Effect of Tooth Brushing Cycles and Dentifrice Fluoride Concentration on a Glazed CAD/CAM Ceramic

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Purpose: To evaluate the effect of tooth brushing and dentifrice fluoride (F-) concentration on changes in color and translucency (ΔE<sub>00</sub> and ΔT<sub>00</sub>, respectively), surface gloss (GS), surface roughness (Sa), and microstructure of a glazed CAD/CAM ceramic. Materials and Methods: Ceramic blocks (e.max/CAD) were sectioned into rectangular plates (14 x 12 x 1 mm), and one surface of each sample was glazed. Samples were divided into three groups according to the F- concentration in the dentifrice (0, 1,100, and 5,000 µg/g) and were then subjected to 60,000 tooth brushing cycles. Luminosity and color were measured using a spectrophotometer at baseline and after every 20,000 cycles to obtain their ΔE<sub>00</sub> and ΔT<sub>00</sub> values. Another set of samples was prepared to measure the GS with a gloss meter and the Sa with a confocal laser microscope. The GS and Sa results were subjected to analysis of variance, Tukey test, and Dunnett test (α = .05). Results: After 60,000 tooth brushing cycles, all of the variables were clinically acceptable, and there were no significant differences in the ΔE<sub>00</sub>, ΔT<sub>00</sub>, GS, or Sa among the fluoridated dentifrices. The GS values decreased significantly as the number of tooth brushing cycles increased. Conclusion: The ΔE<sub>00</sub>, ΔT<sub>00</sub>, GS, and Sa values were all clinically acceptable after the glazed e.max/CAD ceramic had been subjected to 60,000 tooth brushing cycles with dentifrices containing up to 5,000 µg/g of F-. Int J Prosthodont 2021 December 16. doi: 10.11607/ijp.7187. Online ahead of print.

The introduction of fluoridated dentifrices in the 20th century was a significant advancement in controlling dental caries. Tooth brushing disorganizes the biofilm, and the fluoride ion (F-) released by the dentifrices can decrease mineral loss by promoting the precipitation of a more insoluble mineral.¹ This effect reduces further demineralization and activates remineralization of the tooth.² Since this discovery, different F- concentrations have been tested to find a balance between the highest F- benefits (caries prevention and control) and its lowest risk (dental fluorosis).³ Systematic reviews have shown that an anti-caries effect is reached when fluoridated dentifrices containing at least 1,000 µg/g of F- are used.⁴ However, in some specific clinical situations, a higher F- concentration (5,000 µg/g) is recommended; for example, to prevent root caries in patients with gingival recession⁵,⁶ and for patients who have...
a high risk of caries. As life expectancy has increased, the prevalence of gingival recession has also increased, which makes preventing root caries an increasingly important issue. For patients with ceramic restorations, it may be recommended to use dentifrices that contain a high concentration of F−.

Recent advances in dental material technology have created materials that can mimic the tooth’s mechanical and optical behavior in a way that was not previously possible. The possibility of providing excellent function, as well as esthetics, has created a demand by patients to use esthetic materials such as composites and ceramics. Some CAD/CAM glass-ceramics in particular must be stained and glazed with a lower fusing ceramic to reduce the surface porosity, improve esthetics, and increase the surface gloss. Glazing produces a surface that is less prone to changes in color biofilm formation, and toothbrush wear. However, since this glaze layer is thin, it may be lost when exposed to the effects of pH cycling, fatigue loading, or tooth brushing that occur in the mouth.

There is a potentially harmful interaction between the F− and the silicon that is a significant component of the glaze. However, the effect of high concentrations of F− in dentifrices on the degradation of glazed ceramic surfaces has not yet been evaluated. This effect could range from slight surface changes to significant damage to the glaze layer that could then produce changes in color and translucency. Structural damage could occur, causing an increase in biofilm accumulation and reducing the life expectancy of the restoration. Thus, the purpose of this study was to evaluate the effect of tooth brushing and different F− concentrations in dentifrices on the color, translucency, gloss, roughness, and microstructure of a glazed CAD/CAM ceramic. The null hypothesis was that tooth brushing and the higher F− concentration (5,000 µg/g) in the experimental dentifrices would not affect the color, translucency, gloss, roughness, or microstructure of a glazed CAD/CAM ceramic.

**MATERIALS AND METHODS**

CAD/CAM blocks of lithium disilicate ceramics (IPS e.max CAD, shade A1, lot number V06897, Ivoclar Vivadent) were sectioned into 65 plates (14 x 12 x 1 mm) using a slow-speed diamond wafering blade (Isomet 1000 Precision Saw, Buehler). The surfaces of the samples were wet-ground with a 600-grit aluminum oxide abrasive (T216 sandpaper, Norton Abrasives) using a grinding machine (AutoMet 500, Buehler). The ceramic samples were then crystallized, and this was followed by a smooth manual glaze (IPS e.max CAD Crystall/Glaze Paste, lot number X35468, Ivoclar Vivadent) application with a brush on only one of their surfaces (168 mm²). The manufacturer’s instructions were followed, and the blocks were sintered using an oven made by the manufacturer of the same ceramic (Programat P510, Ivoclar Vivadent).

To evaluate the effect of F− concentration on color and translucency, 15 sintered and glazed ceramic plates were randomly divided into three groups (n = 5), each with a different code (A, B, or C). A commercial spectrophotometer (Vita Easynadshade Advance 4.0, Vita Zahnfabrik) was fixed with its tip perpendicular to the glazed surface of the ceramic samples to obtain the coordinates of luminosity (L*), and color (a* and b*) at baseline. The readings were made in a light-controlled box (D65 Minimizer, GTI Graphic Technology) with the samples over a black or white background.

The experimental dentifrices were specially formulated for this research by Colgate-Palmolive from Brazil (Colgate-Palmolive Indústria e Comércio) with identical formulations (NaF/silicon dioxide). They all had the same relative dentin abrasivity (RDA) of 70 and differed only in their F− concentration: 0 (nonfluoridated/control), 1,100, and 5,000 µg/g. The slurry was prepared with distilled water in a 1:3 dentifrice:water ratio (w:w), and each slurry solution was designated to ceramic samples with a different code (A, B, or C) in order to double-blind the researchers. Neither the researcher who prepared the slurry (V.L.B.A.) nor those who conducted the experiments (F.B. and E.F.C.) knew the concentration of each coded slurry. These codes were only revealed after the statistical analyses had been completed.

Nylon toothbrushes (Oral B Indicator Plus, ultra-soft, size 35, Procter and Gamble) were fixed with thermoplastic glue (Bmfctrans, Bumafer) to the articulating arms of a tooth brushing machine (Toothbrush Simulator, Biopdi). The ceramic samples were positioned, immersed in the dentifrice slurry, and subjected to a total of 60,000 tooth brushing cycles (120,000 reciprocal strokes) at a frequency of 6 Hz while applying a 250-g load.

This number of cycles theoretically corresponds to approximately 6 years of tooth brushing in the oral environment. After every 20,000 cycles, the luminosity and color coordinates of the samples were measured, and both the toothbrushes and the slurries were changed.

To calculate the color difference (ΔE00) and to compare values from baseline to the values after 20,000, 40,000, and 60,000 tooth brushing cycles, the L*, a*, and b* coordinates were measured over a white background. The ΔE00 values were calculated using the CIEDE2000 (1:1:1) formula:

\[ΔE_{00} = \left( \frac{ΔL'}{K_L S_L} \right)^2 + \left( \frac{ΔC'}{K_C S_C} \right)^2 + \left( \frac{ΔH'}{K_H S_H} \right)^2 + R_1 \left( \frac{ΔC'}{K_C S_C} \right) \left( \frac{ΔH'}{K_H S_H} \right) \]

ΔL', ΔC', and ΔH' correspond to the luminosity, chroma, and hue differences, respectively, for one sample at CIEDE2000, and R1 is the rotation function that...
accounts for the interaction of the chroma and hue differences in the blue spectrum. The weight-functions $S_L$, $S_C$, and $S_H$ adjust the total color difference to the color difference localization for the $L'$, $a'$, and $b'$ pair of coordinates. The parametric factors $K_L$, $K_C$, and $K_H$ used in the CIEDE2000 color-difference formula are correction terms for the conditions of the experiment and were set at 1:1:1.

To calculate the translucency parameter ($TP_{00}$), the $L^*$, $a^*$, and $b^*$ coordinate values were recorded with the ceramic samples placed over a black or white background, and the CIEDE2000 (1:1:1) color difference formula was used\(^\text{23-25}\):

$$TP_{00} = \left[ \frac{(L'_B - L'_W)^2}{K_S L} + \frac{(C'_B - C'_W)^2}{K_S C} + \frac{(H'_B - H'_W)^2}{K_S H} \right] + \left[ \frac{(L'_B - L'_W) + (C'_B - C'_W) + (H'_B - H'_W)}{K_S L + K_S C + K_S H} \right]^\frac{1}{2}$$

The subscript letters “$B$" and “$W$" refer to the luminosity ($L'$), chroma ($C'$), and hue ($H'$) values of samples over the black and white backgrounds, respectively. The definitions of functions $R$, $S_L$, $S_C$, $S_H$, $K_L$, $K_C$, and $K_H$ are the same as for $\Delta E_{00}$. The higher the $TP_{00}$ value, the greater the translucency of the material. Subsequently, values of translucency difference ($\Delta TP_{00}$) were obtained by subtracting the baseline values from the values obtained after 20,000, 40,000, and 60,000 tooth brushing cycles.

When using the CIEDE2000 color-difference formula to calculate the $\Delta E_{00}$ and $\Delta TP_{00}$, discontinuities due to mean hue computation and hue difference computation were considered as discussed and characterized by Sharma et al.\(^\text{26}\)

To evaluate the gloss and roughness of the specimens, 45 samples were randomly divided into three groups ($n = 15$ each), and an additional 5 unbrushed samples were used as control. As previously described, the dentifrices that contained 0, 1,100, or 5,000 µg/g of F were randomly assigned to the three differently coded groups (A, B, or C). Each group was then divided into three subgroups according to the number of tooth brushing cycles: 20,000, 40,000, and 60,000 ($n = 5$ each). The tooth brushing protocol was followed as previously described, with new toothbrushes used after every 20,000 brushing cycles.

The surface gloss (GS) values were measured with a gloss meter (Nuvo-Curve, Rhopoint Instruments) that had been previously calibrated. The samples were positioned over the acquisition area of the gloss meter and were covered with an opaque light blocker. GS values were obtained at a 60-degree angle with three readings at different positions made in different regions for each sample. The mean of the three repetitions was considered as the GS of each sample ($n = 5$), which was measured in gloss units (GU).

The surface roughness (Sa) values of the glazed surfaces of the same samples were evaluated with a laser confocal microscope (OL55000, Olympus) at x10 magnification. Three readings were taken at different areas for each sample, and the average was considered the Sa of each sample ($n = 5$).

The microstructure of the samples was examined using a digital optical microscope (KH-8700, Hirox), and representative images of each group were taken at x50 magnification.

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**Table 1** Mean ± SD Values for the $L^*$, $a^*$, $b^*$, and $TP_{00}$ Variables at Each F- Concentration in the Dentifrices and After Tooth Brushing

<table>
<thead>
<tr>
<th>Variables</th>
<th>$F^{-}$ concentration in dentifrice</th>
<th>Baseline 0</th>
<th>No. of tooth brushing cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20,000</td>
<td>40,000</td>
<td>60,000</td>
</tr>
<tr>
<td>$L^*$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>97.4 (1.2)$^{\text{Ab}}$</td>
<td>96.7 (0.5)$^{\text{Ab}}$</td>
<td>96.6 (0.6)$^{\text{Ab}}$</td>
</tr>
<tr>
<td>1,100</td>
<td>97.1 (1.3)$^{\text{bc}}$</td>
<td>96.6 (1.2)$^{\text{bc}}$</td>
<td>96.2 (1.3)$^{\text{bc}}$</td>
</tr>
<tr>
<td>5,000</td>
<td>98.6 (1.4)$^{\text{a}}$</td>
<td>98.0 (1.2)$^{\text{a}}$</td>
<td>96.6 (1.2)$^{\text{a}}$</td>
</tr>
<tr>
<td>$a^*$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>–1.3 (0.3)$^{\text{Ab}}$</td>
<td>–1.8 (0.2)$^{\text{Ab}}$</td>
<td>–1.9 (0.1)$^{\text{Ab}}$</td>
</tr>
<tr>
<td>1,100</td>
<td>–1.4 (0.2)$^{\text{Ac}}$</td>
<td>–0.8 (0.1)$^{\text{Ac}}$</td>
<td>–1.3 (0.1)$^{\text{Ac}}$</td>
</tr>
<tr>
<td>5,000</td>
<td>–1.3 (0.2)$^{\text{a}}$</td>
<td>–1.3 (0.2)$^{\text{a}}$</td>
<td>–1.7 (0.2)$^{\text{a}}$</td>
</tr>
<tr>
<td>$b^*$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>9.8 (0.9)$^{\text{Ab}}$</td>
<td>9.8 (0.7)$^{\text{Ab}}$</td>
<td>9.8 (0.8)$^{\text{Ab}}$</td>
</tr>
<tr>
<td>1,100</td>
<td>9.6 (0.8)$^{\text{Ab}}$</td>
<td>8.5 (0.8)$^{\text{Ab}}$</td>
<td>10.1 (0.7)$^{\text{Ab}}$</td>
</tr>
<tr>
<td>5,000</td>
<td>9.8 (0.9)$^{\text{Ab}}$</td>
<td>10.2 (0.8)$^{\text{Ab}}$</td>
<td>10.2 (0.7)$^{\text{Ab}}$</td>
</tr>
<tr>
<td>$TP_{00}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>12.7 (0.8)$^{\text{Ab}}$</td>
<td>12.9 (0.7)$^{\text{Ab}}$</td>
<td>12.9 (0.7)$^{\text{Ab}}$</td>
</tr>
<tr>
<td>1,100</td>
<td>12.4 (0.8)$^{\text{Ab}}$</td>
<td>12.1 (0.7)$^{\text{Ab}}$</td>
<td>12.2 (0.9)$^{\text{Ab}}$</td>
</tr>
</tbody>
</table>

$L^*$ = luminosity; $a^*$ = green-red coordinate; $b^*$ = blue-yellow coordinate; $TP_{00}$ = translucency parameter, $F^{-}$ = fluoride.

Different superscript uppercase letters compare dentifrices for the same number of tooth brushing cycles (within a column), and superscript lowercase letters compare no. of tooth brushing cycles for the same dentifrice (within a row) ($P < .05$). The data were submitted to two-way ANOVA, followed by Tukey HSD test.
Table 2 reports the results from variables \( \Delta E_{00} \), \( \Delta L' \), \( \Delta C' \), \( \Delta H' \), and \( \Delta T_{00} \). With regards to \( \Delta E_{00} \) values, tooth brushing (\( P = .292 \)) had no significant effect, and there was no interaction between the factors (\( P = .092 \)), while there was a significant effect of the dentifrice F- concentration (\( P < .001 \)), although there was no difference among the fluoridated dentifrices after 60,000 tooth brushing cycles (\( P > .05 \)). For \( \Delta L' \) values, there was a significant effect of tooth brushing and dentifrice (\( P = .008 \) and \( P < .001 \), respectively) and of their interaction (\( P = .003 \)). The \( \Delta C' \) and \( \Delta H' \) variables were significantly influenced by both factors alone (\( P < .001 \)) and by their interaction (\( P < .05 \)), while with regard to \( \Delta T_{00} \) values, a significant effect was found for both factors (tooth brushing: \( P = .001 \), and dentifrice: \( P < .001 \)) and for their interaction (\( P = .003 \)).

Table 1 displays results from variables \( L^* \), \( a^* \), \( b^* \), and \( TP_{00} \). Tooth brushing significantly affected coordinate \( L^* \) (\( P = .002 \)), as did the interaction between tooth brushing and dentifrice (\( P = .001 \)), while the dentifrice F- concentration alone had no significant effect (\( P = .098 \)). All samples had negative values for \( a^* \) and positive values for \( b^* \). Regarding coordinate \( a^* \), there was a significant effect of the factors tooth brushing and dentifrice alone (\( P = .009 \) and \( P < .001 \), respectively) and of their interaction (\( P < .001 \)). For coordinate \( b^* \), the dentifrice had no significant effect (\( P = .393 \)), but tooth brushing had a significant effect, as did the interaction between dentifrice and tooth brushing (\( P < .001 \)). \( TP_{00} \) was significantly influenced by tooth brushing (\( P < .001 \)) and the interaction between factors (\( P = .020 \)) but was not influenced by the dentifrice F- concentration (\( P = .193 \)).

The data had normal homogeneity and homoscedasticity. Data of \( L^* \), \( a^* \), \( b^* \), \( TP_{00} \), \( \Delta L' \), \( \Delta C' \), \( \Delta H' \), \( \Delta E_{00} \), and \( \Delta T_{00} \) were submitted to repeated-measures analysis of variance (ANOVA), and the GS and Sa data to two-way ANOVA, all followed by Tukey honest significant difference (HSD) test (\( \alpha = .05 \)). Dunnett test was performed for GS and Sa (\( \alpha = .05 \)). All statistical analyses were performed using the same statistical software (SPSS version 21, IBM).

**RESULTS**

Table 1 displays results from variables \( L^* \), \( a^* \), \( b^* \), and \( TP_{00} \). Tooth brushing significantly affected coordinate \( L^* \) (\( P = .002 \)), as did the interaction between tooth brushing and dentifrice (\( P = .001 \)), while the dentifrice F- concentration alone had no significant effect (\( P = .098 \)). All samples had negative values for \( a^* \) and positive values for \( b^* \). Regarding coordinate \( a^* \), there was a significant effect of the factors tooth brushing and dentifrice alone (\( P = .009 \) and \( P < .001 \), respectively) and of their interaction (\( P < .001 \)). For coordinate \( b^* \), the dentifrice had no significant effect (\( P = .393 \)), but tooth brushing had a significant effect, as did the interaction between dentifrice and tooth brushing (\( P < .001 \)). \( TP_{00} \) was significantly influenced by tooth brushing (\( P < .001 \)) and the interaction between factors (\( P = .020 \)) but was not influenced by the dentifrice F- concentration (\( P = .193 \)).

### Table 2: Mean ± SD Values for the \( \Delta E_{00} \), \( \Delta L' \), \( \Delta C' \), \( \Delta H' \), and \( \Delta T_{00} \) Variables at Each F- Concentration in the Dentifrices and After Tooth Brushing

<table>
<thead>
<tr>
<th>Variables</th>
<th>F- concentration in dentifrice</th>
<th>20,000</th>
<th>40,000</th>
<th>60,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta E_{00} )</td>
<td>0</td>
<td>1.4 (0.9)\textsuperscript{Aa}</td>
<td>1.4 (0.1)\textsuperscript{Aa}</td>
<td>1.5 (0.1)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>1,100</td>
<td>1.1 (0.1)\textsuperscript{Ab}</td>
<td>1.3 (0.1)\textsuperscript{Aa}</td>
<td>0.6 (0.2)\textsuperscript{Ab}</td>
</tr>
<tr>
<td></td>
<td>5,000</td>
<td>0.8 (0.2)\textsuperscript{Aa}</td>
<td>0.6 (0.1)\textsuperscript{Aa}</td>
<td>0.8 (0.1)\textsuperscript{Aa}</td>
</tr>
<tr>
<td>( \Delta L' )</td>
<td>0</td>
<td>–0.1 (1.3)\textsuperscript{Aa}</td>
<td>–0.8 (0.2)\textsuperscript{Aa}</td>
<td>–0.9 (0.2)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>1,100</td>
<td>–1.3 (0.3)\textsuperscript{Ca}</td>
<td>–1.4 (0.2)\textsuperscript{Ca}</td>
<td>–0.8 (0.3)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>5,000</td>
<td>1.2 (0.4)\textsuperscript{Aa}</td>
<td>0.6 (0.1)\textsuperscript{Aa}</td>
<td>–0.8 (0.3)\textsuperscript{Aa}</td>
</tr>
<tr>
<td>( \Delta C' )</td>
<td>0</td>
<td>1.6 (1.2)\textsuperscript{Aa}</td>
<td>1.8 (0.1)\textsuperscript{Aa}</td>
<td>1.9 (0.1)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>1,100</td>
<td>1.1 (0.1)\textsuperscript{Aab}</td>
<td>–1.2 (0.2)\textsuperscript{Ca}</td>
<td>0.5 (0.2)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>5,000</td>
<td>0.2 (0.5)\textsuperscript{Aa}</td>
<td>0.5 (0.5)\textsuperscript{Aa}</td>
<td>0.5 (0.5)\textsuperscript{Aa}</td>
</tr>
<tr>
<td>( \Delta H' )</td>
<td>0</td>
<td>–0.4 (0.5)\textsuperscript{Ca}</td>
<td>0.2 (0.3)\textsuperscript{Aa}</td>
<td>0.3 (0.3)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>1,100</td>
<td>0.2 (0.1)\textsuperscript{Aa}</td>
<td>–0.4 (0.2)\textsuperscript{Ab}</td>
<td>0.2 (0.1)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>5,000</td>
<td>–0.1 (0.2)\textsuperscript{Ab}</td>
<td>–0.1 (0.1)\textsuperscript{Aa}</td>
<td>0.5 (0.1)\textsuperscript{Aa}</td>
</tr>
<tr>
<td>( \Delta T_{00} )</td>
<td>0</td>
<td>0.9 (0.5)\textsuperscript{Aa}</td>
<td>0.3 (0.2)\textsuperscript{Aa}</td>
<td>0.2 (0.3)\textsuperscript{Aa}</td>
</tr>
<tr>
<td></td>
<td>1,100</td>
<td>–0.5 (0.2)\textsuperscript{Ba}</td>
<td>–0.3 (0.2)\textsuperscript{Ba}</td>
<td>–0.2 (0.3)\textsuperscript{Aa}</td>
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<tr>
<td></td>
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<td>0.3 (0.3)\textsuperscript{Aa}</td>
<td>0.3 (0.5)\textsuperscript{Aa}</td>
<td>–0.5 (0.3)\textsuperscript{Ba}</td>
</tr>
</tbody>
</table>

\( \Delta E_{00} \) = color difference; \( \Delta L' \) = luminosity difference; \( \Delta C' \) = chroma difference; \( \Delta H' \) = hue difference; \( \Delta T_{00} \) = translucency difference; F- = fluoride.

Different superscript uppercase letters compare dentifrices for the same number of tooth brushing cycles (within a column), and different superscript lowercase letters compare no. of tooth brushing cycles for the same dentifrice (within a row) (\( P < .05 \)). The data were submitted to two-way ANOVA, followed by Tukey HSD test.
In some samples, spherical pores and grooves were observed in the microscopic analyses in different directions and dimensions (Fig 3). However, in general, tooth brushing did not appear to have much of an effect on the surface morphology of the glazed ceramic.

DISCUSSION

Although the addition of NaF in dentifrices aids in preventing and reducing caries, some adverse effects, such as an increase of roughness and decrease of gloss, have been reported when some ceramic restorations were exposed to F-. However, most of these studies evaluated NaF solutions used in topical applications rather than in dentifrices. The present study tested dentifrices with different F- concentrations, as most commercial toothpastes range from 1,000 to 1,450 µg/g, while others contain 5,000 µg/g (eg, Duraphat 5000 ppm F/Prevident 5000 plus, Colgate-Palmolive). The combined effects of F- in dentifrices and tooth brushing could affect the glazed ceramic surface, and this effect could potentially be even greater when dentifrice with a higher F- concentration is used.5-8 However, the null hypothesis of the present study was rejected, since the higher F- concentration (5,000 µg/g) in dentifrices did not produce more of a change in color, translucency, gloss, roughness, or microstructure of the glazed CAD/CAM ceramic used in the present study.

The L* parameter values obtained in this study were very high (almost 100), which indicates high luminosity, and any reduction due to tooth brushing with the dentifrice was very low (approximately only 1.0%). The previous studies reported lower values of L* for glazed ceramics: 72.3–74.8 and 61.5–62.8. However, these studies evaluated different types of ceramics (feldspathic and leucite-reinforced ceramics) with different spectrophotometers, which can explain the different results obtained compared to the present study. The ∆L' changes in the glazed ceramic were lower than the previously reported 50% acceptability threshold. Thus, the ∆L' of a glazed ceramic after 60,000 tooth brushing cycles, regardless of the F- concentration in dentifrice, was considered to be clinically acceptable.

The variable a* also decreased after tooth brushing, while b* tended to increase. This means that the surface became more green and yellow in color. These variables are critical when calculating the ∆C*. Although lower than the 50% acceptability threshold, the ∆C* for the dentifrice without F- was higher than for the samples brushed for 60,000 cycles with both fluoridated kinds of toothpaste. The ∆C* was mainly influenced by coordinate b*, as it showed a more significant variation than the a* parameter. Thus, the samples became more yellow in color than green. Also, as ∆H' values were positive, tooth brushing for 60,000 cycles decreased the hue of the glazed surface. However, the ∆H' was also lower.
than the 50% acceptability threshold\textsuperscript{32} for all of the dentifrices. As the glaze layer is usually translucent, the progressive removal of glaze from the ceramic surface by tooth brushing increases the influence of the monolithic block on the overall shade of the restoration.\textsuperscript{19,33}

In this study, three different F\textsuperscript{-} concentrations were evaluated. After 60,000 tooth brushing cycles, the $\Delta E_{00}$ of the nonfluoridated dentifrice was higher than both fluoridated versions. $\Delta E_{00}$ was influenced mainly by $\Delta C'$, as both variables showed similar statistical differences among the three versions of the dentifrice and the number of cycles, especially after 60,000 cycles. Also, it can be inferred that the alteration observed in the $b^*$ coordinate after 60,000 cycles for the dentifrice without F\textsuperscript{-} left
the glazed surface slightly more yellow. This influenced the ΔC′, and consequently the ΔE<sub>00</sub>.

Only the dentifrice without F<sup>-</sup> had a ΔE<sub>00</sub> higher than the perceptibility threshold (PT = 0.81) for dental ceramics<sup>34</sup> after 60,000 tooth brushing cycles. In contrast, all dentifrices showed ΔE<sub>00</sub> values that were less than the acceptability threshold (AT = 1.77) for dental ceramics<sup>34</sup>. Thus, the ΔE<sub>00</sub> after 60,000 tooth brushing cycles<sup>15,22</sup> of a glazed ceramic was considered clinically acceptable after using any of the three dentifrices, and the use of F<sup>-</sup> in dentifrices, even in high concentrations such as 5,000 μg/g, results in clinically imperceptible ΔE<sub>00</sub><sup>34</sup> even after 60,000 tooth brushing cycles. Although some previous studies evaluated the effect of tooth brushing in the ΔE of glazed ceramics<sup>30,31,35–37</sup> the few that used the CIEDE2000 formula<sup>37,38</sup> obtained similar results to the present study.

Translucency is a significant clinical parameter in indirect esthetic restorations, as any changes, especially in restorations used to block darkened substrates, may adversely affect esthetics. The TP<sub>00</sub>, calculated using the CIEDE2000 (1:1:1) formula, compares L*, a*, and b* coordinates obtained over a white or black background. The perceptibility (TP: 0.62) and acceptability (TAT: 2.62) thresholds for the ΔTP<sub>00</sub> in dental restorative materials have previously been established.<sup>39</sup> In the present study, the ΔTP<sub>00</sub> was less than the TAT and TPT<sup>39</sup> irrespective of the dentifrice used and the number of tooth brushing cycles, which means that the changes measured are not clinically perceptible.

Another fundamental optical property that can be influenced by tooth brushing is GS, which also affects a restoration’s esthetics. The quality of a resin-based composite gloss can be classified as acceptable (60 to 70 GU), good (70 to 80 GU), or excellent (> 80 GU).<sup>40</sup> Although this study evaluated glazed ceramics, if this classification is considered, the glazed ceramics had excellent gloss at baseline and good gloss retention after 40,000 cycles. After 60,000 cycles, the gloss finish ranged from acceptable to good. Since the human eye cannot distinguish the differences in GS above 70 GU<sup>41</sup> the differences in GS obtained from baseline up to 40,000 tooth brushing cycles<sup>22</sup> would be clinically imperceptible. At 60,000 tooth brushing cycles, only the 1,100 μg/g F<sup>-</sup> dentifrice (70.6 GU) had a GS higher than 70 GU; however, it was not statistically different from the other dentifrices (without F: 68.3 GU; 5,000 μg/g F: 66.4 GU). Therefore, it was concluded that after 60,000 tooth brushing cycles<sup>15,22</sup> the glazed ceramic still had clinically acceptable GS values, irrespective of the F<sup>-</sup> concentration in the dentifrice.

Although a few studies have evaluated the effect of tooth brushing on the GS of ceramics<sup>38,42,43</sup> different ceramics and experimental designs were evaluated in these studies. The outcomes of these studies were not conclusive because, for some ceramics<sup>38,43</sup> the GS decreased after tooth brushing or did not alter for others.<sup>42,44</sup> Also, some of these studies did not apply a glaze to the ceramic surface<sup>42,43</sup> and in one study, the ceramics were stained (two coats) and glazed (spray application).<sup>38</sup> Thus, the present study provides clinically relevant information concerning the effect of tooth brushing on the GS of glazed CAD/CAM ceramics.

Several studies have evaluated the effect of tooth brushing on the roughness of glazed ceramics.<sup>30,31,35–37,44–46</sup> Different outcomes were obtained in such studies; one reported that tooth brushing decreased roughness,<sup>31</sup> while several reported it increased roughness.<sup>30,35,46</sup> Some reported no change<sup>36,37,44,45</sup> in the Sa of the glazed ceramics. Therefore, the influence of tooth brushing on the Sa of glazed ceramic seems to be dependent on both technique and material. However, very few studies have evaluated contemporary materials, such as CAD/CAM ceramics.<sup>35,37</sup> In the present study, the Sa did not have a very predictable behavior because it tended to increase after 20,000 cycles, then decreased after 40,000, and increased again after 60,000. Despite the variations of Sa, all results were clinically acceptable and below the roughness threshold of 0.2 μm.<sup>47,48</sup> Thus, the different Sa among the experimental groups would not result in any difference in terms of plaque accumulation and/or periodontal inflammation<sup>47,48</sup> The differences in Sa were also all well below the 0.5-μm threshold that the tongue can detect.<sup>49</sup>

The F<sup>-</sup> concentration in dentifrice had no significant influence on the Sa after 60,000 tooth brushing cycles. The F<sup>-</sup> present in the dentifrice is in the ionic form obtained from the NaF salt at an alkaline pH. This is different from the solution used for a topical application, where F<sup>-</sup> is sometimes found in an acidulated phosphate fluoride (APF) formulation.<sup>17,18</sup> It is known that when APF is applied for 5 minutes over a glass-ceramic, it can etch the surface due to a chemical reaction of the F<sup>-</sup> with the silicon.<sup>17,18</sup> The alkaline pH found in dentifrices potentially inhibits the F<sup>-</sup> reaction with silicon, thus explaining why no significant increase in Sa was found between the nonfluoridated and the high-fluoride–concentration dentifrices.<sup>18,27–29</sup>

A brush was used to apply the glaze to the ceramic surface manually. The brushstrokes produced grooves in different dimensions and different directions on the ceramic surfaces (Fig 3). To evaluate the micromorphology of these surfaces, the authors chose optical microscopy rather than scanning electron microscopy (SEM) because the grooves could not be identified when using SEM analyses at high magnification for some glazed ceramics.<sup>50,51</sup> It could be hypothesized that these grooves would interfere in the Sa values; however, due to their large size, grooves on the glazed surfaces were not observed when using the confocal laser microscope.
The micrographs obtained with an optical microscope showed that there were spherical pores in the glazed surface of most groups. These pores might be incorporated when the glaze is manually applied to the ceramic surface. The increase in number and size of the pores as the number of tooth brushing cycles increases might have altered the light reflection on the glazed surface. This can help to explain the GS reduction. Despite grooves and pores on the glazed surface, the glaze application technique using a brush for lithium disilicate ceramic is still recommended because it produces a surface with lower roughness compared to using a spray.11,50

This study evaluated only the effect of tooth brushing and the F- concentration in dentifrice on the glaze layer. Some clinical conditions were not reproduced, such as different brands of commercial dentifrices, the pH and temperature variation, presence of oral biofilm, and occlusal loading. Also, other ceramics, different brands of glaze, and different techniques used to apply the glaze may produce different outcomes. These additional factors can greatly influence glaze degradation and are important topics for future research.

CONCLUSIONS

Based on the results of this in vitro study, it was concluded that 60,000 tooth brushing cycles on a glazed IPS e.max CAD/CAM ceramic surface with fluoridated dentifrices in concentrations up to 5,000 µg/g resulted in minimal and clinically acceptable changes in the ∆E00, ∆T00, GS, and Sa.

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