**RESEARCH ARTICLES**

**Recevied/ Geliş Tarihi:** 31.10.2023
**Accepted/ Kabul Tarihi:** 25.02.2024
**Published / Yayın Tarihi:** 17.04.2024

Aydın Dental Journal - Volume **10** Issue **1** - April **2024** (23-34)

Aydın Dental Journal

Journal homepage: http://dergipark.ulakbim.gov.tr/adj

**DOI:** 10.17932/IAU.DENTAL.2015.009/dental_v010i1003

# Evaluation of Surface Roughness and Bacterial Adhesion After Different Finishing Procedures on CAD/CAM Ceramic Materials

# Seramik Esaslı CAD/CAM Materyallerinde Bitim İşlemleri Sonrası Yüzey Pürüzlülüğü ve Bakteri Tutulumunun Değerlendirilmesi

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## ABSTRACT

**Objectives:** The aim of this study is to determine the ideal finishing process for CAD/CAM ceramic materials for use in dental restorations. For this determination, the surface roughness and bacterial adhesion counts of the ceramic surfaces after common finishing procedures are compared.

**Materials and Methods:** A total of 120 samples with a thickness of 1 ± 0.05 mm were obtained from different CAD/CAM ceramic materials (IPS Empress CAD, IPS E-Max CAD, VITA Suprinity and CEREC blocs). The samples from each ceramic group were divided into three subgroups (n = 10) according to the finishing procedure (control, manual polished and glazed). The surface roughness values (Ra) were measured with an optical profilometer before and after each finishing procedure. An additional sample from each group was prepared for scanning, and surface roughness was visualized using scanning electron microscope analysis. A bacterial adhesion test was applied to determine the levels of *Streptococcus mutans* adhesion on each surface.

**Results:** After the finishing process, the highest Ra value was observed in the LC glazed group, and a statistically significant difference was found between the LC glazed group and the manual polished groups ($p < 0.05$). The least amount of bacterial adhesion was observed in the LD glaze group. There were no statistically significant differences between the LD glaze group and the LC and ZL control groups ($p > 0.05$).

**Conclusion:** The polished samples had smoother ceramic surfaces than the glazed samples. When evaluated in terms of bacterial adhesion, the effective polishing method for each ceramic type varied. Therefore, the polishing method should be chosen according to ceramic type.

***Keywords:*** *Bacterial adhesion, Ceramics, Microbiology, Zirconium.*

## ÖZET

**Amaç:** Seramik malzemeler için ideal bitim işlemini yüzey pürüzlülüğü ve bakteriyel adezyon parametreleri ile değerlendirerek belirlemektir.

**Gereç ve Yöntemler:** Farklı CAD/CAM seramik malzemelerinden (IPS Empress CAD, IPS E-Max CAD, VITA Suprinity ve CEREC blokları) 1±0.05 mm kalınlığında 120 numune hazırlandı. Her seramik grubundan hazırlanan numuneler bitirme işlemine göre (kontrol, manuel polisaj ve glaze) üç alt gruba (n=10) ayrıldı. Yüzey pürüzlülük değerleri başlangıçta ve işlem sonrası olmak üzere iki kere optik profilometre cihazı kullanılarak ölçüldü. Taramalı elektron mikroskobu (SEM) analizi için her gruptan birer numune hazırlandı ve yüzey pürüzlülüğü SEM ile görüntülendi. Alınan numunelerin yüzeylerinde S. mutans tutulumu olup olmadığını belirlemek için bakteriyel adezyon testi uygulandı.

**Bulgular:** Bitim işlemlerinden sonra en yüksek Ra değeri LC glaze grubunda gözlendi ve LC glaze grubu ile polisaj grupları arasında istatistiksel olarak anlamlı bir fark bulundu ($p<0.05$). Bakteriyel adezyon miktarı en az LD glaze grubunda gözlenmiştir. LD glaze grubu ile LC kontrol ve ZL kontrol grupları arasında istatistiksel olarak anlamlı fark bulunmamıştır ($p> 0.05$).

**Sonuç:** Polisaj işlemi seramik yüzeyde glaze olan yüzeylere göre daha pürüzsüz alanlar bırakmıştır. Bakteriyel adezyon açısından değerlendirildiğinde her seramik türü için etkili polisaj yöntemi farklı olduğu ortaya çıkmıştır. Bu nedenle seramik cinsine göre polisaj yöntemi tercih edilmelidir.

***Anahtar Kelimeler:*** *Bakteriyel yapışma, Seramikler, Mikrobiyoloji, Zirkonyum.*

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## Introduction

All-ceramic restorations; due to its aesthetic properties, biocompatibility and wear resistance, it is frequently preferred in prosthetic dentistry treatments, especially where it is important to obtain a natural tooth appearance.[1] Dental ceramics have a broad spectrum structurally including glass ceramics, reinforced ceramics, zirconias, alumina ceramics and feldspathic veneer ceramics structures.

Computer-aided design and computer-aided manufacturing (CAD/CAM) technology represent an important part of the modern dentistry field. CAD/CAM restorations has many advantages such as aesthetics, reduced clinical stages, shorter production time and low costs.[2] Attention must be paid to all stages up to the delivery of the restoration in order to fully match restorations produced using CAD/CAM and to further improve the results.[3] With the widespread availability of CAD/CAM devices in the clinic, the aesthetic and functional expectations of the restorations have increased. As a result of this increasing expectation, materials with different combinations, structural and physical properties have been developed.[4] The most frequently used CAD/CAM materials in prosthetic dentistry are zirconium supported lithium silicate ceramics, leucite reinforced glass ceramics, lithium disilicate reinforced glass ceramics, and feldspathic ceramics. In feldspathic ceramics used in CAD/CAM systems, feldspar particles of 3-4 microns in size are evenly distributed in the glass matrix.[4] Leucite-based glass ceramics were first produced by Höland et al. by controlled crystallization of leucite on glass matrix.[5] The flex resistance of lithium disilicate reinforced glass ceramics is 2-3 times higher than feldspathic ceramics (300-400 MPa). In addition, lithium disilicate ($Li_2Si_2O_5$) crystals, which are the basic phase of glass ceramics, are formed by a mechanism called volumetric crystallization.[6] Lithium reinforced with zirconia silicates is an up-to-date glass ceramic material. It is strengthened by adding 10% zirconium to glass ceramic with an innovative manufacturing process. Thus, the first zirconium supported lithium silicate ceramic (ZLDS) was produced.[7]

Polishing processes (glazing) must be carried out before cementation of the restorations. These procedures make surfaces smoother and brighter and at the same time improve restoration biocompatibility, and minimize the incidence of biological complications such as abrasion on the opposite tooth and plaque retention. Also, well-finished surfaces lead to less aesthetic and technical problems because the material is harder, brighter and more stable in color.[8]

There are two types of finishing processes during the production of ceramics restorations. While the polishing process is carried out to remove irregularities at the margin of the restoration, to create contours similar to the natural tooth form and to remove surface roughness primarily, the glazing process is made with small particle size abrasives, to obtain an enamel-like shiny, slippery and smooth surface by reducing micro scratches on the surface. The smooth surface of the restoration material provides both optimum aesthetics and low plaque buildup. The rough tooth structure facilitates the attachment of microorganisms which colonise and form biofilm structures, adversely affects the oral hygiene, increases the possibility of gingival inflammation and secondary caries.[9,10]

The oral cavity is a special structure with its features that include both soft and hard tissues, the presence of saliva and gingival crevicular fluid that washes the surfaces, and its openness to the external environment. Ecologically it consists of very different microenvironments; therefore, it contains a wide variety of microflora.[11] Most of the microorganisms found in the oral cavity belong to communities of microorganisms attached to a surface called biofilm.[12] *Streptococcus Mutans (S. Mutans)*, *Streptococcus Sangius (S. Sangius),* and gram-negative bacteria come first among these microorganism groups. In this study, *S. Mutans* which adhere to tooth hard tissues the most has been examined.

One of the most important factors for the longevity of a ceramic restoration is that it does not cause secondary tooth decay or gingival inflammation. For this, it is very important which surface finish will be applied to the restoration in terms of not leaving roughness on the surface and not causing bacterial adhesion. The aim of this in-vitro study is to examine the roughness and bacterial adhesion on the surface of the materials caused by the different surface finishing techniques used in various CAD/CAM ceramic systems. The null hypothesis of the study; (1) surface finishing procedures applied to four different CAD/CAM ceramic materials would not produce significant effect in terms of surface roughness of materials and (2) surface finishing procedures would not effect bacterial adhesion of the materials.

## Materials and Methods

This study was carried out in the Department of Prosthodontics in the Faculty of Dentistry and in the Department of Microbiology in the Faculty of Medicine at Gaziantep University. Ethical approval was obtained from the Gaziantep University Clinical Researches Ethics Committee. The study was carried out using four different ceramic materials: lithium disilicate reinforced glass ceramic, zirconia reinforced glass ceramic, feldspathic ceramic and leucite reinforced glass ceramic.

The minimum number of samples required to find a statistically significant correlation ($r = 0.80$) between the amount of surface roughness and bacterial adhesion was found to be 9 ($\alpha = 0.05$; $1 - \beta = 0.80$). Power analysis was performed using the G power program, version 3.1.9.2. Ten samples were created for each group in the study. An additional sample from each group was created for scanning electron microscope (SEM) analysis.

Samples with a thickness of 1 ± 0.05 mm were cut from each ceramic block using a precision cutting device (Isomet 1000, Buehler, Lake Bluff, IL, USA). A total of 120 samples were prepared, 30 for each ceramic group. A total of 12 samples were prepared for SEM analysis. One side of each sample was polished by a single operator for 60 seconds using 400, 600 or 800 grit ultra-fine sandpaper (3M ESPE, St. Paul, Minn). Sample thicknesses were measured with a digital micrometre with 0.01 mm accuracy and repeatability (Minitech 233 Press, Grenoble, FRANCE).

The surface finishing processes were applied to the materials used in the study. The ceramic types and finishing procedures used in the study are given in Table 1. A different surface finishing protocol was applied for each ceramic. The reason for this is to perform the most appropriate finishing process in line with the manufacturer's recommendations.

**Table 1.** Ceramic types and surface finishing materials.

| Ceramic Groups | Trade name | Manufacturer | Manuel polishing materials | Glaze materials |
|---|---|---|---|---|
| **Feldspatic ceramic (FC) group** | CEREC Blocs | Sirona Dental Systems, Bensheim, Germany | Meisinger polishing set (luster CAD-CAM lab kit for ceramics) (3M ESPE) | Vita akzent plus glaze powder; (Vita Zahnfabrik) |
| **Glass-ceramic reinforced with lithium disilicate (LD) group** | IPS E-max CAD | Ivoclar-Vivadent, Schaan, Liechtenstein | Optrafine F./P./HP (Ivoclar Vivadent AG) | IPS ıvocolor glaze paste/fluo(Ivoclar Vivadent AG) |
| **Glass ceramic reinforced with leucite (LC) group** | IPS Empress CAD | Ivoclar-Vivadent Schaan, Liechtenstein | Optrafine F./P./HP (Ivoclar Vivadent AG) | IPS ıvocolor glaze paste/fluo(Ivoclar Vivadent AG) |
| **Lithium disilicate reinforced with zirconia (ZL) group** | Vita Suprinity | Vita Zahnfabrik, Bad Säckingen, Germany | Vita Suprinity Polishing set (Vita Zahnfabrik) | Vita akzent plus glaze powder,<br>Vita akzent plus glaze fluid. (Vita Zahnfabrik) |

Feldspatic ceramic (FC) group: Samples obtained from CEREC feldspathic ceramic blocks (LOT no: 78731) (Sirona Dental Systems, Bensheim, Germany) were divided into three subgroups: manual polished (FC-P group) (n = 10), glazed (FC-G group) (n = 10) and control (FC-C group) (n = 10). For the FC-P group's manual polishing process, diamond finishing burs (8 micrometres) and Al2O3-coated flexible discs (Meisinger polishing set, 3M ESPE, 3M company, Minnesota, USA) were used with polishing brushes and polishing pastes. The application was performed by the same operator for 30 min at 10,000 rpm at a 90° angle. For the FC-G group's glazing process, glazed porcelain Vita akzent plus glaze powder (Vita Zahnfabrik, Bad Säckingen, Germany) was applied, and firing operations were performed according to the manufacturer's recommendations.

Glass-ceramic reinforced with lithium disilicate (LD) group: Samples obtained from IPS e.max blocks (LOT no: W86605) (Ivoclar-Vivadent, Schaan, Liechtenstein) were divided into three groups: manual polished (LD-P group) (n = 10), glazed (LD-G group) (n = 10) and control (LD-C group) (n = 10). In the LD-P group, manual polishing with Optrafine (Ivoclar Vivadent AG, Schaan, Liechtenstein) materials was carried out by the same operator at 10,000 rpm for 30 minutes at a 90° angle, in line with the manufacturer's recommendations. In the LD-G group, porcelain glazing (IPS IvoColor glaze paste/ fluo Ivoclar Vivadent AG, Schaan, Liechtenstein) was performed, and firing operations were carried out, again taking into account the manufacturer's recommendations.

Glass-ceramic reinforced with leucite (LC) group: Samples from the IPS Empress blocks (LOT no: U10309) (Ivoclar-Vivadent Schaan, Liechtenstein) were divided into three groups: manual polished (LC-P) (n = 10), glazed (LC-G) (n = 10) and control (LC-C) (n = 10). The manual polishing process was applied using Optrafine F./P./HP (Ivoclar Vivadent AG Schaan, Liechtenstein) materials to the LC-P group, in line with the ceramic manufacturer recommendations. The application was performed by the same operator for 30 min at 10,000 rpm at a 90° angle. In the LD-G group, glazed porcelain IPS IvoColor glaze paste/fluo (Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied, and firing operations were carried out according to glaze the manufacturer recommendations.

Lithium disilicate reinforced with zirconia (ZL) group: Samples obtained from VITA Suprinity blocks (LOT no: 79911) (Vita Zahnfabrik, Bad Säckingen, Germany) were divided into three groups: manual polished (ZL-P) (n = 10), glazed (ZL-G) (n = 10) and control (ZL-C) (n = 10).The manual polishing process was applied to the ZL-P group with VITA Suprinity polishing set materials (VITA Zahnfabrik Bad Säckingen, Germany), in line with the manufacturer's recommendations. The application was performed by the same operator for 30 minutes at 10,000 rpm at a 90□ angle. In the ZL-G group, glazed porcelain Vita akzent plus glaze powder and fluid (VITA Zahnfabrik, Bad Säckingen, Germany) were performed, and firing operations were applied according to the manufacturer's recommendations.

The surface roughness of all samples was measured with an optical profilometer device (Phase Wiew-Verrières-le-Buisson, France), with an approach distance of 10 mm and a scan area of no more than 5 mm2. Since surface scanning was done with a beam and without a mechanical scanning tip, there was no physical contact, and the surface remained intact. Quantitative data and surface roughness parameters were obtained while creating a 3D surface map with the profilometer. The arithmetic roughness values (Ra) were obtained by measuring the samples prior to any finishing process. Measurements were made at a 1024×1024 resolution at 40x magnification. After the surface finishing processes were applied to the samples, the surface roughness of the samples was measured again with an optical profilometer at the appropriate magnification for the material.

One sample from each ceramic group was created for surface roughness observation via SEM analysis. For SEM analysis, the samples were attached to an aluminium metal platform using double-sided adhesive tape. The specimens were gold-plated and carefully observed under an SEM (Jeol, Japan, JSM-6390LV) at 12 kV with 1000x magnification. Representative micrographs of the surface roughness of the samples were then recorded, and descriptive analyses were conducted.

The bacterial adhesion test was conducted in the microbiology laboratory of the Medical Faculty at Gaziantep University. First, the disc samples were packaged separately and then sterilized at 121°C in an autoclave (Core, Turkey) for 15 minutes. For the bacterial adhesion test, Streptococcus mutans (ATCC 25175), cultured in sucrose medium, was used. Ceramic samples were placed in sterile cell-culture plates with 1.5 mL Brain Heart infusion and standard culture supplemented with 5% sucrose (Speser, Turkey), and placed for 24 hours in a 37°C incubator containing 6% CO2.

After incubation, the ceramic samples were cleaned in sterile distilled water to eliminate non-adherent microorganisms. Subsequently, swab samples were taken from the ceramic surface and then spread over the surface of the blood agar plates that had been reinforced with sucrose. After 48 hours of anaerobic incubation at 37°C, colony-forming units (CFU) were calculated using a stereoscope, and the results are recorded as CFU/mL (□ 8.8 × 107 CFU/mL).[13]

The compliance of the data with normal distribution was tested with the Shapiro–Wilk test. The Mann–Whitney U test was used to compare the non-normally distributed properties within two groups, and the Dunn and Kruskal–Wallis multiple comparison tests were used for the comparison of more than two independent groups. The Wilcoxon test was used to compare the measurements of variables that were not normally distributed at two different times. Mean ± standard deviation and median values were given as descriptive statistics for numerical variables. SPSS® for Windows, version 22.0 (SPSS® Inc., Chicago, IL, USA) was used for the statistical analysis; a p-value less than 0.05 was considered statistically significant.

## Results

The surface roughness results of the ceramic samples are shown in Table 2. This table showed that the roughness value of the surfaces after processing, mean/median values in terms of Ra, and whether these values create a statistically significant difference between the groups ($p<0.05$). Before the finishing process, there were no statistically significant differences between the control groups ($p>0.05$). After the finishing process, the highest Ra value was observed in the LC-G group (Ra=0.214). According to the results, no statistically significant difference was found between the LC-G group and the other glazed groups ($p>0.05$). The lowest Ra value was observed in the LC-P group (Ra=0.095), (Table 2).

**Table 2.** Surface roughness results (Ra, µm) (mean ± standard deviation (SD), median values, 25-75% percentile).

| GROUPS | First Measurement | Second Measurement | First Measurement | Second Measurement | P Value |
|---|---|---|---|---|---|
| | **Mean±SD** | **Mean±SD** | **Median[%25-%75]** | **Median[%25-%75]** | |
| FC-G | 0,035 ± 0,025$^{a,A}$ | 0,211± 0,055$^{b,A}$ | 0,025 (0,017 -0,049 )$^{a}$ | 0,19 (0,171 -0,252 )$^{b}$ | **0,002*** |
| FC-C | 0,047 ± 0,031$^{a,A}$ | | 0,043 (0,02 -0,065 )$^{a}$ | | |
| FC-P | 0,058 ± 0,057$^{a,A}$ | 0,102± 0,041$^{b,B,C}$ | 0,041 (0,015 -0,086 )$^{a}$ | 0,102 (0,06 -0,119 )$^{c,d}$ | **0,041*** |
| LD-G | 0,042 ± 0,011$^{a,A}$ | 0,135± 0,057$^{b,C,D,E}$ | 0,039 (0,035 -0,046 )$^{a}$ | 0,129 (0,103 -0,19 )$^{d,e,f}$ | **0,004*** |
| LD-C | 0,038 ± 0,009$^{a,A}$ | | 0,04 (0,03 -0,045 )$^{a}$ | | |
| LD-P | 0,022 ± 0,01$^{a,A}$ | 0,108± 0,023$^{b,B,C}$ | 0,019 (0,017 -0,023 )$^{a}$ | 0,109 (0,089-0,126 )$^{c,d}$ | **0,003*** |
| LC-G | 0,053 ± 0,038$^{a,A}$ | 0,214± 0,105$^{b,A,E}$ | 0,052 (0,018 -0,084 )$^{a}$ | 0,206 (0,114 -0,31 )$^{b,f}$ | **0,004*** |
| LC-C | 0,05 ± 0,034$^{a,A}$ | | 0,035 (0,023 -0,083 )$^{a}$ | | |
| LC-P | 0,041 ± 0,029$^{a,A}$ | 0,095± 0,058$^{b,B}$ | 0,032 (0,021 -0,044 )$^{a}$ | 0,078 (0,067-0,109 )$^{c}$ | **0,022*** |
| ZL-G | 0,038 ± 0,013$^{a,A}$ | 0,203± 0,101$^{b,A,E}$ | 0,033 (0,028 -0,045 )$^{a}$ | 0,2 (0,102 -0,317 )$^{b,f}$ | **0,003*** |
| ZL-C | 0,043 ± 0,007$^{a}$ | | 0,044 (0,038 -0,044 )$^{a}$ | | |
| ZL-P | 0,037 ± 0,005$^{a}$ | 0,18 ± 0,26$^{b,B,D}$ | 0,036 (0,033-0,042)$^{a}$ | 0,098 (0,044-0,183 )$^{c,e}$ | **0,009*** |
| P value | 0,087 | **0,001*** | 0,087 | **0,001*** | |

*Significant at 0.05 level. There is no significant difference between the values indicated with the same uppercase superscript letter in the same column. There is no significant difference between the values indicated with the same lowercase superscript letter in the same row.

According to the results, no statistically significant difference was found between the LC-P group and the other polished groups ($p>0.05$), but a significant difference was found between the other glazed groups ($p<0.05$). In case of intra-group comparisons, more roughness was detected in the glazed samples. Although there was a statistically significant difference between the glazed and polished subgroups in the FC, LC and ZL groups, there was no statistically significant difference in the glazed and polished subgroups within the LD group.

Bacterial adhesion results are shown Table 3. The table displays the bacterial adhesion on the surfaces after the processes were applied to the ceramic surfaces, mean/median values in terms of CFU/ml, and whether these values create a statistically significant difference between the groups ($p<0.05$).

**Table 3.** Bacterial adhesion values (CFU/ml) (mean ± SD, median values, 25-75% percentile)

| GROUPS | Mean±SD | Median (%25-%75) | P |
|---|---|---|---|
| **FC-G** | 100000 ± 0$^{a}$ | 100000 (100000 -100000 )$^{a}$ | |
| **FC-C** | 100000 ± 0$^{a}$ | 100000 (100000 -100000 )$^{a}$ | |
| **FC-P** | 69090,909 ± 20714,51$^{b}$ | 60000 (60000 -80000 )$^{b}$ | |
| **LD-G** | 4545,455 ± 6875,517$^{c}$ | 0 (0 -10000 )$^{c}$ | |
| **LD-C** | 73333,333 ± 15569,979$^{a,b}$ | 70000 (60000 -80000 )$^{a,b}$ | |
| **LD-P** | 57272,727 ± 23702,704$^{b,d}$ | 60000 (40000 -60000 )$^{b,d}$ | **0,001*** |
| **LC-G** | 37272,727 ± 12720,778$^{b,d}$ | 30000 (30000 -40000 )$^{b,d}$ | |
| **LC-C** | 27272,727 ± 7862,454$^{c,d}$ | 30000 (20000 -30000 )$^{c,d}$ | |
| **LC-P** | 48000 ± 22997,584$^{b}$ | 40000 (30000 -60000 )$^{b}$ | |
| **ZL-G** | 76363,636 ± 19632,996$^{a,b}$ | 60000 (60000 -100000 )$^{a,b}$ | |
| **ZL-C** | 6363,636 ± 6741,999$^{c}$ | 10000 (0 -10000 )$^{c}$ | |
| **ZL-P** | 100000 ± 0$^{a}$ | 100000 (100000 -100000 )$^{a}$ | |

*Significant at 0.05 level. There is no significant difference between the values indicated with the same superscript letter in the same column.

The greatest amounts of bacteria retention were observed in the FC-G, FC-C and ZL-P groups, but there was no statistically significant difference between the ZL-G and LD-C groups ($p>0.05$). The lowest amount of bacterial adhesion was observed in the LD-G group. While there was no statistically significant difference between the LD-G group and the LC-C and ZL-C groups ($p>0.05$), there was a statistically significant difference with the other groups ($p<0.05$). In the intergroup evaluations, the polishing groups had the most bacterial adhesion, and there was a statistically significant difference with the glazing groups ($p<0.05$).

The SEM images of the samples are shown in Fig 1. The surfaces of the LC-G and LD-G groups were observed to have the most irregular surfaces. In the study, the lowest surface roughness value was obtained with the ZL-P group. When the SEM images were examined, the smoothest surface appearance was obtained in the ZL-P group after the surface treatment. Similar results were observed when the surface roughness values and the SEM images were compared.

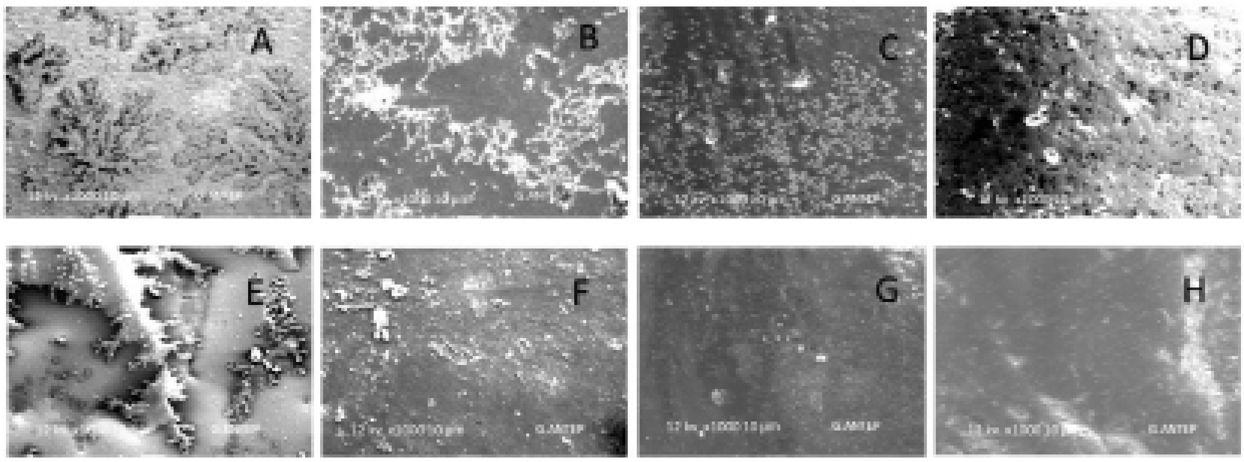


**Figure 1.** SEM images of the polished surfaces of ceramic samples. **(A)** LD-G group, **(B)** LD-P group, **(C)** FC-G group, **(D)** FC-P group, **(E)** LC-G group, **(F)** LC-P group, **(G)** ZL-G group, **(H)** ZL-P group.

The surface roughness results of the ceramic samples are shown in Table 2. This table showed that the roughness value of the surfaces after processing, mean/median values in terms of Ra, and whether these values create a statistically significant difference between the groups ($p<0.05$). Before the finishing process, there were no statistically significant differences between the control groups ($p>0.05$). After the finishing process, the highest Ra value was observed in the LC-G group (Ra=0.214). According to the results, no statistically significant difference was found between the LC-G group and the other glazed groups ($p>0.05$). The lowest Ra value was observed in the LC-P group (Ra=0.095), (Table 2). According to the results, no statistically significant difference was found between the LC-P group and the other polished groups ($p>0.05$), but a significant difference was found between the other glazed groups ($p<0.05$).

In case of intra-group comparisons, more roughness was detected in the glazed samples. Although there was a statistically significant difference between the glazed and polished subgroups in the FC, LC and ZL groups, there was no statistically significant difference in the glazed and polished subgroups within the LD group.

Bacterial adhesion results are shown Table 3. The table displays the bacterial adhesion on the surfaces after the processes were applied to the ceramic surfaces, mean/median values in terms of CFU/ml, and whether these values create a statistically significant difference between the groups ($p<0.05$). The greatest amounts of bacteria retention were observed in the FC-G, FC-C and ZL-P groups, but there was no statistically significant difference between the ZL-G and LD-C groups ($p > 0.05$). The lowest amount of bacterial adhesion was observed in the LD-G group. While there was no statistically significant difference between the LD-G group and the LC-C and ZL-C groups ($p>0.05$), there was a statistically significant difference with the other groups ($p<0.05$). In the intergroup evaluations, the polishing groups had the most bacterial adhesion, and there was a statistically significant difference with the glazing groups ($p<0.05$).

The SEM images of the samples are shown in Fig 1. The surfaces of the LC-G and LD-G groups were observed to have the most irregular surfaces. In the study, the lowest surface roughness value was obtained with the ZL-P group. When the SEM images were examined, the smoothest surface appearance was obtained in the ZL-P group after the surface treatment. Similar results were observed when the surface roughness values and the SEM images were compared.

## Discussion

With the increasing chairside use of CAD/CAM devices in dental clinics, the question of which finishing process can deliver the smoothest material has become popular.[14] Plaque accumulation increases on rough surfaces, and in the long term, many problems, such as gingivitis, superficial coloring, secondary caries, and discoloration, can occur.[15] The aim of this in-vitro study is to examine the surface roughness of CAD/CAM ceramic materials after the various finishing processes used today and to observe bacterial adhesion as a result of these finishing processes. According to the results of this study, the null hypotheses are rejected because surface finishing procedures affected surface roughness and bacterial adhesion of ceramic materials.

It is expected that the instruments and techniques used in the finishing and polishing processes will maximize the bending strength of the restoration by creating a smooth surface, reducing the risk of fractures and cracks, minimizing the abrasion of the opposing teeth by decreasing the abrasive features of the ceramic and avoiding bacteria from sticking to the restoration surface to create a restoration with maximum smoothness.[16] In addition, the aesthetic appearance of CAD/CAM restorations should be improved, as the glossy surface created by the polishing processes will have light reflection and refraction properties similar to natural teeth.[16]

The manual polishing method is an alternative method for ceramic restorations to create a smooth and uniform surface, and it has some advantages, such as saving time and preventing having to glaze. While there are many chairside polishing systems for ceramic restorations, it is not clear that an equally smooth and better surface than before cementation will be obtained with all systems. Due to the existence of various ceramic and polishing systems, it is controversial which polishing system works best for which ceramic. Studies have generally been conducted on the effects of several polishing methods on the surface morphology of varied ceramic materials.[17]

The samples obtained in the study were sanded with 400, 600, and 800 grit silicon carbide (SiC) sandpaper for 60 seconds to imitate the surfaces obtained by a milling device.[18,19] Then, finishing and polishing procedures were applied to the sliced blocks with the aim of achieving smooth and shiny surface properties. Various methods have been used to assess the surface roughness of restorative materials. These are quantitative and qualitative methods, such as optical and scanning electron microscopy and surface profile analysis.[20] Surface topography measurement is a three-dimensional system for displaying the surface properties of the materials.[21] In this study, a noncontact laser profilometer device was used to evaluate the surface roughness of the materials. With the use of this device, the surface damage that may be caused by the mechanical sensor on the surface was prevented.[22] The parameters evaluated after measurement were Ra and Sa. The use of a contact profilometer is revealed by obtaining the average of these values from three or five linear measurements made randomly from the surface. By scanning the entire surface area with a noncontact profilometer, it is possible to detect rough or irregular areas that may be missed with a contact profilometer.[21,22] In this way, not only is a clear mathematical value obtained, but the system also creates a visual map of the specified area. Although there is no common Ra value accepted in the literature as a threshold value for surface roughness, it has been stated that an Ra value above 0.2 mm carries a higher risk for plaque accumulation, caries and periodontal inflammation.[23] In cases with Ra values above this value, there is a decrease in the aesthetic life and durability of the restoration.[23]

In this study, first null hypothesis was not accepted due to the different Ra values obtained by the different polishing systems. In a study by Hulterstrom et al. comparing the finish of dental ceramic surfaces obtained by varnish systems with different clinical stages and different durations (30, 60, 120 and 180 secs), it was reported that clinically satisfactory smooth surfaces were achieved in all the polishing systems, regardless of the increase in application steps and the time spent during polishing in multi-step polishing systems.[24] Similarly, satisfactory smooth surfaces were obtained by all polishing systems in our study, although the highest Ra value was obtained with the LC-G group.

In a study by Fasbinder et al., various finishing/polishing systems were used to create clinically acceptable surfaces on CAD/CAM restorations, and the changes that these systems created on the ceramic surfaces were evaluated.[16] Of the 100 monolithic CAD/CAM blocks, 40 were leucite-containing ceramics (Empress CAD, Ivoclar), 30 were nano-ceramic (LAVA Ultimate, 3M ESPE), and 30 were hybrid ceramics (Enamic, Vita). A single batch of Empress CAD was glazed in a porcelain furnace. The polishing systems consisted of an abrasive-polishing technique (Meisinger Polishing Kit, Brasseler Dialite Kit) and a brush-polishing technique (VH Technology instrument, VITA Enamic Polishing Kit). Although the roughness values of the materials changed according to the processing it was reported that polished ceramic surfaces can be as smooth as glazed ceramic surfaces.16 In this study, unlike Fasbinder et al., ceramics were preferred in all four materials, and it was observed that polished surfaces created smoother surfaces than glazed surfaces.

In a study conducted by Sarac et al., the effect of porcelain polishing systems on the colour and surface properties of feldspathic porcelain was evaluated. Glazed materials were used as the control group, and a polishing stick (Diamond Stick, SHOFU Dental), a polishing paste (Ultra II, SHOFU Dental), an adjustment kit (Porcelain Adjustment Kit, SHOFU Dental) or a polishing wheel (CeraMaster, SHOFU Dental) was applied to the experimental groups.[25] The material surfaces formed by these applied techniques were found to be as smooth as the glazed surfaces.[25] Aravind et al. applied a white and grey silicone polish rubber and a glaze to Ivoclar Classic ceramic samples after applying an aluminium oxide polishing disc or a white and grey silicon glaze rubber and diamond abrasive polishing disc.[26] Later, they applied diamond-filled polishing paste to all the samples except the glazed samples.[26] The researchers observed surface roughness values in the polished groups that were close to those of the glazed groups.[26] Flury et al. reported that Vita Mark II and IPS Empress Cad ceramic samples polished with aluminium oxide (Sof-Lex) had a smoother surface than the glazed samples.[27] In this study, too, the polished groups created a smoother surface than the glazed groups. Smoother surfaces were also obtained from polishing processes than from glazing processes in Han et al.[28]

The smoothing mechanisms of the glazing and polishing processes are dissimilar from each other. While polishing is to remove many imperfections on the processed surface, form smooth particles and reduce roughness, the glaze layer, also defined as the application of glass cover, fills microcracks, reduces the sharpness and depth of cracks on the surface, and closes pores on the porcelain.[29] The difference in the results in the literature can be explained by the variances of certain factors within the studies. The skills of the technicians, the pressures applied to the material, different rotational speeds of the bur, the angles between the specimens and grinders, the polishing times, the grain sizes and the thickness of the glaze layers can each effect the results of glazing or polishing procedures and may result in microstructural failures of the essential materials.[30] Although SEM analysis in previous studies did not show a significant difference between glazed and polished surfaces, the roughness measurements in the study of Muhammedbassir et al. showed that polishing procedures of IPS e.max CAD ceramics created surfaces that were smoother than glazed surfaces.[31,32] When the SEM images were compared in our study, ZL-G group surfaces were observed to be smoother than any other group's surfaces. The most irregular surfaces were observed in the LC-G and LD-G groups. The roughness results obtained in the study were observed by SEM analysis, and the findings are reported in Fig 1.

The oral cavity is constantly contaminated with various microorganisms. Most of these microorganisms attach to hard dental tissues and are responsible for periodontitis (Actinobacillus actinomycetemcomitans and Porphyromonas gingivalis) and caries (Streptococcus mutans and Lactobacillus).[33] Therefore, the surface smoothness of intraoral hard surfaces is of clinical importance in terms of protection from bacteria. Quirynen et al. reported that the Ra value plays a role in bacterial adhesion.[34]

In this study, the hypothesis that there is no difference between bacterial retention on the four ceramic CAD/CAM surfaces after the glazing and polishing procedures are applied was not accepted due to the different bacterial retention counts obtained from each CAD/CAM material. Although there was no statistical significance regarding microbial adhesion on materials in the study by Glass et al., SEM images and CFU counts showed the presence of microorganisms in all test groups.[35] This current study showed significant differences from the work of Glass et al. Furthermore, unlike Glass et al., no bacterial growth was observed in the LDS glaze group in this current study. Another study found that glazed zirconium (3M ESPE, St. Paul, MN, USA) showed more roughness compared to the polished surfaces, and that there was a tendency towards bacterial accumulation; furthermore, a larger colony formation was observed on glazed surfaces compared to polished surfaces.[36] As well, Hahnel et al. revealed differences between various dental ceramic systems in terms of surface properties and streptococcal adhesion, and Aykent et al. showed that bacterial adhesion measurements changed importantly depending on the restorative materials used.[37,38] Similarly, material type affected the results in this study. The chemical composition of the surface is significant for bacterial adhesion, especially when the surface has elements that are harmful or beneficial to the adherent population.[38] The results of surface roughness on bacterial adhesion varies depending on the range of surface roughness, study design, and type of material.[39] This study also confirmed these results; although the materials had similar roughness values within each group, different bacterial retention was observed when the material groups were compared to one another. Quirynen et al. concluded that the effect of a surface's free energy on initial bacterial adhesion to smooth materials in vitro is the most important factor outside of material type.[40] Surface free energy is related to the interaction between cohesion and adhesion forces.[41] Also, keeping surface free energy low reduces the bacteria attraction.[41] Similar to the findings of this study, they also observed that the material type affected bacterial adhesion.

Ceramics are interesting restorative materials due to their aesthetic qualities and biocompatibility; furthermore, smooth surfaces decrease the accumulation of oral biofilms.[42] In a previous study comparing bacterial adhesion on glazed and polished porcelain surfaces, it was observed that surface treatments did not prevent dental biofilm formation.[43] The authors noted that the glazed surfaces had a lower bacterial adhesion measurements compared to the untreated surfaces, but noted that there was no significant difference from the polished surfaces.[43] In this current study, more bacterial involvement was observed in the polished groups than in the control and glazed groups, with the exception of the FC group. A previous work confirmed that the glazed ceramic material (3M ESPE, St. Paul, MN, USA) showed greater roughness and a tendency towards biofilm deposition compared to polished surfaces.[44] Among the materials we used in the study (LD, LC, ZL, FC), only the FC-G group retained more bacteria than the control and polished groups.

In dental biofilm research, surface topography and roughness have been the most important topics. Mostly, a rising in surface roughness and arising in the contact area between the bacterial cells and material surface support bacterial attachment.[45] However, the precise effects of surface roughness on biofilm formation and bacterial adhesion vary according to environmental factors and the shape/size of the bacterial cells. For this reason, there is no perfect roughness that can stop the adhesion of all

bacterial species.[46] The rising in the roughness of the ceramic surfaces from 0.2 μm to 2 μm did not eased biofilm formation of S. mutants.[47]
Our study has some limitations, including the use of four types of ceramic materials, application of surface finishing procedures according to the manufacturer's instructions for each material, use of a single type of bacteria strain, the laboratory conditions and the culture conditions used in the tests. More in-vivo or in-vitro studies on this topic are needed in the future to make more successful long-lasting restorations to guide clinicians.

There are limited studies evaluating bacterial adhesion to monolithic ceramics. Therefore, this investigation of the most ideal finishing processes for the CAD/CAM ceramics commonly used by clinicians will make an important contribution to the literature and to the dental restoration field.

**Conclusion**

According to the outcomes obtained within the limits of the investigations; It has been observed that the polished surfaces of all ceramic types leave smoother areas on the ceramic surface compared to the surfaces that have been glazed. When evaluated in terms of bacterial adhesion, each ceramic group responded differently to the surface finishing process. In the light of all data; Glazing or polishing process when IPS Empress CAD and VITA Suprintiy materials are preferred, glazing process when IPS Emax CAD is preferred, and polishing process when CEREC ceramic material is preferred can be safely preferred by clinicians in the surface finishing procedure because of less bacteria retention.

**Acknowledgements**

The authors thank to Prof. Dr. Seval KUL for statistical analysis of the study.

**Conflict of interest**

None of the authors of this article has any relationship, connection or financial interest in the subject matter or material discussed in the article.

**Sources of Funding**

Gaziantep University Scientific Research Projects Governing Unit supported this study was a PhD thesis of Mahmut Ercil (Project No: DHF.UT.20.04).

**Yazar Katkısı**

Fikir: O.P.O, M.E Tasarım: O.P.O, Y.Z Denetleme: M.E, O.P.O Kaynaklar: O.P.O, Y.Z, M.E Malzemeler: M.E Veri Toplama: M.E, A.M Analiz: M.E, O.P.O Literatür: M.E Yazı: M.E, O.P.O Eleştirel İnceleme: Y.Z

**References**

1. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: Historical roots and current perspectives. J Prosthet Dent 1996; 75: 18-32.

2. Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic- network materials. Dent Mater 2013; 29: 419-26.

3. Kirsch C, Ender A, Attin T, Mehl A. Trueness of four different milling procedures used in dental CAD / CAM systems. Clin Oral Invest 2017; 21: 551-8.

4. Giordano R. Materials for chairside CAD/CAM-produced restorations. J Am Dent Assoc 2006;137:14S-21S.

5. Wildgoose DG, Johnson A, Winstanley RB. Glass/ceramic/refractory techniques, their development and introduction into dentistry: A historical literature review. J Prosthet Dent 2004; 91:136-43.

6. Sannino G, Germano F, Arcuri L, Bigelli E, Arcuri C, Barlattani A. CEREC CAD/CAM Chairside System. Oral Implantol (Rome) 2015; 7: 57-70.

7. Sieper K, Wille S, Kern M. Fracture strength of lithium disilicate crowns compared to polymer-infiltrated ceramic-network and zirconia reinforced lithium silicate crowns. J Mech Behav Biomed Mater 2017; 74: 342-348.

8. Carrabba M, Vichi A, Vultaggio G, Pallari S, Paravina R, Ferrari M. Effect of Finishing and Polishing on the Surface Roughness and Gloss of Feldspathic Ceramic for Chairside CAD/ CAM Systems. Oper Dent 2017; 42: 175-184.

9. Schmidlin PR, Gohring TN. Finishing tooth-colored restorations in vitro: an index of surface alteration and finish-line destruction. Oper Dent 2004; 29: 80-6.

10. Yildiz H, Sen E, Dalcik H, Meseli S.E. Evaluation of cell morphology and adhesion capacity of human gingival fibroblasts on titanium discs with different roughened surfaces: an in vitro scanning electron microscope analysis and cell culture study. Folia Morphol 2023; 82: 63-71.

11. Aas JA, Paster BJ, Stokes LN, Olsen I, Dewhirst FE. Defining the normal bacterial flora of the oral cavity. J Clin Microbiol 2005; 43: 5721-32.

12. Avila M, Ojcius DM, Yilmaz O. The oral microbiota: Living with a permanent guest. DNA Cell Biol 2009; 28: 405-11.

13. Curyl MS, Silva CB, Nogueira RD, Campos MGD, Palma-Dibb RG, Geraldo-Martins VR. Surface roughness and bacterial adhesion on root dentin treated with diode laser and conventional desensitizing agents. Lasers Med Sci 2018; 33: 257-62.

14. Aboushelib MN, Elsafi MH. Survival of resin infiltrated ceramics under influence of fatigue. Dental Materials 2016; 32: 529–534.

15. Jefferies SR. The art and science of abrasive finishing and polishing in restorative dentistry. Dent Clin North Am 1998; 42: 613-27.

16. Fasbinder DJ, Neiva GF. Surface evaluation of polishing techniques for new resilient CAD / CAM restorative materials. J Esthet Restor Dent 2016; 28: 56-66.

17. Han G, Kim J, Lee M, Chae S, Lee Y, Cho B. Performance of a novel polishing rubber wheel in improving surface roughness of feldspathic porcelain. Dent Mater J 2014; 33: 739-748.

18. Tekce N, Fidan S, Tuncer S, Kara D, Demirci M. The effect of glazing and aging on the surface properties of CAD / CAM resin blocks. J Adv Prosthodont 2018; 10: 50-7.

19. El Zohairy AA, De Gee AJ, Mohsen MM, Feilzer AJ. Microtensile bond strength testing of luting cements to prefabricated CAD / CAM ceramic and composite blocks. Dent Mater 2003; 19: 575-83.

20. Whitehead SA, Shearer AC, Watts DC, Wilson NH. Comparison of two stylus methods for measuring surface texture. Dent Mater 1999; 15: 79-86.

21. Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss- meter. J Mater Sci Mater Med 2007; 18: 155-63.

22. Janus J, Fauxpoint G, Arntz Y, Pelletier H, Etienne O. Surface roughness and morphology of three nanocomposites after two different polishing treatments by a multitechnique approach. Dent Mater 2010; 26: 416-25.

23. Heintze SD, Forjanic M, Ohmiti K, Rousson V. Surface deterioration of dental materials after simulated toothbrushing in relation to brushing time and load. Dent Mater 2010; 26: 306-19.

24. Hulterstrom AK, Bergman M. Polishing systems for dental ceramics. Acta Odontol Scand 1993; 5: 229-34.

25. Sarac D, Sarac YS, Yuzbasioglu E, Bal S. The effects of porcelain polishing systems on the color and surface texture of feldspathic porcelain. J Prosthet Dent 2006; 96: 122-8

26. Aravind P, Razak PA, Francis PG, Issac JK, Shanoj RP, Sasikumar TP. Comparative Evaluation of the Efficiency

of Four Ceramic Finishing Systems. J I Oral Health 2013; 5: 59-64.

27. Flury S, Lussi A, Zimmerli B. Performance of different polishing techniques for direct CAD / CAM ceramic restorations. Oper Dent 2010; 35: 470-81.

28. Han GJ, Kim JH, Lee M, Chae SY, Lee YH, Cho BH. Performance of a novel polishing rubber wheel in improving surface roughness of feldspathic porcelain. Dent Mater J 2014; 33:739-748.

29. Albakrya M, Guazzatoa M, Swain MV. Effect of sandblasting, grinding, polishing and glazing on the flexural strength of two pressable all-ceramic dental materials. J Dent 2004; 32: 91-99.

30. Gonuldas F, Ozturk C, Atalay P, Oztas D. Influence of different surface finishing techniques on machinable feldspathic and leucite-reinforced ceramics. Dent Mater J 2019; 38: 317-322.

31. Sulik WD, Plekavich EJ. Surface fi nishing of dental porcelain. J Prosthet Dent 1981; 46: 217-221.

32. Mohammadibassi M, Rezvani MB, Golzari H, Salehi EM, Fahimi MA, Fard MJK. Effect of Two Polishing Systems on Surface Roughness, Topography, and Flexural Strength of a Monolithic Lithium Disilicate Ceramic. J Prosthodont 2019; 28: e172-e180.

33. Quirynen M, Bollen CM, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. Int J Oral Maxillofac Implants 1996; 11: 169-78.

34. Bollen CM, Papaioanno W, Van Eldere J, Schepers E, Quirynen M, van Steenberghe D. The influence of abutment surface roughness on plaque accumulation and peri-implant mucositis. Clin Oral Implants Res 1996; 7: 201-11.

35. Glass RT, Conrad RS, Köhler GA, Warren AJ, Bullard JW. Microbiota found in protective athletic mouthguards. Sports Health 2011; 3: 244-8.

36. Piva AD, Contreras LPC, Ribeiro FC, Anami LC, Camargo SEA, Jorge AOC, Bottino MA. Monolithic Ceramics: Effect of Finishing Techniques on Surface Properties, Bacterial Adhesion and Cell Viability. Oper Dent 2018; 43: 315-25.

37. Hahnel S, Rosentritt M, Handel G, Bürgers R. Surface characterization of dental ceramics and initial streptococcal adhesion in vitro. Dent Mater 2009; 25: 969-75.

38. Aykent F, Yondem I, Ozyesil AG, Gunal SK, Avunduk MC, Ozkan S. Effect of different finishing techniques for restorative materials on surface roughness and bacterial adhesion. J Prosthet Dent 2010; 103: 221-227.

39. Song F, Koo H, Ren D. Effects of material properties on bacterial adhesion and biofilm formation. J Den Res 2015; 94:1027-1034.

40. Quirynen M, Van der Mei HC, Bollen CM, Van den Bossche LH, Doornbusch GI, van Steenberghe D, Busscher HJ. The influence of surface-free energy on supra- and subgingival plaque microbiology: An in vivo study on implants. J Periodontol 1994; 65: 162-7.

41. S Kreve, AC Dos Reis. Effect of surface properties of ceramic materials on bacterial adhesion: A systematic review. J Esthet Restor Dent 2022; 34: 461-472.

42. Aksoy G, Polat H, Polat M, Coskun G. Effect of various treatment and glazing (coating) techniques on the roughness and wettability of ceramic dental restorative surfaces. Colloid Surf B Biointerfaces 2006; 53: 254-9.

43. Lawaf S, Azizi A, Farzad A, Adimi P. Effect of surface treatments of porcelain on adhesion of Candida albicans. Gen Dent 2016; 64: e1-e4.

44. Stti R, Kantorski KZ, Monaco C, Valandro LF, Ciocca L, Bottino MA. SEM evaluation of in situ early bacterial colonization on a Y-TZP ceramic: A pilot study. Int J Prosthodont 2007; 20: 419-22.

45. Teughels W, Van Assche N, Sliepen I, Quirynen M. Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res. 2006; 2: 68–81.

46. Renner LD, Weibel DB. Physicochemical regulation of biofilm formation. MRS Bull 2011; 36: 347-355.

47. Lin HY, Liu YL, Wismeijer D, Crielaard W, Deng DM. Effects of oral implant surface roughness on bacterial biofilm formation and treatment efficacy. Inter J Oral Maxillofacial Implants 2013; 28:1226-31.