Surface roughness of glazed feldspar, alumina, and zirconia-based ceramics

Rugosidade das superfícies vitrificadas de cerâmicas feldspática, a base de zircônia e a base de alumina

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ABSTRACT

The aim of this study was to compare the mean surface roughness (Ra) of feldspar-, alumina-, and zirconia-based ceramics, testing the hypothesis that the feldspathic ceramics have lower average surface roughness (Ra) than the ceramics used for infrastructure. Eight disk specimens (5mm in diameter; 2mm in thickness) of each ceramic material were fabricated according to the manufacturer's specifications: V7-feldspathic veneer ceramic (Vita VM7); VA-feldspathic veneer ceramic (Vitadur-α); IA-slip casted, glass-infiltrated alumina-based ceramic (Vita In-Ceram Alumina); IZS-slip casted, glass-infiltrated zirconia-reinforced alumina-based ceramic (Vita In-Ceram Zirconia); IZB-dry-pressed block of glass-infiltrated zirconia-reinforced alumina-based ceramic (Vita In-Ceram Zirconia 2000 for Cerec InLab). All materials were glazed as recommended by the manufacturer. Four Ra readings (Mitutoyo SJ 400) per specimen were performed, averaging the value per specimen (n=8). Ra values were statistically analyzed using one-way ANOVA and Tukey test (α=0.05). V7 showed the lowest mean Ra value (0.43±0.07 µm) compared to the other ceramics. There were no statistical differences between the mean Ra values of VA (0.94±0.2 µm), IA (0.7±0.13 µm), IZS (0.98±0.3 µm) and IZB (0.75±0.4 µm). The testing hypothesis was partially accepted. V7 showed a smoother ceramic surface than the VA. There were no statistically differences between the mean Ra value of the high crystalline content ceramics (IA, IZS, IZB).

UNITERMS

Ceramics; dental materials; comparative study.

INTRODUCTION

With the increase in the crystalline content of dental ceramics and increase in their mechanical properties, it has become possible to use them more safely in oral rehabilitation[18,28]. Currently, alumina/zirconia-reinforced ceramics can be indicated for fabrication of framework in fixed prosthodontics and implant abutments, as alternative or substitute to the metallic framework[2].

Normally, the framework ceramics present from 80wt% to 99wt% of a crystalline phase and minimum glass phase, such as the glass-infiltrated alumina/zirconia-, densely sintered high-alumina-, and yttrium-oxide-partially-stabilized zirconia-based ceramics, yielding high mechanical resistance, fracture toughness and reliability, especially the yttrium/zirconia-based ceramic industrially machined for the CAD-CAM systems[2,13-4,21,29].

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However, the high crystalline content ceramics can present a rougher surface, since they are mostly composed of zirconium polygonal crystals with irregular shape[13-4,21,29]; besides, their surface roughness can be increased after grinding[1,5]. On the other hand, feldspathic veneering ceramics are constituted of approximately 50wt% of a glass phase (silica oxide) and 40wt%-50wt% of crystalline phase (leucite), which are customarily able to generate a smoother surface than high-ceramics for frameworks[7].

The high crystalline content ceramic framework of metal-free bonded prostheses and implant abutments is often exposed to the oral environment. In these cases, the framework ceramic surface should be as smooth as possible, with the aim of minimizing the bacterial colonization and dental biofilm formation[26].

Grinding and polishing procedures to adjust ceramic restorations may also produce a rougher surface[1,5], which may cause an increased rate of biofilm accumulation, producing gingival inflammation and adverse soft tissue reaction[16,17,26]. In addition, the occlusal adjustments may cause excessive wear of the opposing teeth[15,22], and also impair the strength of the ceramic restorations[4,11].

The correlation between quantity of dental biofilm and surface roughness was verified on the surface of different dental materials, such as ceramics[16]**,** titanium[27] and acrylic resins[30]. Several studies have demonstrated that the bacterial adhesion begins around irregularities and expands to the whole surface[19.20.23]. Moreover, the dental biofilm is formed more quickly on rough areas[12,24,25]. There is a general understanding that bacteria are the primary cause of gingivitis, periodontitis and caries. Although these diseases are explained by specific plaque theories, the removal of all bacterial deposits remains essential to prevent these diseases[3]. Bacterial recolonization on a cleaned surface occurs rapidly[6], being facilitated on rough surfaces and the biofilm maturation occurs more rapidly with presence of more pathogenic bacteria[8,23-25,27].

Some studies have found a correlation between roughness and mechanical resistance of dental ceramics[4,11]. Namely, increasing the surface roughness of ceramics makes the material weaker. Fischer et al.[11] (2003) found that stress distribution and the respective characteristic strength values based on a Weibull stress distribution can be directly correlated to the roughness parameters Ra, Rz, and Rmax for all studied ceramics.

Considering the importance of the surface features of dental ceramics on the mechanical properties and the biofilm formation, the purpose of this study was to compare the mean surface roughness (Ra) of 2 feldspar veneer ceramics and 3 high crystalline content ceramic used as framework material, testing the hypothesis that the feldspathic ceramics have lower mean Ra value than the ceramics used for framework.

Material and methods

Eight disc specimens (5mm in diameter and 2mm in thickness) of each ceramic were fabricated according to the manufacturer's specifications and described as follows:

- **V7:** The powder and liquid of the feldspathic ceramic (Vita VM7 VITA Zahnfabrik, Bad Sackingen, Germany) were mixed and applied into a metallic matrix. The specimens were sintered in the Vacumat furnace (VITA Zahnfabrik), polished using a silicon-carbide abrasive paper #1000 (3M, St Paul, USA) and sonically cleaned (Vitasonic, VITA Zahnfabrik) in distilled water for five minutes. The specimens were glazed using the Vita Akzent 25 (VITA Zahnfabrik).
- **VA:** The feldspathic ceramic (Vitadur-α, VITA Zahnfabrik) specimens were fabricated using same methodology as for V7 specimens, except for the sintering program and glazing (Akzent 24, VITA Zahnfabrik).
- **IA:** The slip material for the glass-infiltrated alumina-based ceramic (Vita In-Ceram Alumina, VITA Zahnfabrik) was prepared, applied into the metallic matrix and allowed to dry. The specimens were sintered (Inceramat furnace, VITA Zahnfabrik) and the glass was applied and infiltration was carried out in the same furnace. All specimens were air-abraded with 110 µm alumina particles to remove the excess of glass. Polishing and cleaning were performed as for V7 specimens. Specimens were glazed using Vita Akzent 25 (VITA Zahnfabrik).
- **IZS:** The slip casted, glass-infiltrated zirconia-reinforced alumina-based ceramic (Vita In-Ceram Zirconia, VITA Zahnfabrik, Bad Säckingen, Germany) specimens were fabricated as for the IA specimens.
- **IZB:** A block of In-Ceram Zirconia for Cerec InLab (VITA Zahnfabrik, Bad Säckingen, Germany) was cut in a cutting machine to produce 2mm-thick square specimens, which were

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rounded to a disk shape of 5mm-diameter using a diamond bur under a light microscope (Carl Zeiss 350, Germany) (x4.5). The remaining fabrication procedures were as for IA specimens.

The average roughness parameter (Ra) was calculated using a roughness analyzer (Mitutoyo SJ-400, Tokyo, Japan). On one face of each specimen, four readings (2 in the x direction and 2 in the y direction, 1 mm apart from each other and cut-off value = 3 mm) were averaged and used to calculate (n=8) the mean value and standard deviation of Ra (in µm).

The Ra values (in µm) were statistically analyzed using one-way analysis of variance (Anova) and Tukey post-hoc test, at 5% significance level. Statistical analysis was performed using Statistics 8.0 for Windows (Analytical Software Inc, Tallahassee, USA).

Results

One-way Anova showed statistically significant differences between the study groups ($p<0.05$) (Table 1). The Tukey post-hoc test (Table 2) revealed that V7 (0.43 ± 0.07 µm) presented the lowest mean surface roughness (Ra) value. Yet, there were no significant differences between the mean Ra values of the ceramics VA (0.94 ± 0.2 µm), IA (0.7 ± 0.13 µm), IZS (0.98 ± 0.3 µm) and IZB (0.75 ± 0.4 µm).

Table 1 – Description of the One-Way Analysis of Variance

Source	DF	SS	MS	F	P*
Between	4	1.55	0.38	6.22	0.0007
Within	35	2.18	0.06		
Total	39	3.74			

Table 2 – Mean values of surface roughness (µm) and standard deviations

	Means (µm)*	SD
V7	0.43b	0.07
VA	0.94a	0.2
IA	0.7a	0.13
IZS	0.98a	0.3
IZB	0.75a	0.39

*Different superscript letters mean statistical difference (α=.05)

Discussion

In the present study, the feldspar ceramic VM7 presented surface roughness significantly lower when compared to the other feldspar ceramic evaluated (Vitadur-α). The differences with relationship to the surface roughness observed among the ceramic can be, probably, attributed to the micro structural characteristic of the materials as size and it forms of the crystals. The manufacturers of the ceramic VM7 comments that its microstructure presents more homogeneous distribution of the vitreous phases, consequently smoother surfaces are obtained, presenting high resistance to the biofilm formation when compared to the conventional ceramic.

The framework ceramics displayed the higher roughness values, when compared to the feldspar

UNESP out_dez 02.indd 14 27.03.07 12:04:29

ceramic VM7. The framework ceramics investigated have a high crystalline content with irregular shape crystals[9].

Considering this study results, care should be taken when the ceramic framework is exposed to the oral environment, due to the reported association of increased surface roughness and formation/accumulation of dental biofilm on dental materials[16,27,30]. Changes in this variable might, therefore, facilitate the prevention of recurrent caries and periodontal disease.

The ceramic framework materials investigated in this study (glass-infiltrated alumina and zirconium) can be indicated for small fixed prostheses and bonded prostheses, and in both clinical situations the framework may be kept without a ceramic veneer. This is especially true for inadequate tooth preparation and bonded prostheses, in which the palatal extension of the prosthesis is usually uncovered.

Scanning electron microscopy studies revealed that the initial adhesion of microorganisms begins in irregularities and is subsequently extended to the entire surface[19,20,23]. These irregularities increase the area available for adhesion and especially protect the bacteria from the shear forces in the oral cavity, such as salivary flow, chewing, swallowing and oral hygiene procedures[24].

As bacterial adhesion theoretically evolves from an initial reversible stage to a stronger adhesion stage, considered irreversible, authors suggested that this change primarily occurs in the irregularities, in which the microorganisms are protected from the shear forces[12,24,25]. Consequently, the biofilm may present faster maturation at these areas.

Rimondini et al.[27] (1997) evaluated the bacterial colonization on titanium samples with different surface roughness values. In smooth samples, there was smaller accumulation of bacteria, and only *cocci* were observed. In specimens with intermediate roughness (presence of grooves), short and long rods were found. In rough samples, with the presence of grooves and porous, there were long bacteria rods aggregated or in layers. Thus, as *cocci* are considered pioneer species and rods are regarded as subsequent species in colonization, the presence of long rods was considered by the authors as an advanced stage of maturation of the biofilm on rough surfaces. Similar findings were reported for fluoride-ethylene-propylene, cellulose acetate, titanium, enamel and cementum specimens[8,23-25]. Thus, the surface roughness of materials increases both the bacterial adhesion and faster maturation of the biofilm formed, which presents clinical implications, since this biofilm may present more pathogenic microorganisms.

Further in vivo studies on bacterial adhesion and dental biofilm formation on the ceramics evaluated in the current study must be conducted.

Other argument widely discussed in the scientific literature is related to the effect of surface roughness on the mechanical strength of dental ceramics. Some authors have shown the direct effect of roughness on the resistance properties of ceramics[4,11]. Fischer et al.[11] (2003) found that stress distribution and the respective characteristic strength values based on a Weibull stress distribution can be directly correlated to the roughness parameters Ra, Rz, and Rmax for all studied ceramics. As also mentioned by Fischer et al.[11] (2003), ceramics normally have a low mechanical reliability, since no exact failure limit can be defined. If the peak-to-valley height of the surface roughness is in the range of the critical defect size value, then roughness can affect the flexural strength. The fundamental fracture mechanics theory (Griffith criterion) shows that an increase in defect size produces a decrease in strength. Since ceramic materials fail because of the ‘weakest-link principle’, the maximum (critical) microscopic defect will cause failure at the critical stress[10,11]. It is important to consider that restorations are adjusted in the mouth using diamond burs, and thus should be polished to produce a smoother or less rough surface[1,5].

Final polishing reduces the roughness by using extremely fine abrasive materials. Polishing of the external restoration surface is very relevant, once rough surfaces have great potential to bacterial adhesion[26-7], and can be more capable of wearing the opposing teeth[15]. Moreover, effective polishing prevents discoloration of rough areas and leads to a more natural appearance of ceramic restorations. Rough or irregular ceramic surfaces, *i.e.* produced after intraoral adjustment of the restorations, may concentrate stresses and initiate crack propagation, resulting in early restoration failure[4,11]. Therefore, the results partially accepted this study hypothesis, since only VM7 ceramic showed the lowest mean Ra value, probably due to its finer microstructure.

Conclusions

The feldspar ceramic VM7 presented the lowest surface roughness values when compared to the feldspar ceramic Vitadur-α, and the to framework ceramics evaluated.

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Resumo

A proposta deste estudo foi comparar a rugosidade superficial de cerâmicas feldspáticas, cerâmicas a base de zircônia e outra de alumina, avaliando a hipótese que cerâmicas feldspáticas apresentam menor rugosidade superficial que cerâmicas de infra-estrutura. Oito discos (diâmetro: 5mm; espessura: 2mm) de cada cerâmica foram fabricados conforme as recomendações dos fabricantes: V7- cerâmica feldspática (Vita VM7); VA- cerâmica feldspática (Vitadur-α); IA- cerâmica de alumina infiltrada por vidro (Vita In-Ceram Alumina); IZS- cerâmica de zircônia-alumina infiltrada por vidro (Vita In-Ceram Zirconia); IZB- cerâmica de zircônia-alumina infiltrada por vidro (Vita In-Ceram Zirconia 2000 for Cerec InLab). Todos os materiais foram glazeados conforme as recomendações do fabricante. Quatro leituras de rugosidade Ra (Mitutoyo SJ 400) por espécime foram feitas, obtendo a média por espécime (n=8). Os dados foram analisados pelo teste de ANOVA 1-fator e de Tukey. (α=0,05). V7 apresentou a mais baixa média de rugosidade (0,43±0,07 µm) comparada às outras cerâmicas. Não houve diferença estatística entre os valores de VA (0,94±0,2 µm), IA (0,7±0,13 µm), IZS (0,98±0,3 µm) e IZB (0,75±0,4 µm). A hipótese foi parcialmente aceita. V7 teve uma superfície mais lisa que VA. Os valores de rugosidade das cerâmicas altamente cristalinas para infra-estrutura (IA, IZS, IZB) não foram diferentes estatisticamente.

Unitermos

Cerâmica; materiais dentários; rugosidade superficial,estudo comparativo

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