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Original Research Article

Enamel surface roughness analysis following bracket debonding using five different residual adhesive removal system: An in vitro study

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Abstract

Objective: This in vitro study aimed to qualitatively and quantitatively evaluate the enamel surface after removal of residual orthodontic adhesive following bracket debonding. Surface evaluation was performed using scanning electron microscopy (SEM), while polishing time and surface roughness were assessed to compare the efficacy of four different adhesive removal techniques.

Materials and Methods: Fifty-one extracted human premolars were randomly allocated into five experimental groups (n = 10 each), with one tooth serving as a control. The adhesive removal methods included: G1 – Tungsten Carbide Burs, G2 – Enhance Polishing Points, G3 – DU10CA-Ortho Disc, G4 – Fiberglass Bur and G5 – Sof-Lex Pop-On Disc. After initial bondinand complete adhesive removal, surface roughness (Ra2) was measured. One sample per group underwent SEM analysis. Time required for adhesive removal and polishing was recorded. Polishing times were analyzed using ANOVA followed by Tukey's post hoc test, while Ra2 values were compared using ANCOVA.

Results: Group 5 showed the lowest mean surface roughness (0.43 µm), followed by Groups 3 (0.71 µm), 4 (1.06 µm), 2 (1.21 µm), and 1 (2.1 µm), with statistically significant differences among groups ($P \leq 0.001$). The fiberglass bur required significantly more time for adhesive removal than the other methods ($P \leq 0.001$). SEM analysis revealed that all methods caused varying degrees of enamel surface damage.

Conclusion: All methods effectively removed adhesive remnants. DU10CA-Ortho and Sof-Lex discs provided smoother enamel surfaces with comparable time efficiency.

Keywords: Enamel, Orthodontic adhesive, Bracket removal, Adhesive remnant removal

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1. Introduction

The advent of adhesive dentistry, driven by the pioneering work of Buonocore, revolutionized orthodontic practice by introducing the technique of directly bonding appliances to tooth enamel.[1] This approach enhanced clinical outcomes by improving aesthetics, providing better technical control, reducing patient discomfort, and facilitating oral hygiene. The adhesive materials used in this process rely on micro-mechanical interlocking with etched enamel surfaces to form strong, durable bonds.[2] However, this same adhesion complicates appliance removal, frequently leaving residual composite resin on the enamel.[3] If inadequately removed, these remnants can lead to plaque accumulation, discoloration, and aesthetic concerns.[4] Additionally, aggressive or improper debonding techniques may damage the enamel's fluoride-rich outer layer, increasing the risk of demineralization, staining, and bacterial colonization.[3] Enamel surface roughness is particularly problematic, as it promotes bacterial adherence and impedes natural remineralization, especially in the presence of oral microorganisms such as *Streptococcus mutans* and *Lactobacillus spp*.[4]

The study aims to identify an adhesive removal method that optimally balances enamel surface preservation, cleaning efficiency, and clinical practicality following orthodontic bracket debonding.[5]

This study will evaluate and compare five commonly used adhesive removal systems—tungsten-carbide burs, Enhance polishing points (Dentsply), fiberglass burs (TDV),

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DU10CA-Ortho discs (DHPRO), and Sof-Lex discs (3M ESPE)—in terms of enamel surface roughness, structural preservation, and time efficiency.[6,7,8]

The study focuses on assessing the effects of these adhesive removal systems through in vitro testing on extracted human premolars. It utilizes advanced analytical tools such as Scanning Electron Microscopy (SEM) and enamel roughness testers to objectively quantify enamel surface changes and validate each method's clinical effectiveness.[6,9] By addressing the lack of a standardized protocol, the study seeks to guide orthodontists toward more effective and enamel-safe post-treatment adhesive removal strategies, thereby enhancing long-term oral health and aesthetics.[10]

2. Materials and Methods

The present randomized controlled in vitro experimental study was designed to evaluate and compare enamel surface roughness after the removal of residual orthodontic adhesive using five different adhesive removal systems. A total of 51 extracted human premolars were collected. Teeth selected met specific inclusion criteria: intact premolars extracted from patients aged 18–35 years, without caries, restorations, enamel defects, or history of orthodontic bonding. Teeth with cracks, trauma, restorations, hypoplasia, or previous bracket bonding were excluded. Among the 51 samples, 50 were divided into five experimental groups (G1–G5), each containing 10 teeth, while one tooth served as the control. **(Figure 1)**

Figure 1 : Tooth sample divided into 5 groups (each group contains 10 tooth)

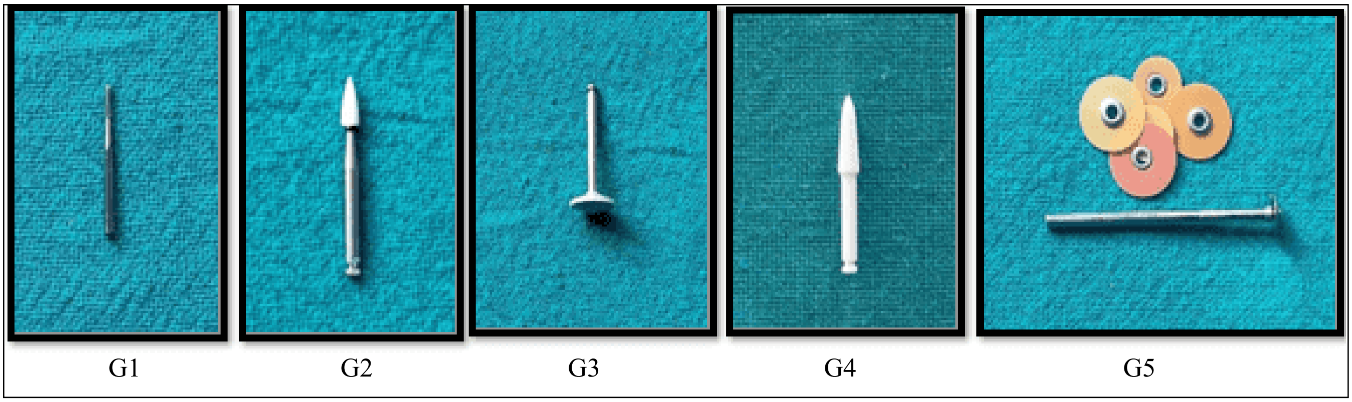

Figure 2 : Polishing systems (G1 tunsten carbide bur,G2 polishing points,G3 polishing disc, G4 fiberglass bur, G5 sof-lex pop on)

Sample size calculation was performed using G*Power software (Version 3.1.9.6, University of Kiel, Germany). Using an effect size of 0.80, an alpha error of 0.05, and 90% power, the minimum required sample size was determined to be 10 per group. The calculated parameters included a non-centrality parameter of 176.765, a critical F-value of 2.39, and an actual power of 0.902, resulting in a total of 51 samples, including the control.

The necessary armamentarium for this study included etchants, light-cured adhesives, standard metal brackets (0.022 × 0.030-in), five adhesive removal systems, a high-speed handpiece, orthodontic debonding pliers, a curing light, the surface roughness tester, and a scanning electron microscope. All procedures were consistently performed by the same operator under controlled laboratory conditions.[11]

Prior to the procedure, the teeth were stored in distilled water to preserve enamel integrity. Bonding was performed using 37% phosphoric acid etching for 30 seconds, followed by rinsing and drying.[12] A light-cured orthodontic adhesive (Alpha bond) was applied to the bracket base and cured for 5 seconds using an LED curing light. After a 7-day bonding period to ensure complete adhesive setting, brackets were removed using orthodontic debonding pliers with care to avoid enamel damage.[13]

Following debonding, residual adhesive was removed using one of five systems: G1 (Tungsten Carbide Burs), G2 (Enhance Polishing Points – Dentsply), G3 (DU10CA-Ortho Discs – DHPRO), G4 (STAINBUSTER Fiberglass Burs – TDV), and G5 (Sof-Lex Pop-On Discs – 3M ESPE). **(Figure 2)**.[14,15,16] Each system was applied under standardized conditions using a slow-speed handpiece with continuous water spray to avoid overheating and minimize enamel abrasion. The adhesive removal process was considered complete when the enamel appeared visually smooth and free of composite under artificial light. The time required for complete adhesive removal and polishing (PoTi) was measured using a stopwatch.[17]

2.1. Roughness analysis

Surface roughness was evaluated before bonding (Ra1) and after adhesive removal (Ra2) using the Mitutoyo SI-410 Series Surface Roughness Tester. Measurements were taken at two different sites on each sample to ensure accuracy, and the arithmetic mean was calculated. One representative sample from each group, with Ra2 values closest to the group mean, was selected for scanning electron microscopy (SEM) evaluation.[18]

2.2. Evaluation in scanning electron Microscope-SEM

For SEM analysis, selected specimens were cleaned, sectioned, and fixed using a 2.5% glutaraldehyde solution. They were then dehydrated through graded ethanol concentrations and mounted on conductive grids using carbon tape. A gold coating of 5–20 nm thickness was applied via sputter coating to prepare the samples for imaging. SEM imaging was performed at magnifications of 1000x, 2000x, 8000x, and 60,000x. All collected data and SEM images were stored for further analysis.

2.3. Statistical analysis

Statistical analysis was conducted using SPSS version 23.0. Descriptive statistics, including means, standard deviations, and percentages, were computed. The Shapiro-Wilk test was used to assess data normality, while Levene's test evaluated homogeneity of variances. One-way ANOVA was employed for intergroup comparisons, followed by Tukey's HSD test for post-hoc pairwise comparisons.[19,20] A significance threshold of $p < 0.05$ was set. The Tukey test was applied to detect significant differences between group means while controlling the family-wise error rate using the studentized range distribution. The final interpretation of the data focused on identifying the resin removal method that offered minimal enamel damage while maintaining clinical effectiveness and optimal polishing outcomes.[21]

3. Results

Intergroup Comparison of Surface Roughness Between Different Groups Tungsten Carbide Burs (Group 1) resulted in the highest mean change in surface roughness (2.1 ± 0.19 µm), indicating that this method caused the roughest enamel surface post-polishing. SOF-Lex Pop-On Polishing Disc (Group 5) exhibited the lowest mean change in surface roughness (0.26 ± 0.10 µm), meaning it resulted in the smoothest surface. Enhance Polishing Points (Group 2), DU10CA-Ortho Disc (Group 3), and Fibre Glass (Group 4) demonstrated intermediate surface roughness values of 1.64 ± 0.17 µm, 0.97 ± 0.14 µm, and 1.28 ± 0.13 µm,**(Table 1)**

Table 1: Intergroup comparison of surface roughness between different groups

Group	Pre polishing	Post polishing	Mean change	f-value	p-value
G1: Tungsten Carbide Burs	0.80 ± 0.13	2.90 ± 0.25	2.1 ± 0.19	108.34	0.001
G2: Enhance Polishing Points	0.86 ± 0.16	2.50 ± 0.22	1.64 ± 0.17	107.32	0.001
G3: DU10CA-Ortho Disc (DHPro)	0.83 ± 0.13	1.80 ± 0.20	0.97 ± 0.14	109.36	0.001
G4: Fibre Glass	0.82 ± 0.12	2.10 ± 0.23	1.28 ± 0.13	108.19	0.001
G5: SOF-Lex Pop-On Polishing Disc (3M ESPE)	0.84 ± 0.11	1.10 ± 0.18	0.26 ± 0.10	106.24	0.001

Table 2: Post-Hoc Analysis of roughness

Group comparison	Mean difference	p-value	Significance
G1 vs G2	0.46	0.001	Significant
G1 vs G3	1.13	0.001	Significant
G1 vs G4	0.82	0.001	Significant
G1 vs G5	1.84	0.001	Significant
G2 vs G3	0.67	0.001	Significant
G2 vs G4	0.36	0.001	Significant
G2 vs G5	1.38	0.001	Significant
G3 vs G4	0.31	0.001	Significant
G3 vs G5	0.71	0.001	Significant
G4 vs G5	1.02	0.001	Significant

Table 3: Time taken for removal of adhesive

Group	Mean	SD	Std Error (SE)	f-value	p-value
G1: Tungsten Carbide Burs	29.46	2.12	0.13	300.73	0.001
G2: Enhance Polishing Points	32.91	2.21	0.17	298.72	0.001
G3: DU10CA-Ortho Disc (DHPro)	62.47	2.87	0.14	301.69	0.001
G4: Fibre Glass	49.95	2.35	0.11	299.68	0.001
G5: SOF-Lex Pop-On Polishing Disc	78.6	2.78	0.12	304.72	0.001

Table 4: Post-Hoc analysis: time taken for removal of adhesive

Group comparison	Mean difference	p-value	Significance
G1 vs G2	–3.45	0.001	Significant
G1 vs G3	–33.01	0.001	Significant
G1 vs G4	–20.49	0.001	Significant
G1 vs G5	–49.14	0.001	Significant
G2 vs G3	–29.56	0.001	Significant
G2 vs G4	–12.52	0.001	Significant
G2 vs G5	–16.13	0.001	Significant
G3 vs G4	–17.04	0.001	Significant
G3 vs G5	–45.69	0.001	Significant
G4 vs G5	-28.65	0.001	Significant

Statistical analysis (f-value = 108.34, p = 0.001) confirmed that the differences in surface roughness among the groups were highly significant. Post-hoc analysis **(Table 2)** revealed that Group 1 (Tungsten Carbide Burs) exhibited significantly higher roughness than all other groups, while Group 5 (SOF-Lex Pop-On Polishing Disc) consistently showed the lowest surface roughness. Group 3 was smoother than Group 2 and Group 4, with Group 4 being smoother than Group 2 **(Table 1)** showing roughness analysis after polishing with different polshing systems. **(Figure 3)** Tungsten Carbide Burs resulted in the roughest enamel surface post-polishing. SOF-Lex Pop-On Polishing Disc produced the smoothest surface.All group comparisons showed statistically significant differences, with Group 1 causing the most enamel roughness and Group 5 causing the least. Post-hoc analysis confirmed that all pairwise comparisons between groups were significant ($p < 0.001$).[22]

Intergroup Comparison evaluation of time taken in different groups**.** Tungsten Carbide Burs (Group 1) was the quickest method for adhesive removal, with an average time of 29.46 seconds. SOF-Lex Pop-On Polishing Disc (Group 5) took the longest time for adhesive removal, with an average time of 78.60 seconds. Enhance Polishing Points (Group 2) and DU10CA-Ortho Disc (Group 3) required 32.91 seconds and 62.47 seconds, respectively, which was significantly less time than Group 5 but more time than Group 1.Statistical analysis (f-value = 300.731, p = 0.001) showed significant differences in the time taken for adhesive removal among all groups. **(Table 3)**

Post-hoc analysis confirmed that Group 1 (Tungsten Carbide Burs) took significantly less time than all other groups, with the difference ranging from 3.45 minutes to 49.14 seconds. Similarly, Group 5 (SOF-Lex Pop-On Polishing Disc) took the longest time to remove adhesive compared to all other groups **(Table 4)** and **(Table 3)** represents time taken by different polishing system.

Tungsten Carbide Burs demonstrated the fastest adhesive removal. SOF-Lex Pop-On Polishing Disc required the most time to remove adhesive.

The difference in time for adhesive removal among all groups was statistically significant ($p < 0.001$). Post-hoc analysis confirmed that all pairwise comparisons were significant, with Group 1 (Tungsten Carbide Burs) being significantly faster than all other groups, and Group 5 (SOF-Lex Pop-On Polishing Disc) being the slowest. Statistical Significance: All intergroup comparisons for both surface roughness and time for adhesive removal were statistically significant ($p < 0.001$), suggesting that the differences observed in both parameters were not due to chance. SEM microphotographs of all five groups (G1, G2, G3, G4 and G5) **(Figure 3)–(Figure 7)**. Tungsten Carbide Burs caused the highest increase in surface roughness, leading to a significantly rougher enamel surface. SOF-Lex Pop-On Polishing Disc produced the smoothest enamel surface post-polishing, with minimal roughness. Time for Adhesive Removal: Tungsten Carbide Burs were the most time-efficient for adhesive removal, while SOF-Lex Pop-On Polishing Disc took the longest time. SEM (scanning electron microscopic) evaluation of all five different groups G1**(Figure 3)**, G2**(Figure 4)**, G3**(Figure 5)**, G4**(Figure 6)**, G5**(Figure 7)** are given below.

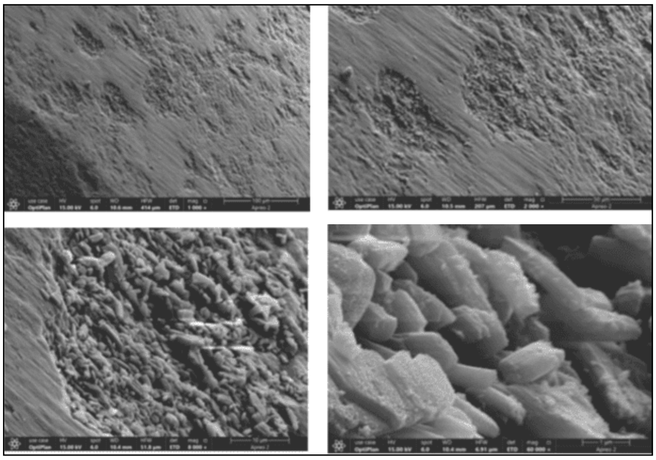

Figure 3: SEM evaluation of enamel surface after polishing with tungsten carbide burs, (G1). At magnification 1000x, 2000, 8000x and 60000x magnification.

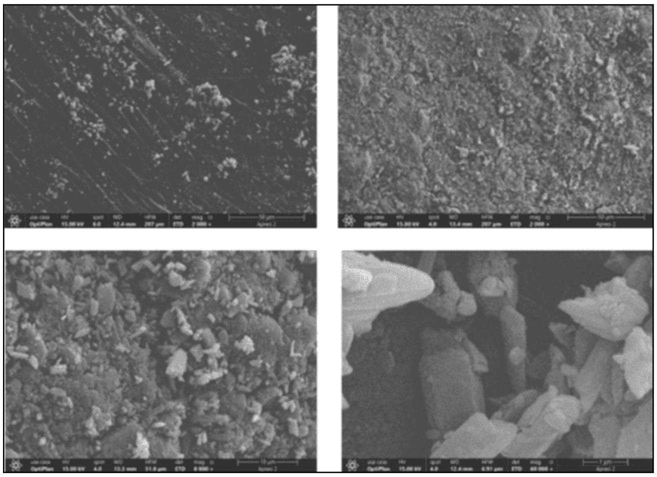

Figure 4: SEM evaluation of enamel surface after polishing with Polishing points(G2).At magnification 1000x, 2000, 8000x and 60000x magnification.

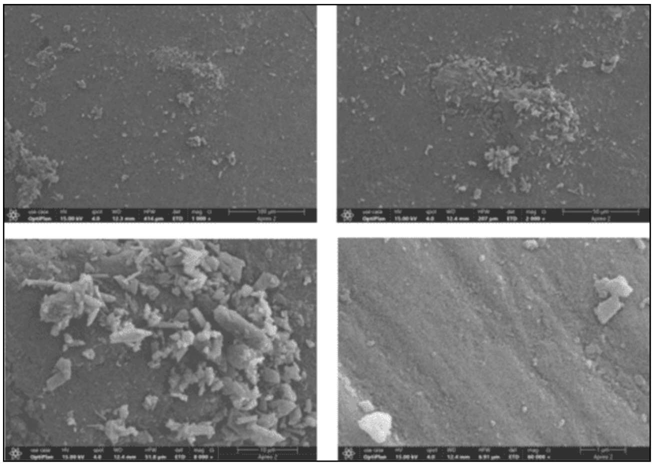

Figure 5: SEM evaluation of enamel surface after polishing with Polishing disc(G3).At magnification 1000x, 2000, 8000x and 60000x magnification

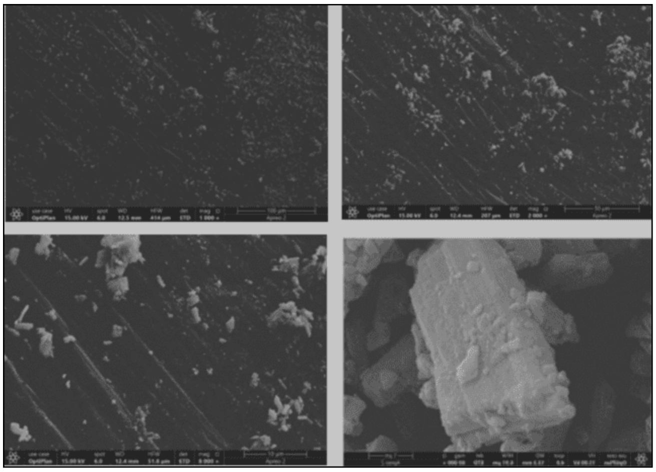

Figure 6: SEM evaluation of enamel surface after polishing with fiberglass bur(G4).At magnification 1000x, 2000, 8000x and 60000x magnification.

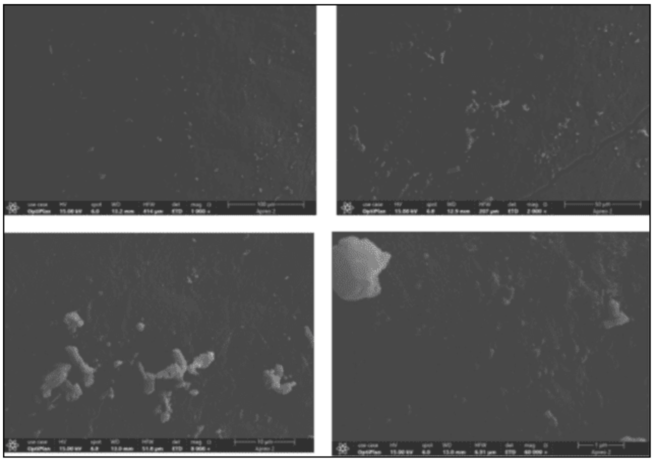

Figure 7: SEM evaluation of enamel surface after polishing with sof-lex pop on disc(G5). At magnification 1000x,2000,8000x and 60000x magnification

4. Discussion

The methodology employed in this study for both quantitative and qualitative evaluation of enamel surface alterations—using a surface roughness tester and Scanning Electron Microscopy (SEM), respectively—has previously been validated as reliable and reproducible for assessing enamel surface morphology following adhesive removal.

Surface roughness is particularly significant as it influences bacterial adhesion, plaque accumulation, and the risk of enamel demineralization, ultimately affecting long-term oral health and aesthetics (Greenhalgh Thys D., 2024).[14]

All methods evaluated in this study demonstrated success in removing residual resin. All methods tested caused enamel alterations to a greater or lesser degree. This study compared five commonly used adhesive removal systems—Tungsten Carbide Burs (G1), Enhance Polishing Points (G2), DU10CA-Ortho Discs (G3), Fibre Glass Burs (G4), and SOF-Lex Pop-on Discs (G5)—with respect to enamel surface roughness and removal time. Distinct morphological changes were observed in all groups under SEM evaluation at varying magnifications (1000x to 60000x).

1. **Group 1:** Tungsten Carbide Burs (G1)Tungsten Carbide Burs demonstrated the highest enamel roughness (2.1 ± 0.19 μm), with SEM images revealing deep, non-parallel, and irregular scratch patterns. This confirms their high cutting efficiency but also their aggressive impact on enamel integrity.[19] Although post-polishing may reduce surface irregularities, as suggested by Greenhalgh et al.[14] roughness in this study remained higher than in some previous reports.
2. **Group 2:** Enhance Polishing Points (G2)Enhance Polishing Points produced moderate surface roughness (1.64 ± 0.17 μm) with finer, more parallel scratch marks, indicating a gentler action compared to burs. These results align with prior studies suggesting that while polishing points are less damaging than carbide burs, they still impart measurable surface abrasion.
3. **Group 3:** DU10CA-Ortho Discs (G3)DU10CA-Ortho Discs exhibited one of the lowest surface roughness values (0.97 ± 0.14 μm), with SEM images showing surfaces closely resembling untreated enamel at higher magnifications. These results corroborate findings by Claudino et al. and Greenhalgh Thys D.[12,14] who highlighted the enamel-preserving characteristics of these discs. Despite their effectiveness, the time required for adhesive removal was relatively long (62.47 seconds), indicating a trade-off between speed and enamel conservation.
4. **Group 4:** Fibre Glass Burs (G4) Fibre Glass Burs resulted in intermediate surface roughness (1.28 ± 0.13 μm), with SEM revealing irregular and chaotic scratch patterns. They were less aggressive than Tungsten Carbide Burs but more abrasive than disc systems. Their adhesive removal time (49.95 seconds) also reflected a balance between efficiency and enamel preservation.
5. **Group 5:** SOF-Lex Pop-on Discs (G5)SOF-Lex Discs yielded the smoothest enamel surfaces (0.26 ± 0.10 μm), with minimal and shallow scratches. However, their use was the most time-consuming (78.60 seconds), making them less efficient for high-paced clinical environments.

Time vs. Enamel Preservation: There was a clear inverse relationship between removal time and enamel surface roughness. Faster systems like Tungsten Carbide Burs (29.46 seconds) and Enhance Polishing Points (32.91 seconds) were also the most abrasive.[15] In contrast, slower systems such as DU10CA-Ortho Discs and SOF-Lex Discs provided superior enamel preservation but at the cost of longer clinical time. This trade-off aligns with the observations of aniszewska-Olszowska.[19] reinforcing the need for clinicians to consider both time constraints and enamel health when selecting an adhesive removal method.

Despite these insights, it is important to acknowledge the limitations of this in vitro study. Biological responses such as pulpal irritation and potential thermal effects from rotary tools could not be assessed. Additionally, clinical conditions may affect polishing times and outcomes, and these might differ from the controlled setting of the present study.

5. Conclusion

1. In conclusion, this study highlights the trade-offs between time efficiency and enamel preservation when selecting adhesive removal techniques. Enamel surface roughness (from highest roughness value to lowest roughness value) among five polishing system: ***G1>G2>G4>G3>G5***. Time taken by all 5 polishing system: ***G5>G3>G4>G2>G1.***
2. Clinicians must carefully weight the need for efficiency against the long-term preservation of enamel integrity when selecting a removal technique. Further studies on the long-term effects of these techniques are necessary to guide clinical decision-making and optimize patient outcomes.
3. 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.

6. Source of Funding

None.

7. Conflict of Interest

None.

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