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Influence of the Finishing Technique on Surface Roughness of Dental Porcelains with Different Microstructures

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Clinical Relevance

After the glaze layer of a ceramic restoration is broken, the clinician should pay attention to the specific porcelain used in the prosthetic work, since the best finishing technique (reglazing versus polishing) depends on the porcelain's characteristics.

SUMMARY

This study compared the surface roughness of 4 dental porcelains with different microstructures (d.Sign-D, Finesse-F, Noritake-N and Symbio-S) using varied surface treatments. The porcelain surfaces were submitted to the following surface treatments: 1) g (glazing only); 2) rg (polishing with a rubber wheel before glazing); 3) 2g (reglazing); 4) r (rubber wheels); 5) rp (rubber wheels + diamond paste); 6) d (sandpaper discs) and 7) dp (sandpaper discs + diamond paste). Treatments 3 through 7 were performed after breaking the glaze layer with a diamond bur. Surface roughness (Ra, in m) was determined using a profilometer (n=10). Visual inspection was made using the scanning electron microscope. Microstructural characterization was also performed (hardness, leucite content and particle size). Reglazed specimens presented significantly rougher surfaces compared to glazed specimens. The use of a polishing paste after the sandpaper discs or after the rubber wheel resulted in a reduction of the Ra value for all materials (except for the dp group of porcelain S). Rubber or discs followed by diamond paste were the best surface treatments for porcelains D (D-rp: 0.21 ± 0.06 µm and D-dp: 0.22 ± 0.05 µm) and F (F-rp and F-dp: 0.17 ± 0.03 µm). For porcelains N and S, both reglazing (2g) and the use of rubber or sandpa-

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per discs followed by diamond paste (groups rp and dp) resulted in similar roughness (N-2g: 0.22 ± 0.03 µm; N-rp: 0.22 ± 0.04 µm; N-dp: 0.20 ± 0.04 µm, S-2g: 0.22 ± 0.04 µm; S-rp: 0.19 ± 0.04 µm ; S-dp: 0.23 ± 0.04 µm). Conclusion: The best choice of surface treatment for leucite-based porcelains depended on the material considered. Porcelains with lower leucite content (F and S) tended to present lower roughness compared to those with higher leucite content after being polished with rubbers or discs followed by diamond pastes.

INTRODUCTION

Ceramic restorations may need some adjustments (in occlusion, shape or proximally) after the glaze cycle has already been carried out. Such adjustments are usually done with fine-grained diamond burs, which will break the glaze layer and increase the restoration's surface roughness, leading to some clinical problems, such as: a) increased wear of the opposed tooth,[1] b) increased dental plaque retention and periodontal tissue inflammation,[2] c) increased staining,[3] d) unsatisfactory esthetics[4] and e) lower resistance to crack propagation.[5]

In order to eliminate the grooves created during adjustments and achieve a smooth, shiny surface, the clinician may choose between reglazing the porcelain (if the restoration is not definitely luted) or polishing (intra- or extraorally). Reglazing has the advantage of reduced chairside time, but it demands an extra session to complete the work (if the clinician does not have an oven at the office). On the other hand, finishing the restoration with a polishing system has the main advantage of completing the work in a single session, although achieving a highly polished porcelain surface with mounted points and pastes is time-consuming.[3]

Studies comparing the efficiency of reglazing and polishing leucite-based porcelains presented controversial results.[6] While some studies have verified that glazing resulted in a smoother surface compared to polishing,[7-10] other studies[11] have found comparable final surfaces for both finishing methods. There have also been studies that showed polished ceramic surfaces to be smoother than glazed surfaces.[3-4,6,12-14] All of the above-cited works evaluated surface roughness using qualitative (scanning electron microscopy or visual inspection) and/or quantitative methods (profilometer or specular reflectance).

Since there are many polishing kits for ceramics available on the market, some works also compared efficiency of the kits in terms of improving the surface quality of ground ceramic restorations. The polishing kits are composed of a variety of materials, such as diamond burs, fluted carbide burs, rubber wheels, rag wheels, mounted points, abrasive stones, sandpaper discs and diamond pastes. Newitter, Schilissel and Wolff[15] compared several polishing kits on one porcelain (Vita) restoration and obtained smoother surfaces using a sequence of rubber wheels (Shofu Porcelain Polishing Kit) and methods that used pumice or polishing pastes at the end of the process. Scurria and Powers[6] found that diamond points produced smoother surfaces than aluminum oxide points and 30-fluted carbide points for 2 porcelains (Ceramco II and Dicor MGC). However, Ward and others[13] compared 8 different intra-oral polishing techniques on 3 opalescent porcelains and found that the use of 30-fluted carbide burs associated with some polishing kits (Brasseler and Premier) produced the smoothest surface analyzed. Moreover, SEM observations demonstrated that good results in terms of finishing are obtained using rubber wheels (Ceramiste), while a felt disc (Dia-finish) was less effective.[16] Regarding the use of a diamond paste at the end of the polishing process, most authors verified that these pastes improve surface smoothness.[6,13-17]

Even though the effects of glazing and polishing on surface roughness have been extensively studied for leucite-based porcelains, the influence of the material's microstructure (leucite content, size, shape and distribution) still needs to be determined. Thus, this study compared the surface roughness of 4 dental porcelains with different microstructure, using a variety of surface finishing treatments (reglazing and different polishing systems). The hypothesis tested is that different finishing methods produce equal surface roughness for the materials tested.

METHODS AND MATERIALS

The 4 porcelains selected for this study are described in Table 1. For each material, 77 cylinders with a diameter and height of 6 mm were produced. Green bodies were prepared by mixing the porcelain powders with their respective liquids and pouring the slurry into a plastic mold. Five specimens were simultaneously fired in a porcelain oven Keramat I (Knebel Produtos Dentários Ltda, Porto Alegre, RS, Brazil) according to the manufacturers' instructions (Table 1). The surfaces of the specimens were then ground using 180, 320 and 600-grit sandpaper (3M do Brasil Ltda, Brazil). In the study, 7 surface treatments (described below) were analyzed (n=10):

1) **Glaze (g):** specimens were glazed according to each manufacturer's recommendations.

2) **Rubber + glaze (rg):** Before glazing (as in **group g**), the specimens were polished with gray and pink rubber wheels (Komet, Gebr Brasseler GmbH& Co KG, Germany) at low speed and moderate pressure for 30 seconds.

3) **Second glaze (2g):** At first, these specimens were glazed as described in **Group g**; they were then

ground with fine (3098F—KG Sorensen, Brazil) and extra-fine (3098FF—KG Sorensen, Brazil) diamond burs to break the glaze layer. Next, the surfaces were smoothed using a white stone (Shofu Dental Corporation, USA) and a second glaze cycle was carried out, as described in **Group g.**

4) **Rubber wheels (r):** After the glaze layer was broken as described in **Group 2g**, the specimens were polished with a sequence of 3 rubber wheels (gray, pink and "glaze" Komet, Gebr Brasseler GmbH& Co KG, Germany) for 30 seconds each, using moderate pressure.

5) **Rubber wheels + diamond paste (rp):** Once the procedures described in **Group r** were completed, the surfaces were polished for 30 seconds, using moderate pressure and diamond paste (KG Sorensen, Germany) applied with a felt wheel (Komet, Gebr Brasseler GmbH& Co KG, Germany).

6) **Sandpaper discs (d):** After the glaze layer was broken as described in **Group 2g**, the specimens were polished with medium, fine and extra-fine sandpaper discs (Sof-Lex, 3M do Brasil Ltda, Brazil) for 20 seconds each using light pressure.

7) **Sandpaper discs + diamond paste (dp):** After the procedures described in **group d** were completed, a felt wheel polished the surfaces for 30 seconds using moderate pressure and the same diamond paste as **Group rp**.

All procedures were performed by a single operator and, after each procedure, the specimens were ultrasonically cleaned in distilled water and embedded in acrylic resin to make handling easier.

Surface Roughness Test

A profilometer (Surftest 301, series 178, Mitutoyo Co, Kanagawa, Japan) was used to measure arithmetic mean roughness (Ra) of the surfaces. Ra corresponds to the area created by the line of the profile above and below the central line divided by the scanned length.[18] The cutoff was set at 0.25 mm, and the total transverse length was 1.25 mm. Five measurements were performed on each specimen. After each measurement, the specimen was rotated 60 degrees. The average of these 5 values was used for statistical analysis.

Scanning Electron Microscopy (SEM)

For all materials, 7 specimens (1 from each experimental group) were analyzed using a scanning electron microscope (model JSM 6100, Jeol Co Ltd, Japan) coupled to an energy dispersive spectroscope (EDS) (Noran Instruments, Middletown, WI, USA) in order to observe the surface features of each finishing treatment. To analyze the porcelains' microstructure at SEM, one block of each material (3 x 4 x 4 mm) was polished in a polishing machine and etched with 2% hydrofluoric acid (HF) for 15 seconds. The leucite volume fraction of the materials studied was determined by the point-count method using a 4 x 4 point grid and 90 fields. The mean particle size of all materials was measured on SEM micrographs of the polished and etched surfaces with the help of an image analyzer (Leica QWin, Leica Microsystems GmbH, Strasse, Germany).

Table 1: *Description of the Porcelains Used in this Study*

Ceramic	Symbol	Manufacturer	Firing Cycle Initial Temp (°C)	Firing Cycle Final Temp (°C)	Heating Rate (°C/minute)	Manufacturers' Description
IPS d.Sign	**D**	Ivoclar Vivadent AG, Schann, Liechtenstein	450	869	60	Low-fusing, leucite-based porcelain, used for metal-ceramic or all ceramic restorations, containing leucite particles and crystals of fluorapatite.
Finesse	**F**	Dentsply, Ceramco, Burlington, NJ, USA	450	760	35	Low-fusing, leucite-based porcelain, used for metal-ceramic or all ceramic restorations, containing fine-grained leucite particles.
Super Porcelain EX 3	**N**	Noritake Co Ltd, Nagoya, Japan	600	925	45	High-fusing, leucite-based porcelain, used for metal-ceramic or all ceramic restorations, containing leucite particles.
Symbio	**S**	Degussa, Dental GmgH&Co KG, Rosbach, Germany	575	810	100	Low-fusing, leucite-based porcelain, used for metal-ceramic or all ceramic restorations, containing leucite particles.

Hardness

Specimen hardness was determined by indenting the surfaces of the glazed samples with a Vickers microhardness tester (MVK-H-3, Mitutoyo, Brazil) with a load of 9.8 N and a dwell time of 20 seconds. For each material, 5 of the previously tested specimens were used (n=5). In each specimen, 5 indentations were made in order to obtain a mean value that was used to calculate the mean value of each group. The material's hardness (H) was calculated using the following equation: $H=0.5\ P/a^2$; where P is the indentation load and a is the average indentation half-diagonal.

Statistical Analysis

For roughness testing, the mean values were analyzed using 2-way ANOVA. Leucite content, particle size and hardness data were analyzed by means of 1-way ANOVA. For all tests, when significant differences were found, the means were compared using Tukey's intervals with a confidence level of 95%.

RESULTS

In terms of surface roughness (Ra), interaction between the factors studied (porcelain and surface treatment) was statistically significant ($p<0.05$). Table 2 shows that the mean Ra values for **Groups g** and **rg** were statistically similar for porcelains **D**, **F** and **S**. For porcelain **N**, **Group rg** presented a significantly higher Ra value compared to **Group g**. For all materials, the reglazed specimens (**Group 2g**) presented significantly rougher surfaces compared to the glazed specimens (**Group g**). Also, for materials **D**, **N** and **S**, the Ra values for **Groups r** and **d** were statistically higher compared to the glazed specimens (**Group g**). However, for porcelain **F**, the Ra values for **Groups r** and **d** were statistically similar to that of **Group g**. The use of a polishing paste after the discs (**Group dp**) or the rubber wheel (**Group rp**) resulted in a reduction in the Ra value for all materials (except for **Group dp** of porcelain **S**), though differences were not always statistically significant.

A comparison of the Ra values of the 4 materials showed that they were ranked differently according to the type of surface treatment performed. For example, when the glazed groups (**g**) were considered, porcelain **F** presented a rougher surface compared to **N** and **S** (Table 2). However, when a rubber wheel was used before the glazing cycle (**Group rg**), porcelains **D**, **F** and **N** presented similar roughness, while porcelain **S** showed the lowest Ra value. The use of a second glaze cycle after breaking the glaze layer (**Group 2g**) resulted in a statistically higher value of Ra for porcelain **F** compared to the other materials. When **Groups r, rp, d** and **dp** were considered, porcelains **F** and **S** tended to present lower Ra values.

SEM analysis confirmed the results obtained in the roughness test. Figure 1 shows 2 micrographs of porcelain **S**, where it is possible to notice that reglazing resulted in a surface with more irregularities compared to the glazed surface. Figure 2 shows that polishing porcelain **D** with only a sandpaper disc resulted in a rougher surface compared to the glazed surface. It is

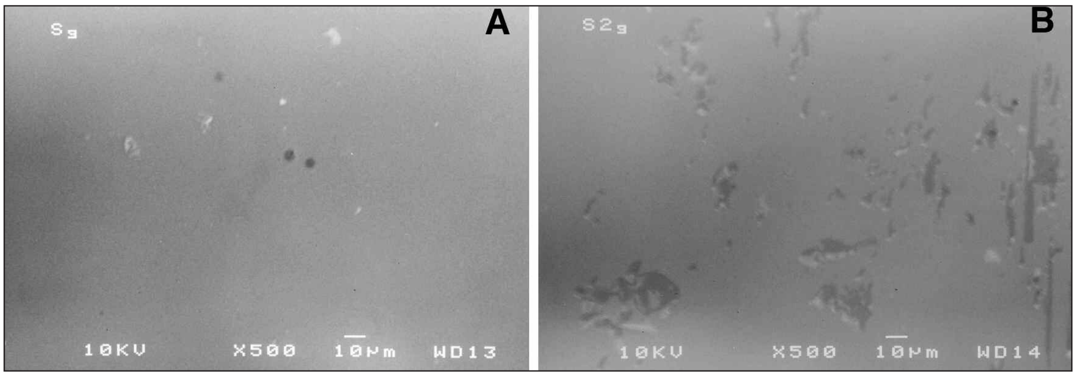

Figure 1: *Comparison between glazed (A) and reglazed (B) surfaces of porcelain S (Symbio). It is possible to notice that reglazing did not heal flaws generated by grinding.*

Table 2: *Mean Values of Ra (m) for the Porcelains Studied as a Function of the Surface Treatment Performed*

Group	D	F	N	S
g	0.16 (0.03)[c]	0.19 (0.03)[b,c]	0.11 (0.01)[c]	0.08 (0.01)[b]
rg	0.19 (0.04)[c]	0.21 (0.03)[b,c]	0.20 (0.01)[b]	0.13 (0.03)[b]
2g	0.28 (0.03)[a]	0.38 (0.05)[a]	0.22 (0.03)[a,b]	0.22 (0.04)[a]
r	0.27 (0.03)[a,b]	0.23 (0.06)[b,c]	0.27 (0.05)[a]	0.22 (0.04)[a]
rp	0.21 (0.06)[c]	0.17 (0.03)[c]	0.22 (0.04)[a,b]	0.19 (0.04)[a]
d	0.28 (0.05)[a]	0.24 (0.05)[b]	0.26 (0.04)[a,b]	0.20 (0.04)[a]
dp	0.22 (0.05)[b,c]	0.17 (0.03)[c]	0.20 (0.04)[b]	0.23 (0.04)[a]

For each column, values followed by the same superscript are not statistically different (p>0.05). (D: d.Sign; F: Finesse; N: Noritake; S: Symbio; g: glazed; rg: rubber before glazing; 2g: second glaze; r: only rubber; rp: rubber + diamond paste; d: only disc; dp: disc + diamond paste).

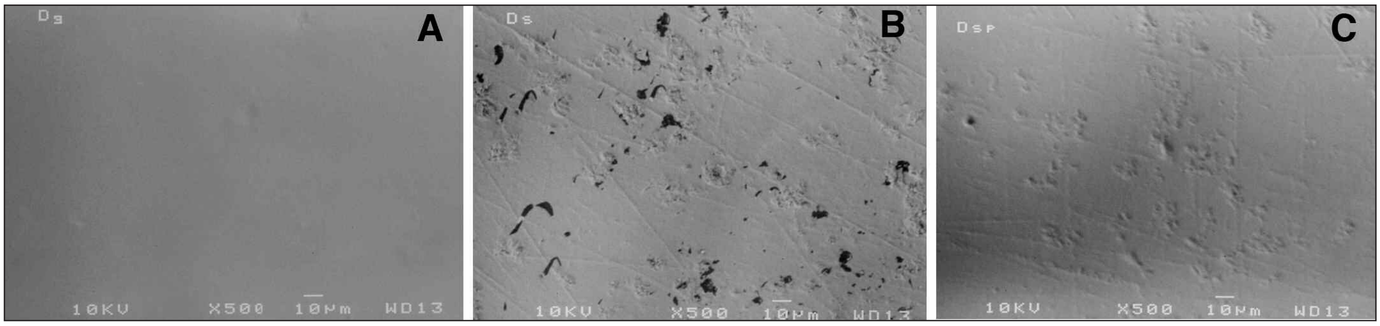

Figure 2: *Surfaces of porcelain D (d.Sign): glazed (A), polished with sandpaper disc (B), and polished with discs followed by diamond paste (C).*

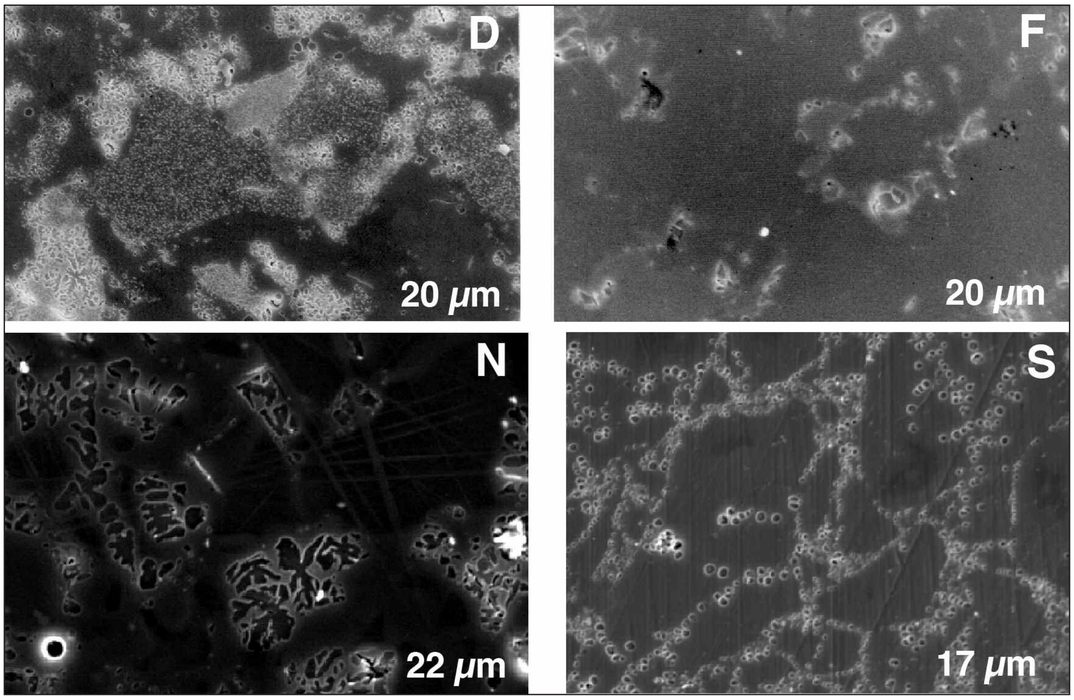

Figure 3: *Micrographs of the polished surfaces of the 4 porcelains etched with 2% hydrofluoric acid (HF) for 15 seconds (D: d.Sign; F: Finesse; N: Noritake; S: Symbio).*

also possible to notice that use of a diamond paste (Figure 2C) partially reduced the depth of the grooves left by the disc.

Microstructural analysis (Figure 3) showed the presence of leucite in all porcelains. Distribution of leucite in the glassy matrix was heterogeneous, and the particles were grouped in clusters. The leucite particles of porcelains **F** and **S** were equiaxial, while those for porcelain **D** and **N** had a dendritic morphology. Porcelain **D** also presented fine particles dispersed in some regions of the glassy matrix, most likely of fluorapatite, since EDS analysis of these particles showed the presence of fluorine. Table 3 shows the leucite content, mean particle size and hardness. The leucite content of porcelain **D** (15%) was statistically higher than the other materials. Porcelains **N** and **S** showed intermediary leucite contents (10% and 8%, respectively), and porcelain **F** presented the lowest value (6%). Regarding mean particle size, there were significant differences among all materials. The particle size decreased in the following order: **F**, **D**, **N**, **S**. There were also statistically significant differences among all hardness values, and the materials were classified according to hardness in the following decreasing order: **D**, **F**, **N**, **S**.

DISCUSSION

The main hypothesis of this work was rejected, since there were statistical differences among the finishing techniques for all materials tested. **Group rg** was created in order to check if the dental technician should

Table 3: *Leucite Content, Mean Particle Size and Hardness of the 4 Porcelains Tested.*

Group	Leucite Content (%)	Mean Particle Size (μm)	Hardness (GPa)
d.Sign	15 ± 3[a]	1.9 ± 0.5[b]	7.7 ± 0.2[a]
Finesse	6 ± 2[c]	3.5 ± 1.4[a]	7.4 ± 0.1[b]
Noritake	10 ± 1[b]	1.7 ± 1.2[c]	7.0 ± 0.2[c]
Symbio	8 ± 1[b,c]	0.6 ± 0.2[d]	6.6 ± 0.3[d]

For each column values followed by the same superscript are not statistically different (p>0.05).

use a rubber wheel before glazing the porcelain to improve its smoothness. According to the results presented in Table 2, this procedure is not necessary, since it did not improve smoothness for any of the materials tested. In the case of porcelain **N**, there was even a statistically significant increase in roughness when the rubber wheel was used, indicating that this type of finishing should be avoided for this material.

The unsatisfactory performance of the reglazed groups (**2g**) compared to the glazed groups (**g**) may be explained by differences in the previous surface treatments carried out on these groups. In **Group g**, specimens were ground with 600-grit sandpaper, while in **Group 2g**, final polishing was performed with a white stone. It is likely that the second glaze cycle did not remove the scratches created by the stone as efficiently as the first glaze cycle removed the scratches left by the sandpaper. Moreover, it should be considered that precise control of the desired degree of luster may have been limited during the second glaze cycle, since furnaces have temperature fluctuations that may result in "overglazed" or "underglazed" restorations.[19] Possibly, the reglazed surfaces of **Group 2g** were "underglazed" and, consequently, rougher than those of **Group g**, meaning that the reglazing cycles recommended by the manufacturers were not well adjusted to eliminate the irregularities created when the first glaze layer was broken by a diamond bur (Figure 1). In fact, Oilo[20] showed that the firing schedule (starting temperature and holding time) is critical to generate an adequate flow of glass and to limit the number and size of defects in dental porcelains.

The use of rubber wheels (**Group r**) or sandpaper discs (**Group d**) did not produce surfaces as smooth as those obtained by glazing (**Group g**), since the use of these finishing materials resulted in rougher surfaces compared to the glazed specimens (Table 2, Figure 2A and 2B). The purpose for using a diamond paste after a rubber wheel or disc is to improve the smoothness of the restoration by means of a systematic decrease in particle size of the abrasive[4]. This effect was noted for porcelains **D**, **F** and **N**, even though the reduction in Ra values after using the diamond paste was not always statistically significant. In Figure 2C, it is possible to see that use of the diamond paste reduced the depth of scratches left by the disc (Figure 2B). These findings are in accordance with other authors,[6,13-15,17] who showed that use of a diamond paste in the end of the polishing process improves the smoothness of the restoration. However, in this work, the use of a diamond paste after the sandpaper disc (**group dp**) was not suitable for porcelain **S**, since it increased the roughness of this material. Another work[4] also showed that use of a diamond polishing paste may produce an "inadequate" surface, depending on the porcelain and the polishing sequence used.

The results shown in Table 2 indicate that the clinician should take into account the dental porcelain used when choosing the best surface treatment after the glaze layer is broken. Considering porcelains **D** and **F**, the use of rubber or sandpaper discs followed by diamond pastes (**Groups rp** and **dp**) should be preferred over reglazing (**Group 2g**). However, for porcelains **N** and **S**, both reglazing and the use of rubber or discs, followed by diamond pastes, results in similar roughness.

The influence of microstructure on the performance of the porcelains studied was difficult to determine. When glazing (**Group g**) or reglazing (**Group 2g**) is considered, it is possible to notice that some porcelains (**N** and **S**) were more easily glazed (that is, achieved smoother surfaces after glazing). This is probably related to the composition of their glassy matrix and their behavior under the heat of the glaze cycle. When **Groups r**, **rp**, **d** and **dp** were considered separately, porcelains with lower leucite content (**F** and **S**) tended to present lower Ra values when compared to those porcelains with higher leucite content (**D** and **N**) (except for porcelain **S** in **group dp**). This finding indicates that leucite content may play an important role in the ease of polishing these materials. It was not possible to determine the influence of particle size on polishing, since porcelains **F** and **S**, respectively, presented the largest and smallest particle sizes. Regarding hardness, it is likely that the higher mean value of porcelain **D** makes it more difficult to polish with discs and rubbers compared to porcelains **F** and **S**; however, the same difficulty was noticed for porcelain **N**, which has lower hardness than porcelain **F**. Thus, it is not clear how these 3 factors (leucite content, particle size and hardness) interact to determine the ease of polishing leucite-based porcelains. Other factors, such as the chemical composition of the glassy matrix and particle shape, may play a role. A more controlled experiment (for example, 1 porcelain with given chemical composition and varied leucite content or particle size) would be necessary to clarify this issue.

CONCLUSIONS

Within the limits of this study, it is possible to conclude that, after the glaze layer is broken, the best choice for surface treatment depends on the porcelain used. Although the influence of microstructure on the ease of polishing was difficult to determine, the leucite content of the materials seems to play an important role, since porcelains with lower leucite content (**F** and **S**) tended to present lower roughness compared to those with higher leucite content after polishing with rubber or discs followed by diamond pastes.

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