Original Article

Soft adhesives may cause more iatrogenic damage than hard adhesives during cleanup following bracket removal

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ABSTRACT

Objectives: To determine if adhesive remnants and enamel loss after debonding and cleanup with a finishing bur were affected by hardness properties of the adhesive resins.

Materials and Methods: Stainless steel orthodontic brackets (American Orthodontics, Mini Master series) were bonded on facial surfaces of extracted premolars using a relatively soft bioactive resin (ACTIVA BioACTIVE-Restorative, Pulpdent) or harder traditional adhesive (Transbond XT, 3M; N $=$ 20/group). Bracketed teeth underwent 5000 thermocycles before brackets were debonded. Debonding surfaces were examined qualitatively and categorized by three examiners. Remaining adhesive was removed with a carbide finishing bur. Teeth were scanned with an optical scanner before brackets were bonded (baseline), after debonding, and after cleanup. Surface changes (mean thickness or depth, affected surface area, and volume) were calculated quantitatively after aligning scans to the baseline. Differences between the two groups were analyzed statistically with Mann-Whitney *U*-test or pairwise comparison at a significance level of 0.05.

Results: Qualitative examination of debonded surfaces did not show a significant difference ($P = .7949$) in adhesive remnants between groups, which was confirmed by quantitative evaluation ($P > .05$). After cleanup, enamel loss was significantly higher in the softer bioactive resin group (mean depth $= 91 \pm 16$ μm, area $= 24.48 \pm 9.88$ mm^2) than the harder traditional adhesive (mean depth $= 66 \pm 9$ μm, area $= 6.34 \pm 4.41$ mm^2; $P < .0001$).

Conclusions: The likelihood of adhesive remnants after debonding a bracket bonded with the bioactive resin was similar to traditional adhesive. However, enamel loss from cleaning up with a finishing bur was higher for the softer bioactive resin. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Iatrogenic damage; Adhesive remnant; Enamel loss; Hardness; 3D scanning; Bracket cleanup

INTRODUCTION

Orthodontic treatment has many beneficial effects on dentition, but it should ensure minimal negative iatrogenic effects. Iatrogenic damage to the enamel surface can occur during orthodontic treatment or posttreatment when brackets are debonded. Debonding often leaves adhesive remnants on a tooth surface that needs to be cleaned up.[1] The amount of adhesive remnants can be scored visually using the Adhesive Remnant Index (ARI).[2] ARI scores characterize the mode of failure by the amount of adhesive that needs to be removed in a

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subsequent cleanup step. Some consider adhesive remnants advantageous because they minimize enamel damage during bracket removal.[3] However, others consider less adhesive remnants better because less cleanup is required, resulting in a lower chance of causing enamel damage.[4,5] The main cause of enamel damage is a high-speed handpiece with finishing bur used during cleanup.[5]

ARI scores are subjective and do not include enamel damage. Various quantitative methods for measuring enamel loss have been employed to overcome the limitations of ARI scores by providing an objective determination of the amount of adhesive remnants as well as enamel loss. Examples of such methods are microcomputed tomography,[6,7] null-point contact stylus systems,[8] laser scanning,[4] scanning electron microscopy,[9] atomic force microscopy,[10] and digital/optical scanning techniques.[3,11] Determining adhesive remnants and enamel loss helps develop optimal procedures for removing remnants without damaging the underlying and surrounding tooth structure.[12,13] The risk of enamel damage may be affected by physical properties of an adhesive. No previous authors have evaluated the influence of adhesive properties on enamel damage following remnant removal.

Recently, bioactive restorative resin has shown promising bracket bonding qualities in comparison with traditional orthodontic adhesive.[14] However, this resin has inherently low hardness.[15] A material with low hardness may result in more residual remnants after bracket debonding due to increased excess material or in less enamel damage due to easier post-treatment cleanup. The objective of this in vitro study was to examine adhesive remnants and enamel damage after bracket debonding and cleanup when using a softer adhesive compared with a traditional orthodontic adhesive. The null hypotheses were that the adhesive resin type and its hardness would not result in differences in adhesive remnants or enamel loss after debonding and cleanup.

MATERIALS AND METHODS

Tooth Collection and Mounting

Premolar teeth extracted for orthodontic purposes were collected following Institutional Review Board approval (23-09284-NHSR). The teeth were visually inspected for imperfections of the anatomical crown and excluded from the study if they contained restorations, caries, decalcification, or damage to the facial surface. The teeth were stored in a saline solution and disinfected with CaviCide™ (Metrex™, Orange, Calif) before use. The roots of the teeth were mounted in acrylic resin (Ortho-Jet™ Powder, Lang Dental Mfg. Co., Inc., Wheeling, Ill) and shaped to allow insertion into a Kilgore dental typodont (Kilgore International Inc, Coldwater, Mich). Teeth were randomly divided into two adhesive groups and numbered.

Baseline Scan

The anatomic crown of each tooth was etched with 37% phosphoric acid etch (Ultra-Etch, UltraDent, South Jordan, Utah) for 30 seconds, rinsed with water for 10 seconds, and dried until the enamel surface appeared frosted to improve subsequent optical scanning. The teeth were scanned to obtain a baseline using a three-dimensional optical scanner (COMET Xs, Steinbichler Vision Systems, Neubeuern, Germany). This scanner has an accuracy of 5 μm and a lateral resolution of 60 μm.[3] The scans were saved in standard tessellation language (STL) format.

Bracket Bonding

The facial surfaces of the premolars were primed with Assure Plus (Reliance Orthodontic Products, Itasca, Ill), air-thinned, and light-cured using a light-emitting diode curing light (VALO, UltraDent) for 15 seconds. Metal brackets (Metal Twin 0.022 $\times$ 0.028 slot, American MBT Mini Master Series, Sheboygan, Wis) were bonded with a bioactive resin (ACTIVA BioACTIVE-RESTORATIVE, Pulpdent, Watertown, Mass) or a traditional resin-based orthodontic adhesive (Transbond XT, 3M, St Paul, Minn). Hand pressure was applied to the bracket using a sickle scaler until the bracket was no longer depressible. Excess resin around the bracket was removed with an explorer. The resin under the bracket was light-cured (VALO, UltraDent) for 15 seconds from the mesial, distal, apical, and incisal aspects of the tooth. With an expected 0.5 standard deviation and accepting 25% margin of error, minimum sample size was 15. In this study, we used 20 samples per adhesive group.

Thermocycling

The bracketed premolars were kept in distilled water at 37°C prior to thermocycling (OMC250L, Odeme Dental Research, Anchieta, SC, Brazil), and the specimens were cycled 5000 times between 5°C and 55°C water baths. The alternating temperatures caused cyclic thermal stresses across the bonded bracket interface to simulate temperature changes encountered in the oral environment.[16] The 5000 cycles are thought to represent approximately 6 months in the oral environment.[17]

Bracket Debonding and Postdebond Scan

After thermocycling, the teeth were placed in the typodont and mounted in a manikin. The brackets were

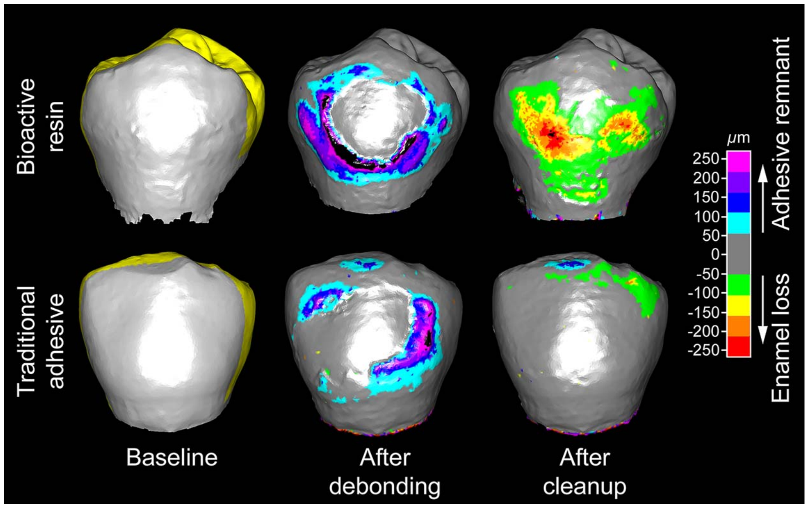

Figure 1. Representative scanned surfaces, showing the baseline scan (fitting area indicated in yellow), the surface after debonding of the bracket, and the surface following cleanup of adhesive remnants (upper row: bioactive resin; lower row: traditional adhesive). Adhesive remnants are shown in blue-purple-magenta; enamel loss is shown in green-yellow-orange-red.

debonded using a debonding plier (Bracket Remover Plier, 678-220L, HuFriedyGroup, Chicago, Ill). After debonding, residual adhesive on the teeth was visually assessed to determine an ARI score. A score of 0 indicated no resin was left on the tooth. A score of 1 indicated less than 50% of the resin remained on the tooth. A score of 2 indicated 50–100% of the resin remained on the tooth. A score of 3 indicated all (100%) of the resin remained on the tooth.[18] Three investigators wearing loupes at 2.5 × magnification scored the debonding surfaces independently.[14] If scores differed among the investigators, an agreed value was reached. The results were compared between the two adhesives using the Mann-Whitney *U*-test at a 0.05 significance level. After the debonding surfaces had been visually inspected and scored, they were scanned for the postdebond stage.

Cleanup and Postcleanup Scan

The teeth were placed back into the typodont and manikin for the cleanup step. Cleanup was performed using a high-speed handpiece (Forza M5, Brasseler, Savannah, Ga) at 20,000 revolutions per minute with a 12-fluted carbide flame-shape finishing bur (H48L.31.012, Brasseler, Savannah, Ga) without water. Each sample used a new bur. After cleanup, a final postcleanup scan was made.

Analysis of Surface Changes

Postdebond and postcleanup scans were superimposed and precisely aligned on the baseline scan using Cumulus software (Regents of the University of Minnesota, Minneapolis, Minn) using tooth areas that had not changed (fitting area). Figure 1 shows two examples of selected fitting areas on the baseline scans, highlighted in yellow. The Cumulus software used an algorithm that minimized the root-mean-square difference between the baseline and superimposed scan.[19] Once aligned, surface changes could be visualized with a color scale. Figure 1 shows an example where areas of surface gain, representing adhesive remnants, are highlighted in light blue, blue, purple, and magenta, while enamel surface loss is shown in green, yellow, orange, and red. The mean and maximum thickness/depth, the affected surface area, and the volume gain/loss were calculated using custom-developed software (CuspFlex). The results of the two adhesives, postdebond and postcleanup, were compared using pairwise comparisons at a significance level of 0.05.

Hardness Test

The hardness of the bioactive resin and traditional adhesive was determined using a Vickers hardness test. The adhesives were placed in cylindrical cavities (3 mm diameter × 1.5 mm depth) made in acrylic molds, covered with a glass cover slip, and light cured (VALO) for 20 seconds. The samples were stored at room temperature in a dark environment for 24 hours and surface hardness was measured using a Vickers indenter (QV-1000 Micro Hardness Tester, Qualitest, Fort Lauderdale, Fla) at 50 grams with a dwell time of 15 seconds. The hardness value (Vickers hardness number [VHN]) for each sample was determined as the average of three measurements. The sample size was 10 per group because the expected standard deviation was 0.1. The results of the two adhesives were compared using a *t*-test at a significance level of 0.05.

Table 1. Number of Teeth With Adhesive Remnant Index (ARI) Scores After Debonding Brackets for the Two Adhesive Types

	ARI Scores[a]			
Adhesive	0	1	2	3
Bioactive resin	1	16	3	0
Traditional adhesive	0	16	2	1

[a] ARI score: 0 indicates no resin left on tooth surface (0%); 1, less than half of the resin left on tooth surface (≤50%); 2, more than half of the resin left on tooth surface (>50%); and 3, indicates all resin left on tooth surface with bracket imprint showing (100%). ARI results were not significantly different between adhesive groups (Mann-Whitney *U*-test).

RESULTS

The ARI scores (Table 1) showed that most brackets left less than half of the adhesive on the tooth surface after debonding, regardless of the type of adhesive. The Mann-Whitney *U*-test was performed to compare the ARI scores of the bioactive resin and traditional adhesive. No significant differences were found between the ARI scores of the two adhesives ($z = -0.26$, $P = .7949$).

The results of adhesive remnants and enamel loss measured on the scanned facial surfaces are listed in Table 2. Representative examples of the two groups are shown in Figure 1. Before cleanup, average thickness of the adhesive remnants was approximately 125 μm, covering an area of approximately 16 mm^2, while average enamel loss was negligible at about 4 μm. One tooth in the bioactive resin group and one in the traditional adhesive group experienced enamel loss during debonding (mean depth/surface area = 53 μm/0.09 mm^2 and 90 μm/0.24 mm^2, respectively).

During cleanup, the operator did not observe differences in shade or translucency that made either adhesive remnant stand out more against the tooth surface. After cleanup in both groups, small amounts of adhesive remnants, approximately 40 μm to 45 μm, could still be detected by the scanner covering about 1 mm^2 of the facial area, while mean enamel loss ranged from 66 μm to 91 μm over a surface area of 6 mm^2 to 24 mm^2. One specimen in the traditional adhesive group had a significantly higher amount of adhesive remnants after cleanup (555 μm thickness, 39 mm^2 area) than other specimens, which was attributed to being the first specimen; it was, therefore, omitted as an outlier.

Statistical analysis indicated that the type of adhesive did not significantly affect the amount of adhesive remnants, either after debonding or after cleanup ($P > .05$). Enamel loss after debonding was also similar for both adhesives, but after cleanup, the amount of enamel loss was significantly higher for the bioactive resin than the traditional adhesive ($P < .0001$).

The hardness measurements confirmed that the bioactive resin (17.4 ± 1.7 VHN) was significantly softer than the traditional adhesive (38.4 ± 1.9 VHN; $P < .0001$).

DISCUSSION

In this study, we investigated if the hardness of an adhesive resin could affect the amount of iatrogenic damage after bracket debonding. Two adhesives, bioactive and traditional, were used to examine this question. According to previous studies, the tested adhesives had similar bracket bond strengths, but the bioactive resin was significantly softer than the traditional adhesive.[14,15] A softer adhesive may increase excess around a bracket, leading to higher ARI scores after debonding, necessitating more cleanup with an increased risk of enamel damage.

Using qualitative ARI scoring,[2,20,21] no significant differences in adhesive remnants were found between the two adhesives. Subsequent quantitative measurements of the scanned surfaces confirmed the qualitative examination, also showing similar amounts of adhesive left on the facial tooth surface after debonding of the two adhesives. The first null hypothesis that no difference in adhesive remnants would be found between the two adhesives was, therefore, not rejected.

Table 2. Adhesive Remnants and Enamel Loss for Two Adhesives Used for Bonding Orthodontic Brackets (Mean ± SD) After Debonding and After Cleanup[a]

	Bioactive Resin		Traditional Adhesive	
	Adhesive Remnants	Enamel Loss	Adhesive Remnants	Enamel Loss
After debonding				
Mean depth/thickness (μm)	118 ± 21 a	−3 ± 12 c	132 ± 48 a	−5 ± 21 c
Affected area (mm^2)	17.74 ± 7.12 a	0.00 ± 0.02 c	14.91 ± 6.98 a	0.01 ± 0.06 c
Volume (mm^3)	2.126 ± 0.894 a	0.000 ± 0.001 c	2.056 ± 1.487 a	0.001 ± 0.005 c
After cleanup				
Mean depth/thickness (μm)	40 ± 39 b	−91 ± 16 a	45 ± 46 b	−66 ± 9 b
Affected area (mm^2)	0.92 ± 1.98 b	24.48 ± 9.88 a	1.33 ± 1.75 b	6.34 ± 4.41 b
Volume (mm^3)	0.076 ± 0.166 b	2.315 ± 1.201 a	0.116 ± 0.152 b	0.429 ± 0.309 b

[a] Same letters in comparable groups indicate no significant difference (significance level 0.05).

The ARI method only observes adhesive remnants after debonding and does not examine the amount of adhesive after cleanup or enamel loss after debonding and after cleanup.[20,22] Using the quantitative measurements of the scanned facial surfaces, a significant reduction in adhesive remnants after cleanup was confirmed, albeit a small amount remaining. The hardness of the tested adhesives did not seem to affect the effectiveness of cleaning off the adhesive remnants. However, when comparing enamel loss after the cleanup, a significant difference between the two adhesives was found. Cleaning up the softer adhesive resin caused significantly more enamel damage than cleaning up the harder traditional adhesive. The second null hypothesis that no difference in enamel loss would be found between adhesives with different hardnesses was, therefore, rejected.

Previously, authors of several studies have measured enamel loss following orthodontic adhesive cleanup.[3,23,24] In a systematic review, enamel loss (volume) for Transbond was summarized to be in the range of 0.02 mm^3 to 0.61 mm^3[3,4-6,25] which was consistent with the value found in this study. In the present study, we used a softer adhesive under comparable conditions—same operator, similar bond strength, and similar adhesive remnants, with the same appearance—and found an approximately five times higher enamel loss by volume. It may have been expected that a softer material would be easier to remove, hence leading to less damage. However, the results of this study suggest the opposite. It is possible that less resistance to the finishing bur of the softer resin during the cleanup process allowed the clinician to remove the resin more easily and reach the underlying enamel faster than the harder adhesive remnants.

The results in this study were obtained in vitro. However, clinical protocols were simulated, such as following standard clinical protocols and positioning the bracketed teeth in a manikin during bonding, debonding, and cleanup procedures. Additionally, the bonded brackets were thermocycled to simulate 6 months in the oral environment,[17] and unlike bracket bond strength tests, debonding was achieved using a debonding plier. Only two adhesives were tested, and only one type of carbide finishing bur was used. More adhesives, with a wider array of hardness properties, should be tested to confirm the general principle that the risk of iatrogenic damage is higher when cleaning up softer resins. Authors of future studies could also examine a wider range of adhesive hardness and burs, although the carbide finishing bur used in this study has been recommended.[26,27] In this study, we used only one operator to standardize the operator variable. The amount of enamel removed from the tooth surface likely varies among individual clinicians. Authors of future studies could investigate the operator effect. Nevertheless, the results of this study suggest that operators using a relatively soft orthodontic adhesive should take extra care to minimize iatrogenic damage during cleanup with a finishing bur.

CONCLUSIONS

- Differences in hardness between a bioactive resin and traditional adhesive did not lead to significantly different adhesive remnant amount after debonding or cleanup with a finishing bur.
- Cleaning off the remnants of the softer adhesive with a finishing bur resulted in significantly more enamel loss than when cleaning off remnants of the harder orthodontic adhesive.

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DISCLOSURE

The authors have no conflict of interest.

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