Original Article

In vitro enamel surface roughness analysis of 4 methods for removal of remaining orthodontic adhesive after bracket debonding

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ABSTRACT

Objectives: To perform an in vitro qualitative and quantitative evaluation of the enamel surface (by scanning electronic microscopy [SEM] and measuring polishing time and roughness analysis, respectively) among four methods to remove remaining orthodontic adhesive after bracket debonding.

Materials and Methods: Forty-one human premolars were randomly divided into four groups ($n = 10$) according to the adhesive remnant removal method and one tooth was used as control: Group 1 (G1): Enhance (Dentsply, Milford, USA); Group 2 (G2): Fiberglass (TDV, Pomerode, Brazil); Group 3 (G3): DU10CA-Ortho (Dian Fong Industrial, Shenzhen, China); Group 4 (G4): Sof-Lex Pop-On (3M ESPE, Seefeld, Germany). Roughness was measured before bonding and after complete removal of the remaining adhesive (Ra2). SEM analysis was performed on one sample of each group after adhesive removal and polishing. The time required for adhesive remnant removal and polishing was measured in all groups. Analysis of variance and Tukey post hoc for pairwise comparison was applied to compare polishing times among groups and analysis of covariance was used to compare Ra2 means.

Results: Comparison between groups show that G4 presented the lowest Ra2 mean (0.43 μm)[c] followed by G3 (0.71 μm)[ac], G1 (1.06 μm)[ab], and G2 (1.21 μm)[b] - different letters, statistically different at $P \leq 0.05$. In addition, Fiberglass was more time-consuming for adhesive remnant removal than other methods ($P \leq .05$). SEM analysis showed that some enamel damage occurred for all methods.

Conclusions: All methods were able to remove the remaining adhesive and polish the enamel. The DU10CA-Ortho and Sof-Lex methods promoted better polishing of the enamel surface and exhibited a similar time-consuming process. (*Angle Orthod.* 2023;93:213–221.)

KEY WORDS: Enamel; Orthodontic adhesive; Orthodontic brackets; Orthodontic adhesive removal

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INTRODUCTION

With the advent of adhesive dentistry advocated by Buonocore,[1] the technique of direct bonding of orthodontic appliances became feasible, having many advantages: less discomfort, simplicity, technical control, more pleasant esthetics, better cleaning, and more. Adhesive-dependent materials have physicochemical and mechanical characteristics that promote intimate contact of the adherent material to the enamel surface. Then, it may be difficult to remove appliances after the completion of orthodontic treatment without causing damage to the enamel surface.[2,3] Thus, the ideal debonding method should remove the bracket and all the remaining adhesive, causing minimal changes to the teeth.

Several studies recommend different methods for the removal of bonding resin remnants.[2–8] Among them are manual removal methods with curettes or band-removing pliers,[5,9] tungsten carbide burs of 8 to 30 blades mounted in low- or high-speed handpieces,[6–8,10–12] polishing and finishing abrasive discs,[5,7,13,14] pumice or zirconia paste,[15] polishing tips,[16] ultrasonic devices,[6,17] hydroabrasion,[18] and lasers.[19] Some more conservative polishers have been promoted, such as polishers with diamond particles,[3,20] aluminum oxide polishers,[3] and fiberglass tips reinforced with zirconium silicate.[2,21] All methods for removal of the resin residue produce, to a greater or lesser extent, undesirable changes in the tooth surface, such as grooves,[2,22] cracks, depressions, and enamel loss.[2] Additionally, many, although safe, are excessively time-consuming for use in clinical practice.[2,8,13,16,20]

Some polishing materials are traditional, were on the market for a long time, and have been extensively tested for resin removal and enamel polishing, while others were introduced more recently and were less well-tested. Less-well-known manufacturers claim excellent results at more affordable prices than reputable companies. Additionally, despite being a previously researched topic, there is no consensus or established protocol for removal of the remaining resin. It is known that polishing materials usually take a long time to remove thicker layers of resin, while burs usually remove it quickly but scratch and damage the enamel more often. Therefore, proposals for new protocols with or without combinations of materials may implement better results and time savings for clinical practice.

Seeking to propose a protocol for daily practice, using materials that are easily accessible, the aim of this study was to perform an in vitro qualitative and quantitative comparison of the effects on the enamel surface among four different methods to remove the remaining resin after bracket debonding. Additionally, the association between surface roughness and the time spent to remove excess adhesive and resin was evaluated.

MATERIALS AND METHODS

The present study was approved by the Institutional Review Board of Lutheran Higher Institute and Educational Center Bom Jesus/IELUSC, Joinville, Brazil.

As a result of preliminary pilot work for this study, the sample size was calculated (in GPower 3.1.9.4 software) and a required minimum sample size for 80% power was $n = 36$ ($n = 9$ per group). Thus, 41 human premolars from the biorepository of the Department of Dentistry, Regional University of Joinville were used. The teeth had no caries, fractures, or coronal cracks. The roots were sectioned and the crowns were included and fixed in silicone molds with epoxy resin.

All specimens were cleaned with pumice powder mixture (MAQUIRA, extrafine, Maringá-PR, Brazil) using a rubber cup (Microdont, São Paulo-SP, Brazil) in low rotation for 10 seconds. Four perforations of approximately 0.5-mm depth were drilled with a 1/2 spherical bur (KG Sorensen, Cotia, SP, Brazil) to delimit the bonding area (Figure 1), and areas for the roughness-metric analysis (initial and final), and subsequent evaluation by scanning electron microscopy (SEM) (Zeiss DSM-940A, Oberkochen, Germany).

Forty specimens were randomly assigned to four groups ($n = 10$) according to the adhesive remnant removal method used, and one tooth was used as a control for qualitative analysis ($n = 1$). Before bonding brackets, all samples underwent initial roughness analysis.

The enamel was etched with 37% phosphoric acid (Alpha Etch, DFL, Rio de Janeiro, Brazil) for 30 seconds, then washed with water spray for 20 seconds, and dried for 20 seconds with oil-free compressed air. Premolar standard edgewise brackets (0.022×0.030-in.; Morelli, Sorocaba, Brazil), were bonded with the AlphaBond Light (DFL, Rio de Janeiro, Brazil) adhesive system and light-cured (PolyWireless, KAVO, Joinville, Brazil) for 10 seconds on each side (40 seconds total).

After bonding, all samples were stored for 7 days at 37°C in distilled water. The brackets were removed with straight pliers (346R, Zatty, Iacanga, Brazil), pressing the bracket parallel to the slot axis. During removal procedures, three specimens exhibited enamel fracture and were excluded.

In all groups, remaining adhesive removal and polishing were performed by a single operator. The thick excess of adhesive was removed with a 24-blade rounded-end, truncated cone carbide bur (CF375R-Orthometric, Marília, Brazil) with high speed for 20 seconds. The aim of this step was to partially remove the adhesive, leaving only a thin layer. After that, the resin remnant was removed with one of the four methods described in Table 1 and Figure 2. Resin removal was considered complete when the enamel surface was smooth and free of composite to the naked eye under the light of an artificial lamp.[23] The time required for removal of the fine adhesive remnant and polishing (PoTi variable) in each sample was measured by stopwatch.

Roughness Analysis

The enamel surface roughness analysis was performed in a rugosimeter (Form Talysurf Series 2, Taylor Hobson, Illinois, USA) operated with a total

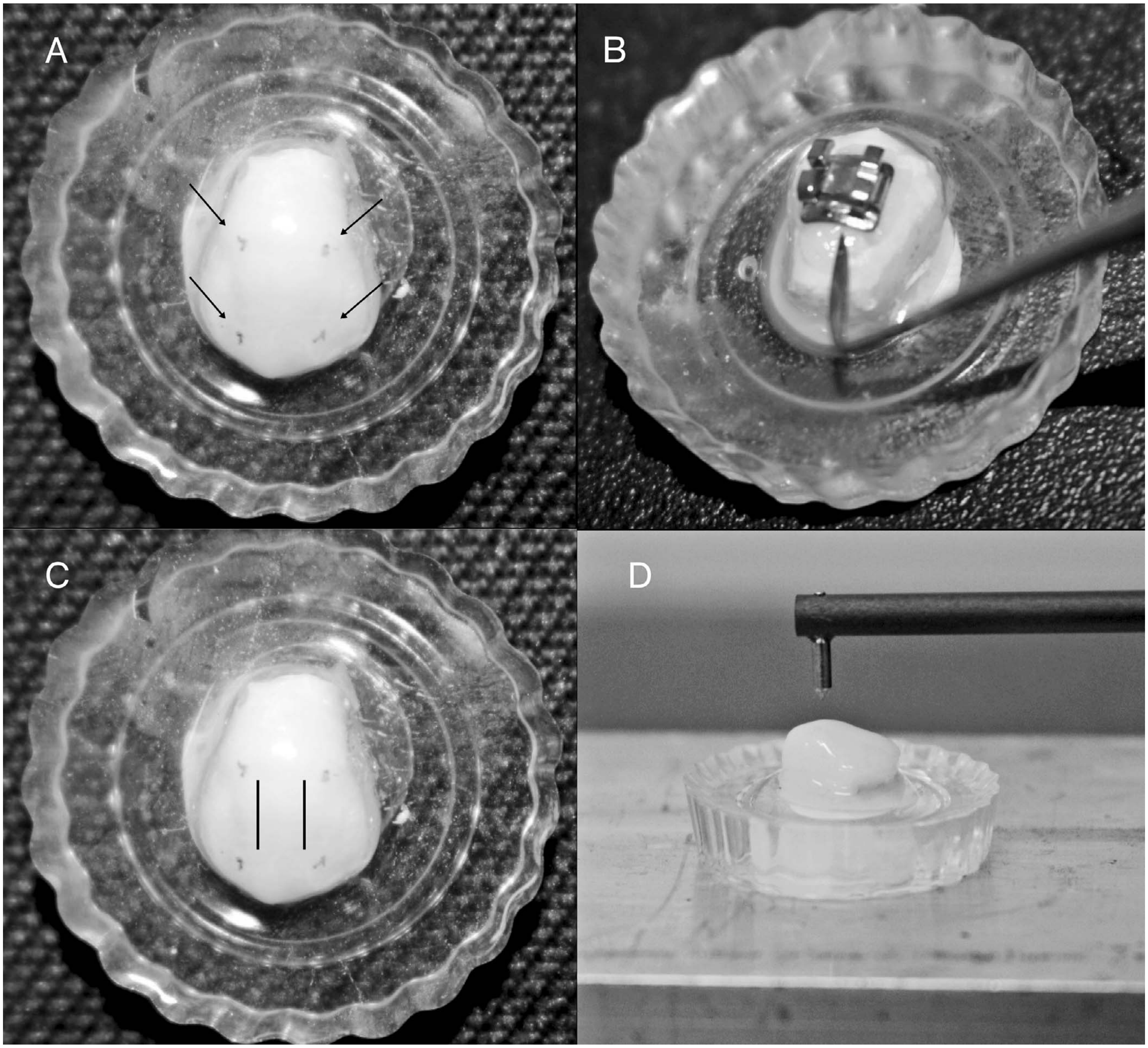

Figure 1. Delimited bonding area (A); bonding bracket inside delimited area (B); locations of roughness measurement (C); positioning the specimen in the measuring device (D).

length (Lumen or Lm) of 1.6 mm and a *cut-off* value of 0.8 mm.

The average roughness (Ra) in micrometers (μm), was measured in the bracket bonding area, in two different locations (Figure 1); therefore, two values were obtained for each specimen of average roughness (Ra). Roughness was measured before bonding and after complete removal of the remaining resin; therefore, there were two values of initial mean roughness (Ra1) and two values of final mean roughness (Ra2) for each specimen. The arithmetic mean of the values for initial and final Ra was calculated.

Evaluation in Scanning Electron Microscope—SEM

Qualitative analysis after removal of the remaining resin and polishing was performed using SEM (Zeiss DSM-940A, Oberkochen, Germany). The specimens selected for SEM evaluation were those that exhibited Ra2 similar to the average roughness of the group, plus the control specimen (C0). The selected specimens were stored in distilled water until the time of preparation for analysis.

The buccal surfaces were previously prepared with gold/palladium alloy with a thickness of approximately

Table 1. Materials Used in the Removal of Remnant Adhesive by Group

Group	Material	Method
Group 1 (G1):	Enhance finishing system (Dentsply, Milford, USA)	at low speed in intermittent use and with light to moderate pressure
Group 2 (G2):	Fiberglass (TDV, Pomerode, Brazil)	at low speed, under light pressure and with air cooling
Group 3 (G3):	DU10CA - Ortho polishers (Dian Fong Industrial, Shenzhen, China)	applied in sequence (coarse, medium, and fine abrasive grades), followed by the high-gloss tip P22U3K - Ortho (Dian Fong Industrial, Shenzhen, China), at low speed. The entire adhesive remnant was removed with coarse grade, as manufacturer instructions, and the medium, fine, and high gloss in sequence were used for final polishing.
Group 4 (G4):	Group 4: Sof-Lex Pop-On discs (3M ESPE, Seefeld, Germany)	applied in sequence (coarse, medium, fine, and superfine abrasive grades) at low speed with light pressure. The coarse grade was applied until the enamel surface was visualized, not exceeding 15 seconds.

3 μm. Photomicrographs were obtained at 100×, 200×, 500×, and 1000× magnification.

Statistical Analysis

Roughness and polishing time data were statistically analyzed using R Package Software version 3.6.1. To compare the PoTi means among groups, analysis of variance (ANOVA) was used, followed by Tukey post hoc for pairwise comparison. To compare the means of Ra2 among the groups, analysis of covariance (ANCOVA) was used, considering Ra2 the dependent variable and Ra1 and PoTi as covariates. These variables were inserted in the model to adjust for possible influence of these on the values of Ra2. Subsequently, Tukey post hoc was applied for pairwise comparison. The normality of the residuals was confirmed by the Shapiro-Wilk test, the homogeneity of variances by the Breusch-Pagan test, and evaluation of influential points in the model by Cook's distance.

The sensitivity test for the sample used was performed to calculate the effect size with GPower 3.1.9.4 software using alpha value (0.05), test power (80%), sample size (37), and number of groups (four). The effect size of 0.58 was obtained.

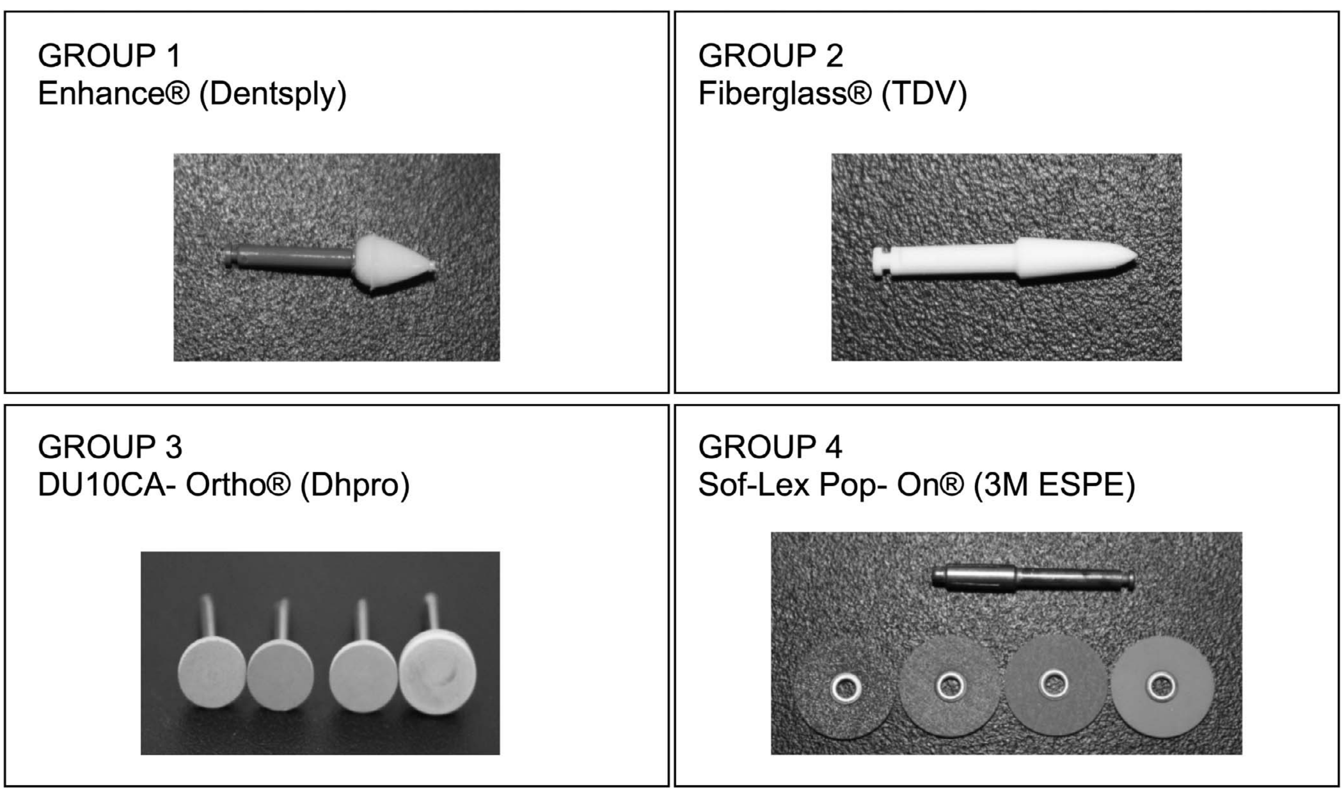

Figure 2. Materials used in the removal of remnant adhesive divided by groups.

Table 2. Comparison of the Mean Polishing Time (PoTi) (Minutes), Initial Roughness (Ra1), and Final Roughness (Ra2) Between Groups (micrometers, μm)*

	PoTi Means (min ± SD)	Ra1 Means (μm ± SD)	Ra2 Means (μm ± SD)
G1 Enhance	1.00^{I} (0.19)	1.58^{A} (0.90)	1.06^{ab} (0.43)
G2 Fiberglass	1.47^{II} (0.31)	1.75^{A} (1.56)	1.21^{b} (0.45)
G3 DhPro	1.10^{I} (0.18)	1.95^{A} (1.15)	0.71^{ac} (0.18)
G4 Sof-Lex	1.01^{I} (0.09)	1.58^{A} (0.72)	0.43^{c} (0.25)

* Means followed by different roman numbers, statistically different from each other at 5% significance level ($P \leq .05$); Means followed by different letters, statistically different from each other at 5% significance level ($P \leq .05$): uppercase letters for variable Ra1, lowercase letters for variable Ra2 comparisons.

RESULTS

ANOVA test was applied for PoTi means comparison and the normality test did not confirm residual normal distribution. Therefore, *BOX-COX* transformation was performed. ANOVA and the normality test were applied to the transformed variable PoTi and a significant difference was observed among groups ($P \leq .05$) and there was normality of residuals ($P > .05$), respectively. The variance homogeneity requirements were met. The model analysis showed no influential points. For pairwise analysis, Tukey post hoc test was applied. The effect size was 0.93, larger than the effect size calculated for the sample. The results show that G2 exhibited a mean time (1.47 min) significantly longer than all others groups (G1 = 1.00, G3 = 1.10, and G4 = 1.01 minutes) and no statistically significant difference was found among the others (Table 2 and Figure 3).

The ANCOVA model for Ra2 showed that covariates Ra1 and PoTi were not significant ($P > .05$) and that were no interactions between them. Thus, only Ra2 was used in the adjusted model and one-way ANOVA and Tukey post hoc were applied for group comparison. The normality distribution and homogeneity of variance of the residuals were confirmed and the model analysis showed no influential points. The calculated effect size for the test was 0.95, larger than that calculated for the sample. Group 4 presented the lowest Ra2 mean (0.43 μm) followed by G3 (0.71 μm), G1 (1.06 μm), and G2, the highest (1.21 μm); the individual differences and statistical results among the groups are presented in Table 2 and Figure 4.

The photomicrographs demonstrated that, for all the techniques tested, the resin residue was effectively removed. In the G1 specimen at 100× magnification, parallel scratches arranged in a regular manner across the enamel surface were observed. More pronounced scars were visualized at 200×, 500×, and 1000× magnification (Figure 5). The surface of the G2 specimen at 100× magnification, also showed soft scratches, but finer than the G1 specimen at the same magnification. The G2 specimen surface also showed fine parallel scratches arranged as intermittent lines throughout the area observed at 200×, 500×, and 1000× magnification (Figure 6), which were softer than those of the G1 specimen. The G3 specimen (Figure 7) had the smoothest surface, similar to the enamel of the control (Figure 8), although there were soft and parallel

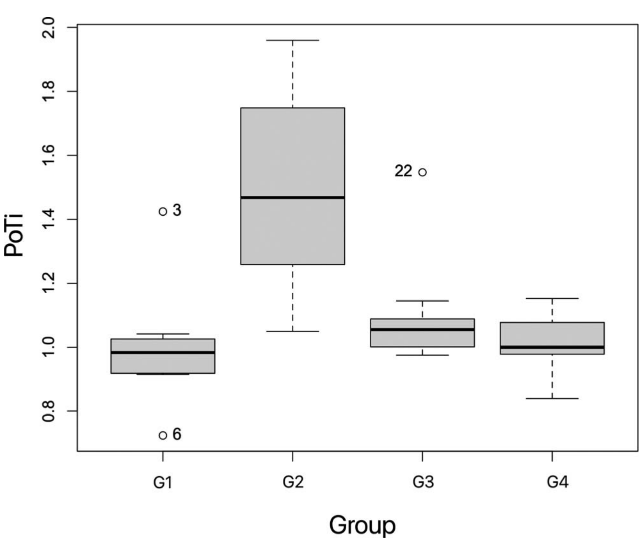

Figure 3. Boxplot. Results of polishing time (PoTi) among groups.

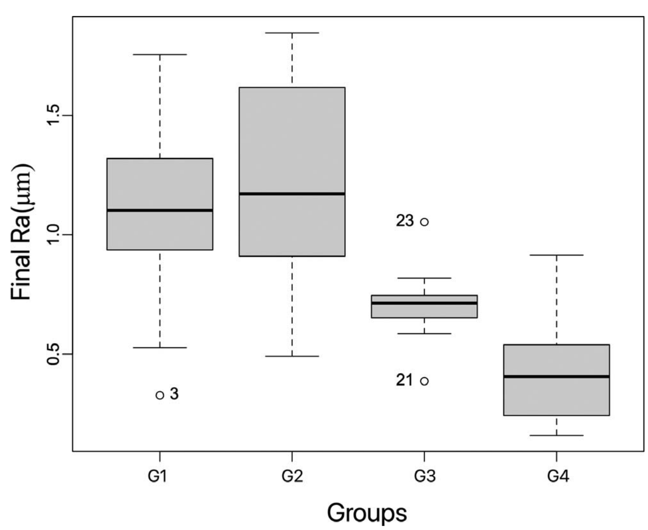

Figure 4. Boxplot. Comparison of final roughness (Ra2) among groups.

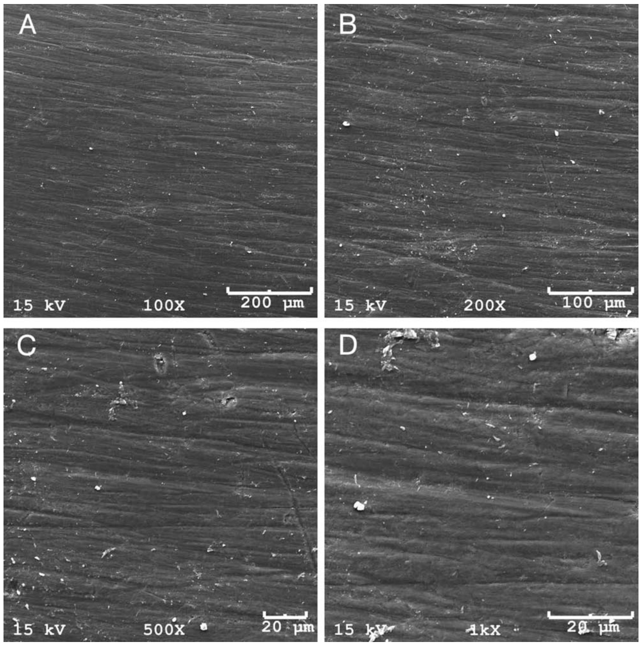

Figure 5. Evaluation in SEM. G1 (Enhance). Photomicrographs obtained at 100×(A); 200×(B); 500×(C); and 1000×(D) magnification.

scratches at 500× and 1000× magnification. The G4 specimen (Figure 9) showed few scratches at 100× magnification and irregular scratches at 200×, 500×, and 1000× magnification, which were more intense than the specimen from G3 at the same magnifications. Compared with the G1 specimen at 500× and 1000×

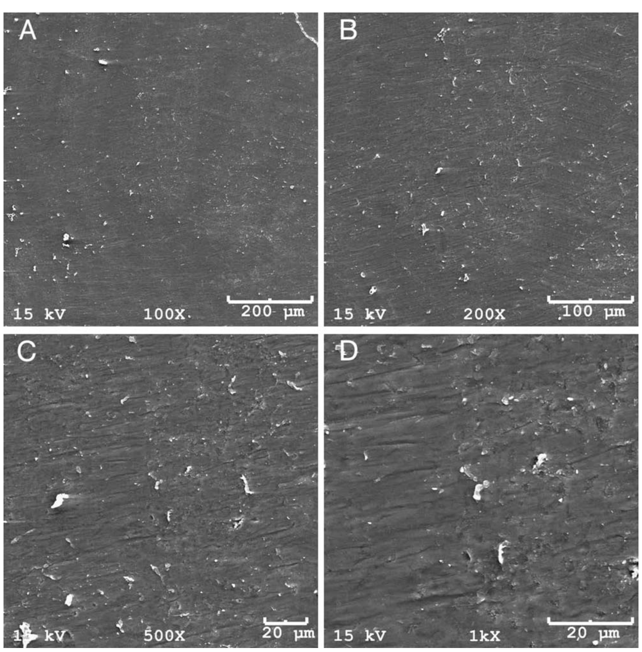

Figure 6. Evaluation in SEM. G2 (Fiberglass). Photomicrographs obtained at 100×(A); 200×(B); 500×(C); and 1000×(D) magnification.

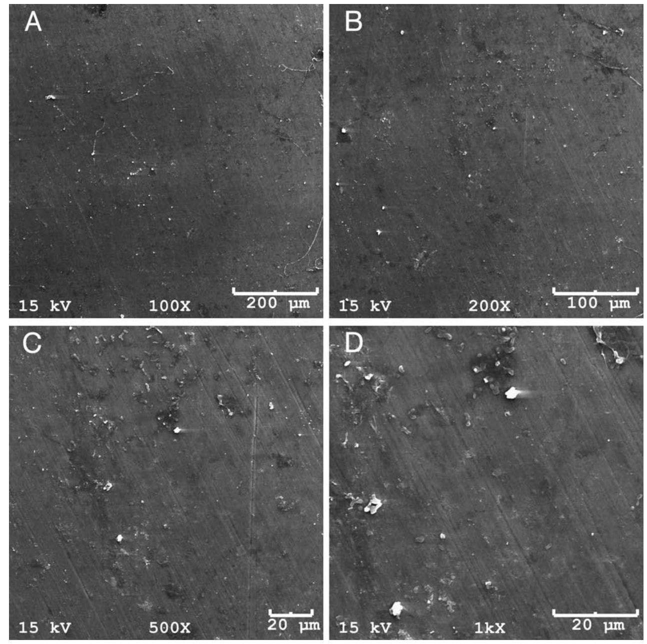

Figure 7. Evaluation in SEM. G3 (DU10CA-Ortho). Photomicrographs obtained at 100×(A); 200×(B); 500×(C); and 1000×(D) magnification.

magnification, G4 presented fewer and smooth scratches. Compared with G2 at 100× and 200× magnification, similar patterns for G4 and G2 were observed. When analyzed at 500× and 1000× magnification it was noted that G2 showed parallel scratches and G4 exhibited deeper and irregular scratches.

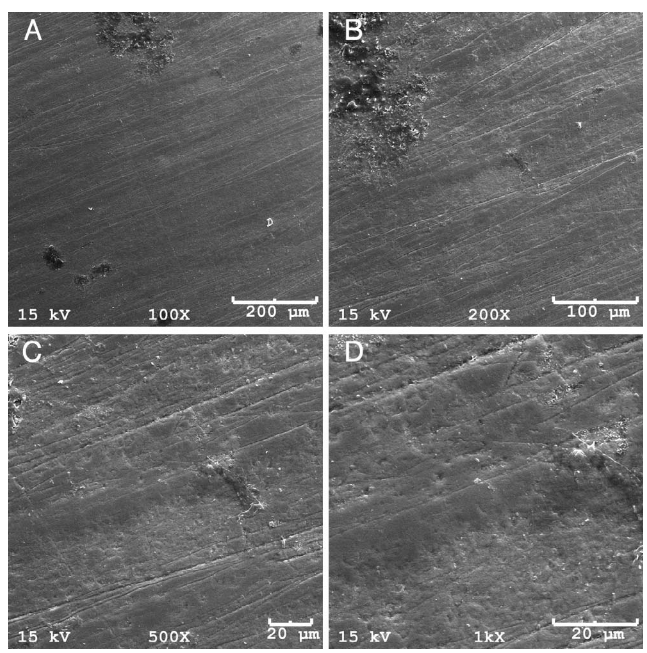

Figure 8. Evaluation in SEM. Control. Photomicrographs obtained at 100×(A); 200×(B); 500×(C); and 1000×(D) magnification.

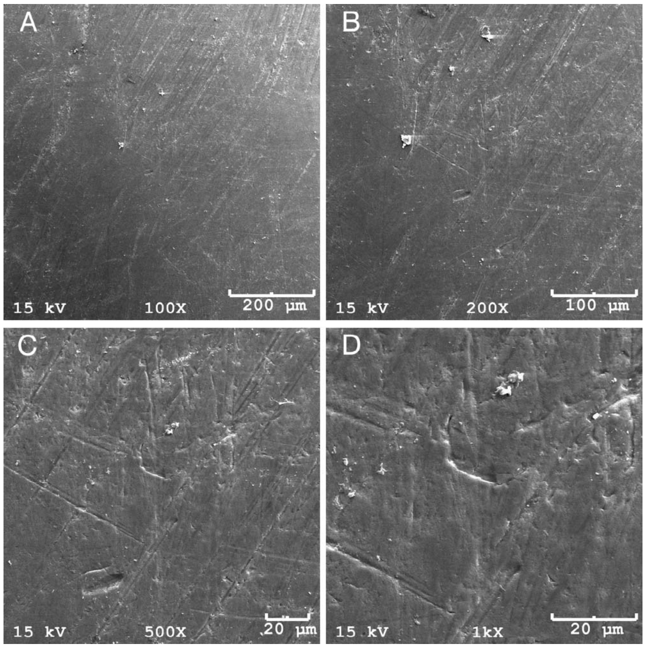

Figure 9. Evaluation in SEM. G4 (Sof-Lex Pop-On). Photomicrographs obtained at 100×(A); 200×(B); 500×(C); and 1000×(D) magnification.

DISCUSSION

The methodology used in this study for qualitative and quantitative enamel surface evaluation with SEM and roughness-metric analysis, respectively, has already been extensively tested for this purpose and demonstrated reliable and reproducible results.[3,8,14,16,17,20,23–25]

All methods evaluated in this study demonstrated success in removing residual resin. All methods tested caused enamel alterations to a greater or lesser degree. The lowest means of final roughness were observed for G3 and G4; this result might possibly have been because these groups had more polishers and steps than the others. G1 and G2 were single-step methods, suggesting that more polishing steps promoted greater wear of the tooth surface, leaving it more polished and, therefore, reducing Ra2. In a similar study, Can-Karabulut et al.[21] observed that Sof-Lex discs showed lower final Ra values than the fiberglass tip. Sugsompian et al.[24] also observed that Sof-Lex discs (and sandblaster groups) showed significantly less rough enamel surfaces than other groups. Cesur et al.,[26] in a micro-computed tomography analysis after bracket debonding, found that the use of composite burs and Sof-Lex discs in sequence could help minimize enamel damage.

Analyzing the polishing time, the fiberglass tip method was significantly slower, though this was a single-step method and, for all groups with more than one step, the time spent in changing tips was included in the calculation. Ruiz et al.,[27] in a similar study, recommended the use of the fiberglass tip, though it was slow. Karan et al.[2] also observed that the time spent for the removal of the resin remnant with the fiberglass tip was significantly greater than for the tungsten carbide bur. Sigilião et al.[20] found that DU10CA-Ortho points showed polishing times similar to the other faster methods tested, and Vidor et al.[16] found similar results for polishing times with Enhance. Zarrinia et al.[7] and Eminkahyagil et al.[23] showed that the method using Sof-Lex was slower than the others but, in both studies, the entire disc sequence was not used, which may have slowed down the remnant removal. Additionally, it was found that the polishing time had no influence on the final roughness values as shown by the covariance analysis used.

Comparing the photomicrographs between the control and the test groups, the change in dental enamel topography at the expense of surface removal may be observed. In G1, regular striations were observed after the procedure which, if compared to the micrographs of the control, increased the number of irregularities seen in the enamel topography without treatment. Groups G2 and G3 also exhibited regular grooves, although not as deep as in G1 and, when compared to the control, also exhibited a change in surface topography; they were more polished than the control, and consequently lost enamel. G4 showed striations with irregular orientation, confirming the enamel surface changes when compared with the control and similar to results observed in studies of Sigilião et al.,[20] Cardoso et al.,[28] and Sugsompian et al.[24]

The photomicrographs show that G2 at 500× and 1000× magnifications showed more pronounced scar regions than G3 at the same magnifications. Differently, according to Sigilião et al.,[20] the polisher DU10CA-Ortho promoted more marked and deeper scratches. However, the present study used the full sequence of polishers as suggested by the manufacturer, while the previous study[20] used only one polisher. Similar performance was observed for G4 when compared to G1 and G2 on SEM analyses. G1 showed regions of deep scars at 200×, 500×, and 1000× magnifications. G2 showed deep scratches at 500× and 1000× magnifications, while G4 showed slight scratches at the same magnifications. Similar results were observed by Soares-Tenório et al.,[25] in which the tungsten carbide and fiberglass burs resulted in a similar pattern, showing an irregular enamel surface and scratches in every direction on SEM evaluation. According to Vidor et al.,[16] the method that exhibited the least enamel scratches was Enhance, in contrast to photomicrographic observations in the present study, in which G1 was the group that exhibited the greatest degree of scratches. Additionally, on visual inspection, G1 showed the worst brightness, followed by G2.

Vidor et al.[16] showed that the Sof-Lex discs caused the greatest damage to the enamel surface, the opposite of the findings of the present study. It is possible that this difference was due to the fact that the time of application of the coarse-grained disc was not limited in that study as it was in the present study (maximum of 15 seconds), therefore causing deeper grooves on the enamel surface. In addition, bovine teeth were used in that study, which may limit the comparison between results. Additionally, according to other studies,[4,28] the Sof-Lex discs promoted greater surface smoothness, more similar to the original enamel, despite the scratches.[15,29]

The DU10CA-Ortho method promoted better surface smoothness and most closely resembled the surface of the control in SEM analysis. On visual inspection, it was possible to observe that the group with the best gloss was G3 and that group G4 showed satisfactory gloss. Sigilião et al.[20] concluded that the DU10CA-Ortho tip promoted a decrease in the original enamel gloss. However, as mentioned earlier, that study used only one polisher while, in the present study, a sequence of polishers was used. Zachrisson et al.[15] concluded that Sof-Lex discs increased the brightness, but were not able to remove soft scratches.

Finally, it is important to consider that there were limitations in this in vitro study. Biological reactions, especially pulp reactions and effects from possible heating caused by rotating objects, could not be evaluated. Also, the time spent for polishing under actual clinical conditions may vary from those observed in the present study.

CONCLUSIONS

- Considering the in vitro study limitations, it can be stated that all the methods studied were able to remove the remaining adhesive and polish the enamel after the removal of orthodontic brackets. In addition, for all methods, some enamel damage occurred.
- The DU10CA-Ortho and Sof-Lex methods promoted better polishing of the enamel surface. The Fiberglass method had the worst enamel polishing performance and was the most time-consuming method among those tested.
- After bracket removal, it is recommended that a 24-blade rounded-end truncated cone carbide bur be used to eliminate the thick excess of adhesive and then that the resin remnant be removed with DU10CA-Ortho tips or Sof-Lex discs.

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