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Evaluation of Polishing Systems for CAD/CAM Polymer-Infiltrated Ceramic-Network Restorations

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Clinical Relevance

Although a company proprietary system is recommended for polishing of computer-aided design and computer-aided manufacturing (CAD/CAM) polymer-infiltrated ceramic-network restorations, ceramic and composite polishing systems may also improve surface characteristics of such materials. However, ceramic polishing systems tend to perform better than composite polishing systems from nanoscale and visual assessments.

SUMMARY

Objective: The purpose of this study was to evaluate the effectiveness of five different polishing systems on a computer-aided design and computer-aided manufacturing (CAD/CAM) polymer-infiltrated ceramic-network restoration with nanoscale assessment using atomic force microscopy (AFM) and visual assessment performed by dental school senior students and faculty members.

Method: Forty-eight full coverage crowns were milled out of polymer-infiltrated ceramic-network CAD/CAM blocks (Vita Enamic) for polishing with one company proprietary, two ceramic and

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two composite polishing systems. The prepared crowns were divided into six groups: (1) no polishing (control); (2) polishing with Vita Enamic Polishing Kit (VEna); (3) polishing with Shofu Porcelain Laminate Polishing Kit (SCer); (4) polishing with Brasseler Dialite Feather lite All-Ceramic Adjusting & Polishing System (BCer); (5) polishing with Shofu Composite Polishing Kit (SCom); and (6) polishing with Brasseler Composite Polishing Kit (BCom). The polished crown surface topography was observed, and surface roughness and area were measured with AFM. In addition, polished crowns were visually assessed by 15 senior dental students and 15 dental school faculty members.

Results: All polishing treatments significantly reduced the surface roughness and area of the crown compared with the control. SCom and BCom showed significantly higher surface area than VEna, and the SCer and BCer groups were intermediate, showing no significant difference from either VEna or SCom and BCom. There were no significant differences in surface roughness between any of the systems. Dental students and faculty members classified the groups polished with VEna, SCer, and BCer groups as clinically acceptable, and they selected BCer group as the best polished restorations and the control group as the least polished restorations.

Conclusions: Ceramic and composite polishing systems produced similar polishing results as that observed using a company proprietary polishing system. However, effectiveness for polishing using a company proprietary and ceramic polishing system tends to be higher than composite polishing systems.

INTRODUCTION

Chairside dental computer-aided design and computer-aided manufacturing (CAD/CAM) systems have evolved and improved in all aspects since the first CEREC chairside treatment (CEREC 1 prototype unit, called *lemon*) was introduced by Dr Werner Mörmann and Dr Marco Brandestini in September 1985 at the Center of Dental Medicine of the University of Zurich.[1] Currently, chairside dental CAD/CAM systems can fabricate ceramic restorations in a single appointment allowing clinicians to design and mill a restoration in the clinic within minutes.[2] However, the CAD/CAM milling process does not create a smooth surface ready for clinical placement. Thus, prior to cementation, milled restorations need to be finished and polished or glazed after fabrication.[3]

A chairside polishing system used for finishing and polishing should create a smooth surface for restorations that will maximize their toughness[4] and minimize the incidence of biological complications such as facilitating discoloration, enhancement of bacterial adhesion and colonization;[5] the risk of fracture or chipping of restoration,[6] and tribological wear of opposing dental enamel[7] as well as restorations.[8] In addition, optimal finishing and polishing procedures enhance the esthetic appearance such as gloss[9] and color stability[10] and translucency[11] of the milled CAD/CAM restorations because they create a polished surface that mimics normal tooth surfaces.

A newly developed polymer-infiltrated ceramic-network (PICN) material (Vita Enamic Vita Zahnfabrik, Bad Säckingen, Germany) is now available in different shades and variable degrees of translucency based on the outcome of a study by Nguyen and others.[12] It is a combination of 86% of sintered ceramic matrix and 14% polymer matrix[13] and recognized as a material between ceramic and resin composite in mechanical properties and as a literal combination of the two material types.[14] This material is fabricated by first infiltrating a porous ceramic-base structure with a monomeric mixture of a new cross-linked polymethacrylate polymer material and then polymerized under high pressure and temperature.[15] This material can be used to fabricate single-unit crowns, inlays, and onlays in the anterior and posterior regions, and it has its own polishing system (Vita Enamic Polishing Set, Vita Zahnfabrik) to provide patient comfort and to yield optimal esthetics and excellent biological and mechanical properties. While the manufacturer recommends the use of this proprietary polishing system, clinicians may not have access or choose not to use a specific polishing system for each type of restorative material they may use. However, there is little information currently available regarding the effectiveness of commercially available polishing systems, including ceramic and composite polishing systems, for a PICN material.

The aim of this study was to evaluate the effectiveness of five different polishing systems on a PICN material with nanoscale assessment using atomic force microscopy (AFM) and visual assessment by dental students and faculty members. The first null hypothesis was that ceramic and composite polishing systems would provide the same nanoscale assessment as a company proprietary system. The second null hypothesis was that all polishing systems would provide clinically acceptable results after being visually assessed.

METHODS AND MATERIALS

Specimen Preparation

A typodont tooth 17 was prepared for an all-ceramic crown restoration with a chamfer finish line (the occlusal clearance for the preparation was 1.5 mm). The prepared tooth and opposing arch were scanned with a chairside intra-oral scanner (Bluecam, CEREC, Dentsply Sirona, York, PA, USA), and the accompanying software provided an ideal restoration design. Forty-eight PICN crowns were then milled out of Vita Enamic shade A1 blocks.

The crowns were divided in six groups each of eight crowns as follows: (1) control (no polishing); (2) restorations polished using a proprietary polishing system (VEna; Vita Enamic Polishing Set, VITA Zahnfabrik); (3) restorations polished with a ceramic polishing system (SCer; Shofu Porcelain Laminate Polishing Kit, Shofu, Kyoto, Japan); (4) restorations polished with another ceramic polishing system (BCer; Brasseler Dialite Feather Lite All Ceramic Adjusting & Polishing System, Brasseler USA Dental, Savanna, GA, USA); (5) restorations polished with a composite polishing system (SCom; Shofu Composite Polishing Kit); and (6) restorations polished with another composite polishing kit (BCom; Brasseler Composite Polishing Kit, Brasseler USA Dental). The experimental design is summarized in Table 1. The polishing procedure was performed by a single prosthodontist following the speed recommended by the manufacturers for two minutes.

AFM Evaluation

An AFM (Agilent 5420 Scanning Probe Microscope/AFM, Agilent Technologies, Santa Clara, CA, USA) was used to assess and measure the surface topography of the PICN crowns. AFM images were obtained in constant force mode with a silicon nitride cantilever (Budget Sensors, Sofia, Bulgaria). Eight samples (n=3 scans each) were imaged for each group. Surface roughness (Ra), the arithmetic mean of the absolute values of the profile height deviations from the average, was measured and recorded. The surface area was similarly measured, which quantified the modified surface area (above 900 μm^2 for a flat surface) due to roughness features across the PICN crowns.

Visual Assessment

For the visual assessment, PICN crowns with and without polishing from each group were visually evaluated by 15 dental school senior students and 15 dental school faculty members. These individuals were chosen randomly from among volunteers. These examiners did not know which method had been used to polish which samples, but the samples were grouped into those that had been polished using the same method. Each of the 30 examiners visually evaluated the restorations under similar lighting conditions and completed a form in which they classified the restorations as clinically acceptable or nonclinically acceptable. They were also asked to select the group showing the best polished and the poorest polished surface.

Statistical Analysis

Statistical analysis was conducted with a commercial statistical software package (SPSS Statistics Base, IBM, Armonk, NY, USA). A statistical power analysis was conducted, showing that eight samples would have a power of over 0.7 at an effect size of 0.5 and a 0.05 significance level. This was judged to be adequate. A one-way analysis of variance with Tukey post hoc honest significant difference test was used to analyze the gathered surface roughness and area data.

Table 1: *Materials Used in this Study*

Group	Polishing System	Manufacturer
Group 1 (Control)	No polishing	None
Group 2 (VEna)	Vita Enamic Polishing Set	Vita Zahnfabrik, Bad Säckingen, Germany
Group 3 (SCer)	Shofu Porcelain Laminate Polishing Kit	Shofu, Kyoto, Japan
Group 4 (BCer)	Brasseler Dialite Feather Lite All Ceramic Adjusting & Polishing System	Brasseler USA Dental, Savanna, GA, USA
Group 5 (SCom)	Shofu Composite Polishing Kit	Shofu
Group 6 (BCom)	Brasseler Composite Polishing Kit	Brasseler USA Dental

Abbreviations: BCer, Brasseler Dialite Feather lite All-Ceramic Adjusting & Polishing System; BCom, Brasseler Composite Polishing Kit; SCer, Shofu Porcelain Laminate Polishing Kit; SCom, Shofu Composite Polishing Kit; VEna, Vita Enamic Polishing Kit

RESULTS

Three-Dimensional Topographic Observations

Upon qualitative visual inspection of AFM micrographs (Figure 1), group 1 (control) displayed a relatively rough surface with many peaks in the range of 4 μm in height. However, after all polishing treatments (groups 2-6), the surface of restorations became visually smoother and showed peaks with an approximate height of 2 μm. Groups 2 and 4 showed smoother surfaces than the other groups.

Surface Roughness (Ra) and Surface Area Measurements

Surface roughness (Ra) values (Table 2) of PICN crowns showed that all polishing treatment regimens (group 2-6) significantly reduced ($p<0.05$) the roughness compared with the control (group 1). However, there were no significant differences ($p>0.05$) among the polishing treatments. Surface area (Table 2) of PICN crowns showed that all polishing treatments significantly reduced ($p<0.05$) the surface area of the 30 x 30 μm scans compared with the control (group 1). Although group 3 (SCer) and group 4 (BCer) did not show any statistical differences to group 2 (VEna), group 5 (SCom) and group 6 (BCom) exhibited significantly greater surface area than group 2 (VEna).

Visual Assessment

The results of dental school senior students and faculty members visual assessment of the PICN crowns with and without polishing are shown in Tables 2 and 3. Group 2-4 (VEP, SCer, and BCer) were selected as clinically acceptable; groups 1, 5, and 6 (control, SCom, and BCom) were chosen as nonclinically acceptable (Table 2). Moreover, group 4 (BCer) was the first choice as the best polished surface, and group 1 (control) was the selected as the least polished surface (Table 4). Good agreement was seen between dental school senior students and faculty members in all cases; the ranking of the groups was the same for both types of assessor, and the overall numbers for each group were very similar.

DISCUSSION

Scanning electron microscope (SEM) is commonly used for two-dimensional imaging evaluation of polished surfaces.[16] In the present study, AFM was used for three-dimensional imaging with a lateral resolution of approximately 5 nm (<1 nm height resolution).[17] This method can be applied to either hard (i.e., enamel, composites, or ceramics) or soft tissue (such as mucosal tissue).[18] AFM is advantageous compared with conventional SEM because AFM does not require a vacuum environment and sputter coating for proper operation; this means little to no sample preparation is needed leading to minimized damage of the sample.[19] Most importantly, AFM can provide quantitative information such as surface roughness and area, compared with simply qualitative SEM analysis.[20] Surface roughness and area, as two-dimensional metrics of a three-dimensional surface, are inherently limited

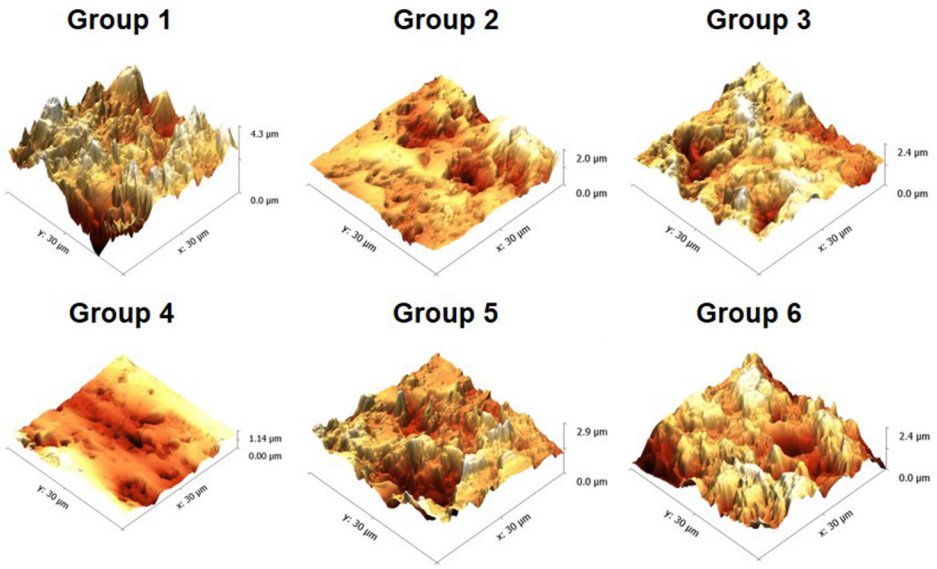

Figure 1. *Atomic force microscopy images of the polished restorations. Group 1 (control); group 2 (VEna); group 3 (SCer); group 4 (BCer); group 5 (SCom); group 6 (BCom).*

Table 2: *Surface Roughness and Area Measurements with AFM*

Group	Surface Roughness (nm)[a]	Surface Area (μm²)[a]
Group 1 (Control)	534.4 (107.3) a	1131.0 (82.1) a
Group 2 (VEna)	263.4 (133.8) b	944.0 (38.2) b
Group 3 (SCer)	284.2 (109.3) b	970.6 (35.9) b,c
Group 4 (BCer)	204.9 (81.7) b	934.1 (29.7) b,c
Group 5 (SCom)	232.4 (73.9) b	990.1 (41.2) c,d
Group 6 (BCom)	295.2 (109.6) b	1000.4 (38.3) c,d

Abbreviations: BCer, Brasseler Dialite Feather lite All-Ceramic Adjusting & Polishing System; BCom, Brasseler Composite Polishing Kit; SCer, Shofu Porcelain Laminate Polishing Kit; SCom, Shofu Composite Polishing Kit; VEna, Vita Enamic Polishing Kit.

[a]Values in parentheses are standard deviations. Same letter in same column indicates no significant difference (p>0.05).

Table 3: *Dental School Senior Students and Faculty Members Visual Assessment of the Polymer-Infiltrated Ceramic-Network Crowns; Clinical Acceptability*

Group	Clinically Unacceptable Senior Students/Faculty Members	Clinically Acceptable Senior Students/ Faculty Members
Group 1 (Control)	13/14	2/1
Group 2 (VEna)	1/1	14/14
Group 3 (SCer)	3/4	12/11
Group 4 (BCer)	0/0	15/15
Group 5 (SCom)	10/11	5/4
Group 6 (BCom)	8/9	7/6

Abbreviations: BCer, Brasseler Dialite Feather lite All-Ceramic Adjusting & Polishing System; BCom, Brasseler Composite Polishing Kit; SCer, Shofu Porcelain Laminate Polishing Kit; SCom, Shofu Composite Polishing Kit; VEna, Vita Enamic Polishing Kit

Table 4: *Dental School Senior Students and Faculty Members Visual Assessment of the Polymer-Infiltrated Ceramic-Network Crowns; Best or Poorest Polished Restoration*

Group	Visually Classified as the Best Polished Restoration	Visually Classified as the Poorest Polished Restoration
Group 1 (Control)	0	25
Group 2 (VEna)	5	0
Group 3 (SCer)	1	0
Group 4 (BCer)	24	0
Group 5 (SCom)	0	5
Group 6 (BCom)	0	0

Abbreviations: BCer, Brasseler Dialite Feather lite All-Ceramic Adjusting & Polishing System; BCom, Brasseler Composite Polishing Kit; SCer, Shofu Porcelain Laminate Polishing Kit; SCom, Shofu Composite Polishing Kit; VEna, Vita Enamic Polishing Kit

to fully characterizing the surface. However, they are complementary and can correlate with one another, but both are good visual metrics for the total amount of exposed surface and the morphology of that surface. These are important, and occasionally disparate, attributes for any dental surface, whether considering bacterial colonization to adhesion properties.[7,17]

While there is a trend of combining different types of ceramics and/or polymers in the same CAD/CAM block, there is no clear information on what type of polishing system should be used in situations where a clinician does not have access to the company proprietary polishing system. VITA Zahnfabrik developed a PICN material and its own proprietary polishing system specially designed for their material. This study sought to find suitable polishing systems for PICN material and assess their effects on quality and quantity of surface roughness and area and visual assessment by dental school senior students and faculty members.

Based on the results obtained, both a company proprietary system and ceramic polishing systems tended to provide a smoother finish for PICN restorations compared with composite polishing systems. The first null hypothesis that the ceramic and composite polishing systems would provide the same results as a company proprietary system was partially rejected.

Visual assessment of restorations that were finished and polished by the company proprietary and ceramic polishing systems were found to be clinically acceptable, whereas the restoration finished with composite polishing systems were rated as nonclinically acceptable. Despite the lack of statistically significant differences in surface roughness, there was a very high level of consensus between the assessors, and they selected the samples with the lowest roughness and surface area as the best. This suggests that this visual inspection is more discriminating and efficient than quantitative measurement and can be used in the assessment of polishing methods. Therefore, the second hypothesis that all polishing systems would provide clinically acceptable results after being visually assessed was rejected.

An earlier study reported that an ideal threshold surface roughness is below 200 nm, bacterial retention is facilitated, and the incidence of biological complications is increased if above this level.[21] However, previous studies revealed that surface roughness of polished ceramic restorations ranging from 200 to 700 nm have been achieved.[22] In addition, superficial roughness higher than 500 nm can be detected by the sensorial fibers of the tongue, resulting in discomfort for the patient.[23] Nevertheless, normal enamel surface roughness is reported to range between 640 and 900 nm with differences due to tooth type, location, and patient age.[24] When referring to the clinical acceptability of the finished surfaces, all the Ra values measured in the present study were 204.9-295.2 nm (control: 534.4 nm), which is far below 500 nm for discomfort and 640 nm for natural tooth surfaces. Therefore, based on these criteria, all polishing systems appear to achieve a clinically acceptable surface for the polymer-infiltrated ceramic-network restoration evaluated.

However, the visual assessment results made by dental school senior students and faculty members should be interpreted with caution. It is interesting that, even though all polishing systems resulted in surface roughness values far below 500 nm, some were judged to be clinically acceptable, while others were not. Further, the visual judgments were highly consistent between the assessors, even though statistical analysis did not reveal significant differences between the polished surfaces in many cases. This suggests that the trained human eye is sensitive to parameters that either are not easy to measure or were not measured in this experiment. It is interesting, for example, that BCom, with higher surface roughness and area than SCom, was nevertheless more likely to be judged clinically acceptable, although opinions were divided much more on these two groups than on others. Further investigation of this subject would be valuable.

A recent study compared surface roughness of CAD/CAM restorative materials after polishing or glazing and concluded that manually polished CAD/CAM materials were significantly smoother ($p<0.05$) than glazed equivalents.[25] This suggests that a workflow based on manual polishing may be the best way to deal with these materials. This is particularly clinically relevant considering the increasing use of chairside CAD/CAM restorations. In the present study, however, the AFM images showed some surface undulations on the polished surface with all the manual polishing systems, and so the development of an optimal polishing system for a polymer-infiltrated ceramic-network material that can create completely flat surfaces is highly desirable.

CONCLUSION

AFM assessment of PICN restorations found that all polishing systems evaluated could improve the surface roughness to a similar level of the company propriety system, whereas lower surface area was found with the company propriety system and ceramic polishing system compared with a composite polishing system. Visual assessment of PICN restorations found that the company propriety and ceramic polishing system

produced a clinically acceptable surface finish, although a commercially available composite polishing system was less reliable.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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