subsequent super-fine polisher (NTI CeraGlaze P30001, NTI-Kahla) was used for 1 minute at 6,000 rpm. Finally, in the PP group, a goat-hair brush (NTI P1259, NTI-Kahla) with diamond polishing paste (Zirkopol) was used for 1 minute at 15,000 rpm. All instrumentation was carried out by applying light pressure and choosing the optimal rotation speed following manufacturers' instructions and by the same professional dental technician (R.A.), imitating regular zirconia processing. The polishing protocols are summarized in Fig 1. After polishing and prior to measurements, all samples were cleaned in an ultrasonic bath with 35°C distilled water for 10 minutes.

An optical profilometer (PLμ 2300, Sensofar) was used to evaluate surface roughness. Objective

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**Table 1 Polishing Set and Materials**

<table>
<thead>
<tr>
<th>Polisher</th>
<th>Color code</th>
<th>Lot</th>
<th>Grain size (µm)</th>
<th>ISO code</th>
<th>Grain size range (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepolishing</td>
<td>Green</td>
<td>P301</td>
<td>120</td>
<td>ISO 534</td>
<td>107 to 181</td>
</tr>
<tr>
<td>Refined finish</td>
<td>Blue</td>
<td>P3001</td>
<td>80</td>
<td>ISO 524</td>
<td>64 to 126</td>
</tr>
<tr>
<td>High-shine polishing</td>
<td>Yellow</td>
<td>P30001</td>
<td>30</td>
<td>ISO 504</td>
<td>10 to 36</td>
</tr>
</tbody>
</table>

ISO = International Organization for Standardization.

*Manufacturer: NTI-Kahla Rotary Dental Instruments.

RESULTS

Visual inspection of the specimens’ surfaces in the contour view window of the optic profilometer showed a gradual smoothing (Fig 2). Unpolished specimens in the control group showed a coarse surface texture (Fig 2a) distinctively different from the polished samples of the Co, F, and SF groups, which showed similar surface structures characterized by longitudinal straight grooves (the marks of the polishers). The grooves steadily reduced in number and became shallower following the polishing sequence from the Co to SF groups (Figs 2b to 2d). Almost no grooves could be distinguished in the PP samples (Fig 2e), and the surface appeared entirely smooth and homogenous.

Topographic properties (Ra, Rq, Rz, Rt) of the surfaces are displayed in Table 2.

Table 2 Descriptive Statistics for Comparison of Surface Roughness (µm)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SD</th>
<th>SE</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.525</td>
<td>0.099</td>
<td>0.035</td>
<td>0.509</td>
<td>0.398</td>
<td>0.658</td>
<td>0.198</td>
</tr>
<tr>
<td>Coarse</td>
<td>0.252</td>
<td>0.038</td>
<td>0.013</td>
<td>0.252</td>
<td>0.210</td>
<td>0.314</td>
<td>0.069</td>
</tr>
<tr>
<td>Fine</td>
<td>0.196</td>
<td>0.035</td>
<td>0.009</td>
<td>0.189</td>
<td>0.138</td>
<td>0.263</td>
<td>0.049</td>
</tr>
<tr>
<td>Super fine</td>
<td>0.114</td>
<td>0.031</td>
<td>0.008</td>
<td>0.113</td>
<td>0.060</td>
<td>0.166</td>
<td>0.051</td>
</tr>
<tr>
<td>Polishing paste</td>
<td>0.054</td>
<td>0.020</td>
<td>0.002</td>
<td>0.049</td>
<td>0.028</td>
<td>0.126</td>
<td>0.023</td>
</tr>
</tbody>
</table>

SD = standard deviation; SE = standard error; IQR = interquartile range.

epi-fluorescence (EPI) ×20 lens with a scanning area of 636.61 × 477.25 µm², Z scan range ± 50 µm mode, was chosen. The device was calibrated according to the manufacturer’s instructions. Each sample was scanned three times at three different locations: the middle, 1 mm right from the middle area, and 1 mm left from the middle area. Ra, root mean square roughness (Rq), mean maximum height of the profile (Rz), and maximum height of the roughness (Rt) were calculated based on eight different measurements in a scanned area using built-in software.

Statistical analysis was done using IBM SPSS Statistics 20. Normal distribution of the data rows was determined using Shapiro-Wilk test ($P > .05$). Levene test revealed heterogeneity of variance ($P < .05$); thus, analysis of variance (ANOVA) and Games-Howell post hoc tests were utilized to detect differences between groups. The significance level was set to $\alpha = .05$. 

Fig 1 Polishing protocols and parameters.
Statistical analysis of the five groups showed a gradual reduction in Ra of zirconia samples, as shown in Table 3. Various values of surface roughness could be achieved using different polishing protocols. The smoothest surface was obtained in the PP group (Ra = 0.054 ± standard deviation 0.020 µm). Comparing Ra among groups showed statistically significant differences ($P < .05$) (Fig 3).

**DISCUSSION**

The results of this experiment showed that it is possible to polish zirconium oxide to the level of 0.054 µm, which is considered to be ultra smooth. This is smoother than in the Happe et al$^{19}$ study, which produced polished zirconia plates of 0.09-µm roughness, while Bollen et al$^{18}$ reported that zirconia could be polished up to 0.06 µm. Nothdurft et al$^{16}$ used various commercially available polishing systems and achieved surface smoothness of zirconia up to 0.12 µm, which is comparable to the SF stage of polishing in the present study (0.114 µm). However, Huh et al did not use any polishing paste, as was done in the current study, to further polish the zirconia. It is important to note that each polisher in the present study added more smoothness to the sample in a statistically significant way, enabling the dental technician to achieve the preferred smoothness of zirconia.

There are several opinions on how smooth the subgingival part of the implant restoration should be. One view insists that the abutment should have a certain degree of roughness in order to promote better attachment of the cells.$^{20}$ It is hypothesized within the levels of animal and clinical human histology evidence that rough channels promote the ingrowth of the fibroblasts to create sufficient protective resistance to oral threats.$^{21-23}$ This approach might be disputed...
study, van Brakel et al32 confirmed less probing depth around zirconia abutments compared to titanium ones. It must be noted that the authors inspected overden - ture abutments, meaning that probing depths might have been more precise in comparison to the probing of implant restorations, which have profile contours precluding perpendicular positioning of the periodontal probe, thus leading to less accuracy. On the other hand, it was clearly shown that a cross-sectional difference in probing depth is not an indicator of disease; therefore, statements of reduced probing depth should not be considered as a sign of stronger soft tissue protection.30

Quirynen et al 24 established a surface smoothness threshold of 0.2 µm, below which the accumulation of plaque is not reduced. From this point of view, smoother surfaces would not make sense; however, it should not be forgotten that this recommendation is based on titanium abutments, meaning that its implications for zirconia abutments might be limited or lower. Currently, there are no data showing that surfaces with smooth-ness below 0.2 µm are more beneficial in terms of plaque adherence.24

Fig 3  Roughness average (Ra) values with bars for standard error. There were significant differences among all groups (Games-Howell post hoc test, \( P < .05 \)). a\( P < .001 \). b\( P = .025 \).

Discussion about polished zirconia would be futile without the schematic picturing of peri-implant soft

because the presence of a rough surface poses the risk for bacteria enrollment, as accumulation of the plaque may increase by up to 25 times if the subgingival surface roughness increases to 0.8 µm.24

When zirconia is discussed as a subgingival implant prosthetic material, several points of view are available. One opinion, supported by an observational case report,13 suggests that the subgingival restoration part could be polished to be as smooth as possible—it is hypothesized that better adhesion of epithelial cells to a polished zirconia surface can be achieved, as it is known that epithelial cells prefer smoother surfaces.25–29 In addition, studies report reduced bacteria accumulation and lower inflammation levels around zirconia,6–10,30 and it can be speculated that a less inflammatory en-vironment could lead to a tighter and more rigid peri-implant sulcus. Critics of this approach suggest that an ultra-polished abutment surface leads to recession of the tissues and increased probing depth and thus cannot be recommended,24 as it is assumed that ultra-smooth surfaces preclude the attachment of cell tissues. However, the Quirynen et al24 paper researched titani-um abutments, which are not the same as zirconia. Due to the different properties, the present authors cannot suggest that recession over smooth titanium abutments implies the same outcome for zirconia abutments. Oth-er differences, such as zirconia’s lower plaque attraction compared to titanium—probably due to the lower elec-trical charge—might influence the outcome as well.6–9,30,31 In this context, it is important to mention the Bollen et al18 study, which examined the influence of ultra-smooth zirconia and regular-smoothness titanium abutments on probing depth, recession, and bleeding on probing around implants. Although the study did not report any differences between test and control sites except for plaque accumulation, this study is often quoted to show that smooth zirconia abutments had higher probing depths.18 It is interesting to observe that empirical numbers show the opposite: 2.91 µm for zir-conia and 3.12 µm for titanium. There was no statistical difference between those measures, and this remains an odd fact in the scientific literature, considering how this study is sometimes referred to. In a split-mouth study, van Brakel et al32 confirmed less probing depth around zirconia abutments compared to titanium ones. It must be noted that the authors inspected overden-ture abutments, meaning that probing depths might have been more precise in comparison to the probing of implant restorations, which have profile contours precluding perpendicular positioning of the periodontal probe, thus leading to less accuracy. On the other hand, it was clearly shown that a cross-sectional difference in probing depth is not an indicator of disease; therefore, statements of reduced probing depth should not be considered as a sign of stronger soft tissue protection.30

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Discussion about polished zirconia would be futile without the schematic picturing of peri-implant soft

<table>
<thead>
<tr>
<th>Group</th>
<th>Ra</th>
<th>Rq</th>
<th>Rz</th>
<th>Rt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.525 ± 0.099</td>
<td>0.644 ± 0.134</td>
<td>2.127 ± 0.301</td>
<td>3.605 ± 0.675</td>
</tr>
<tr>
<td>Coarse</td>
<td>0.252 ± 0.038</td>
<td>0.326 ± 0.041</td>
<td>1.547 ± 0.109</td>
<td>2.074 ± 0.131</td>
</tr>
<tr>
<td>Fine</td>
<td>0.196 ± 0.035</td>
<td>0.225 ± 0.020</td>
<td>1.048 ± 0.175</td>
<td>1.333 ± 0.226</td>
</tr>
<tr>
<td>Super fine</td>
<td>0.114 ± 0.031</td>
<td>0.138 ± 0.033</td>
<td>0.497 ± 0.126</td>
<td>0.869 ± 0.227</td>
</tr>
<tr>
<td>Polishing paste</td>
<td>0.054 ± 0.020</td>
<td>0.068 ± 0.025</td>
<td>0.267 ± 0.041</td>
<td>0.347 ± 0.084</td>
</tr>
</tbody>
</table>

All data are reported as mean ± standard deviation.
Ra = roughness average; Rq = root mean square roughness; Rz = average maximum height of profile; Rt = maximum height of roughness.

Table 3  Surface Topography Properties (µm)
The International Journal of Prosthodontics

**Fundamental Research**

The current study shows that zirconium oxide can be polished up to 0.054 µm, while the surface roughness of stock titanium abutments was reported to be in the range of 0.1 to 0.2 µm.\(^24\),\(^32\),\(^41\) Thus, it can be hypothesized that adhesion of epithelial cells to zirconia can be achieved better than to titanium. Recent in vitro studies show that the roughness of the material is important for the behavior of cells on zirconia and titanium,\(^16\) and it was found that polished zirconia surfaces provide better adhesion for epithelial cells compared to titanium. Of course, these hypotheses should be tested in clinical trials, comparing the reaction of the tissues to different smoothness of the material; however, the current results can at least provide the exact protocol of how to achieve the desired smoothness of zirconia.

The current study used linear surface roughness (Ra, Rq, Rz, Rt) values, which represent the average of individual measurements of a surface’s peaks and valleys, to report the smoothness of the surface, as many previous studies have used the same measurements.\(^14\),\(^15\),\(^21\) and having the same measurements ensures that the studies can be compared to each other. Another similar measurement is Sa, which expresses the difference in height of each point compared to the arithmetic mean of the surface. However, this measurement is considered more difficult and thus used less in the field. In addition, some of the samples had irregular waviness, which could not be leveled into a plane properly using the provided software without additional distortions of the area.

Hand polishing of the samples was done by a dental technician with 20 years of work experience as a single operator (R.A.). This fact could be considered a setback of the study by some, as there is the potential for human error compared to other studies that used standardized polishing machines.\(^19\) Alternatively, hand polishing brings to this trial a more realistic touch, as in daily practice the polishing of the abutments is performed in the lab by technicians. In addition, the measurements of the polished plates were performed in three locations to increase the reliability of data and to reduce the influence of possible human error introduced by hand polishing.

**CONCLUSIONS**

With these limitations in mind, it can be concluded that zirconium oxide can be polished to various surface roughnesses using commercially available polishing tools and products. A roughness of 0.054 µm can be achieved if a full zirconium polishing protocol is used. The possibility to control surface roughness in a dental laboratory is an important advantage of custom-made zirconia abutments.

**ACKNOWLEDGMENTS**

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Accuracy of Single Molecular Biomarkers in Saliva for the Diagnosis of Periodontitis: A Systematic Review and Meta-Analysis

The purpose of this study was to analyze, using a meta-analytic approach, the diagnostic accuracy of single molecular biomarkers in saliva for the detection of periodontitis in systemically healthy subjects. Articles on molecular biomarkers in saliva providing a binary contingency table (or sensitivity and specificity values and group sample sizes) in individuals with clinically diagnosed periodontitis were considered eligible. Searches for candidate articles were conducted in six electronic databases. Methodologic quality was assessed using the Quality Assessment of Diagnostic Studies tool. Meta-analyses were performed using a hierarchical summary receiver operating characteristic model. Meta-analysis was possible for 5 of the 32 biomarkers studied. The highest values of sensitivity for the diagnosis of periodontitis were obtained for IL-1 beta (78.7%), followed by MMP8 (72.5%) and then IL-6 and hemoglobin (72.0% for both molecules). The lowest sensitivity value was for MMP9 (70.3%). In terms of specificity estimates, MMP9 had the best result (81.5%), followed by IL-1 beta (78.0%) and hemoglobin (75.2%). MMP8 had the lowest specificity (70.5%). MMP8, MMP9, IL-1 beta, IL-6, and hemoglobin were salivary biomarkers with good capability of detecting periodontitis in systemically healthy subjects. MMP8 and IL-1 beta are the most researched biomarkers in the field, and both show clinically moderate effectiveness for the diagnosis of periodontitis.


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