Original Article

Enamel loss following ceramic bracket debonding: A quantitative analysis in vitro

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ABSTRACT

Objective: To measure enamel surface changes after ceramic bracket debonding and after cleanup.

Materials and Methods: Forty extracted teeth were scanned in three dimensions using an optical scanner (baseline). Two ceramic bracket systems were placed (19 metal-reinforced polycrystalline ceramic brackets; 21 monocrystalline ceramic brackets). Seven days later, brackets were debonded and teeth scanned (post-debond). Adhesive remnants and bracket fragments were recorded. Tooth surfaces were cleaned using a finishing carbide bur and scanned again (post-cleanup). Post-debond and post-cleanup scans were aligned with the baseline, and surface changes were quantified. Results were statistically compared using *t*-tests and Mann-Whitney tests ($\alpha = .05$).

Results: The depth of enamel loss (mean \pm standard deviation) post-debond was 21 \pm 8 µm and 33 µm and post-cleanup was 28 \pm 14 µm and 18 \pm 8 µm (P = .0191); the post-debond remnant thickness was 188 \pm 113 µm and 120 \pm 37 µm (P = .2381) and post-cleanup was 16 \pm 5 µm and 15 µm for polycrystalline and monocrystalline ceramic brackets, respectively. The monocrystalline ceramic brackets predominantly left all adhesive on the tooth; the polycrystalline ceramic brackets were more likely to leave bracket fragments attached.

Conclusion: Both systems allowed successful removal of the brackets with minimal enamel loss. However, the polycrystalline ceramic brackets left more fragments on the tooth, which complicated cleanup efforts. (*Angle Orthod.* 2015;85:651–656.)

KEY WORDS: Enamel loss; Debonding; Ceramic bracket; Dental finishing; Digital scan

INTRODUCTION

The dental specialty of orthodontics has experienced numerous advancements in the past century. One of the most significant was the introduction of enamel

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Accepted: July 2014. Submitted: March 2014.

Published Online: September 29, 2014

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etching, adhesive resins, and their use in orthodontics to bond orthodontic brackets onto the enamel surface of teeth.^{1–3} Prior to this discovery, the only reliable method of attaching orthodontic brackets to teeth was via metal banding of every tooth in the dental arch.⁴

Although the introduction of direct bracket bonding was a major advance over metal banding, it also poses new challenges. While a strong and reliable bond to enamel is desirable to prevent the premature loss of brackets, a high bond strength also increases the likelihood of damaging the tooth surface during the debonding process.⁵ The effect of debonding and resin removal on the underlying enamel has been a concern since the introduction of direct bracket bonding and has been called an acute clinical problem.⁶

The concern for enamel damage is especially critical when debonding ceramic brackets.⁷ Ceramic brackets have become increasingly popular since the 1980s, primarily because of the demand for esthetic alternatives to metal brackets.⁸ However, some of the first-generation ceramic brackets resulted in gross enamel damage during debonding.^{7,9,10} Enamel damage as high as

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63.3% was reported when ceramic brackets were debonded in an in vitro study, which concluded that enamel damage was more likely to occur with ceramic brackets.¹¹

Since their introduction, ceramic brackets have been significantly improved. Manufacturers assure that newer generation ceramic brackets are safe to debond and that the likelihood of enamel damage is decreased due to modifications in their base design.¹² However, quantitative evidence to support such claims is scarce.

Advances in technology allow quantitative measurement of the small tooth surface changes that can occur during the bracket debonding process.^{13–16} For metal brackets, adhesive remnants were reported after debonding as well as 20- to 50-µm enamel loss after removing the residual adhesive.^{13,14} The aim of this study was to investigate two current-generation ceramic bracket systems and to quantify enamel surface changes after debonding. A three-dimensional (3D) optical scanner will be used to digitize the tooth surfaces before bracket bonding, after debonding, and after cleanup to precisely quantify the surface changes.

MATERIALS AND METHODS

Forty human premolars, extracted for orthodontic reasons, were collected from the oral surgery clinic (Institutional Review Board approval 13-02375-xm). Teeth were inspected and excluded from the study if they had any signs of enamel damage, caries, calculus, or restorations. The teeth were rinsed with water and stored in 10% formalin acetate until use.

The teeth were etched with 38% phosphoric acid etch (Reliance Orthodontic Products, Itasca, III) for 30 seconds, rinsed, and dried until a frosty enamel surface was obtained. The frosty appearance improved the scanning performance of the optical scanner. A baseline scan of all teeth was obtained using a 3D optical scanner (COMET xS, Steinbichler Vision Systems, Neubeuern, Germany). The scanner has an accuracy of 5 µm and a lateral resolution (distance between measured points) of 60 µm. Transbond XT bonding agent (3M Unitek, Monrovia, Calif) was applied to the facial surface of the teeth and air dried, and two different bracket systems were bonded to the teeth using Transbond XT orthodontic adhesive (3M Unitek). To replicate clinical conditions, moderate hand pressure was applied to the brackets using a hand instrument until the brackets could not be pushed further. All excess adhesive was removed to ensure that no adhesive flash was left. The adhesive was light cured for 45 seconds using a halogen curing light (VIP Junior, BISCO Dental Products, Schaumburg, III). The teeth were divided into two experimental groups based on the type of bracket used. Group 1 (19 teeth) was bonded with metal-reinforced polycrystalline ceramic brackets (Clarity, 3M Unitek), which is a white opaque material. Group 2 (21 teeth) was bonded with clear monocrystalline ceramic brackets (Inspire-ICE, Ormco, Orange, Calif). After bracket bonding, the teeth were stored dark in a humidified chamber at room temperature for 7 days to allow complete polymerization of the adhesives.

The polycrystalline ceramic brackets were debonded mechanically using Weingart pliers (Ortho-Pli, Philadelphia, Penn), and the monocrystalline ceramic brackets were debonded using the recommended plastic debonding instrument (Ormco), following the manufacturer's debonding protocols. After debonding, the number of bracket fragments was recorded as well as the number of teeth that had bracket fragments attached after debonding. A second scan (post-debond) was obtained for all of the teeth. Residual adhesive on the teeth was also assessed visually, using a modified Adhesive Remnant Index (ARI) reference that is commonly used in debonding studies since it provides a simple method to record the site of bond failure.17 Any residual adhesive was removed with a high-speed handpiece and a multifluted carbide bur (H48LQ, KOMET of America, Schaumburg, III). A third and final scan (post-cleanup) was obtained after the cleanup.

All scans were saved in standard tessellation language (STL) format and exported to Cumulus software (Regents of the University of Minnesota, Minneapolis, Minn). To determine changes at the enamel surface where brackets had been placed, the post-debond and post-cleanup scans were superimposed on the baseline scan using all of the unaffected tooth surfaces as reference areas for precise alignment (Figure 1A). The alignment algorithm in Cumulus minimized the root-mean-square difference between the unchanged surface areas (not affected by the bracket placement) of the baseline and subsequent scans.^{18,19} At least 90% of the points on the reference surfaces were fit within 5 μ m (scanner accuracy). After the scans were fit, surface changes were visualized using a linear color scale, showing the areas of surface gain (adhesive remnants) and/or surface loss (enamel loss). The outlines of the area where brackets had been bonded were traced, and surface changes (volume and mean depth) within those areas were calculated using the Cumulus algorithms. Bonding areas that showed both volume loss (enamel loss) and volume gain (adhesive remnant) were analyzed separately to avoid loss and gain canceling each other out (Figure 1B). The volume and mean depth results were compared between the two bracket systems using the *t*-test. The ARI scores were compared using the Mann-Whitney test. The significance level was .05.

Table 1. E	Enamel Loss After B	racket Debonding and	After Cleanup (Me	ean \pm Standard Deviation)
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	Metal-Reinforced Polycrystalline Ceramic Brackets		Clear Monocrystalline Ceramic Brackets	
Enamel Loss	Post-debond	Post-cleanup	Post-debond	Post-cleanup
Number of samples with enamel loss	5	15	1	18
Volume, μm ³	144 ± 183	420 ± 287*	36	$238 \pm 136^{*}$
Depth, µm	21 ± 8	$28\pm14^{**}$	33	$18 \pm 8^{**}$

* P = .0245 (*t*-test); ** P = .0191 (*t*-test).

RESULTS

The metal-reinforced polycrystalline ceramic brackets were bonded on 19 teeth and the clear monocrystalline ceramic brackets on 21 teeth. Two polycrystalline ceramic bracket samples and two monocrystalline ceramic bracket samples were excluded from the study because of incomplete scans, bringing the sample size to 17 for the polycrystalline ceramic bracket group and 19 for the monocrystalline ceramic brackets.

Bracket debonding resulted in localized enamel loss and/or adhesive remnants left on the tooth surface (Tables 1 and 2). Five teeth from the polycrystalline ceramic bracket group and one tooth from the monocrystalline ceramic bracket group showed enamel loss after bracket removal prior to cleanup (postdebond, Table 1). The post-debond enamel loss (mean depth) was 21 μ m for the polycrystalline ceramic brackets vs 33 μ m for the monocrystalline ceramic brackets. The volume of enamel loss for the polycrystalline ceramic bracket group was 144 μ m³ vs 36 μ m³ for the monocrystalline ceramic bracket group.

Results from the 3D scans showed that all teeth except for one in the polycrystalline ceramic bracket group had adhesive remnants left on the tooth surface after debonding (post-debond, Table 2). The mean thickness of adhesive remnants post-debond for the polycrystalline ceramic bracket group was 188 μ m and for the monocrystalline ceramic bracket group was 188 μ m and for the monocrystalline ceramic bracket group was 120 μ m. The difference in the mean thickness of the adhesive remnants between the two brackets was significant (*t*-test; *P* = .0164), but the difference in volume of the adhesive remnants was not significant (*t*-test; *P* = .2381). Using the ARI classification (Table 3), it was found that the amount of adhesive remnant left on the teeth after debonding (post-debond) was significantly higher for the monocrystalline ceramic brackets

compared with the polycrystalline ceramic brackets (Mann-Whitney test; P = .016).

The adhesive remnants were removed with the carbide bur in the cleanup process. Only two teeth from the polycrystalline ceramic bracket group and one from the monocrystalline ceramic bracket group still had adhesive remaining after cleanup, with an average thickness of 16 µm for the polycrystalline ceramic brackets and 15 um for the monocrystalline ceramic brackets (post-cleanup, Table 2). However, the cleanup process also removed a small amount of enamel, resulting in an average enamel loss (depth) of 28 µm for the polycrystalline ceramic bracket group and 18 µm for the monocrystalline ceramic bracket group. Enamel loss after cleanup was significantly different between the two bracket models (post-cleanup, Table 2), both for volume (*t*-test; P = .0245) and for mean depth (*t*-test; P = .0191).

The fracture characteristics with regard to the number of bracket fragments were significantly different between the polycrystalline ceramic brackets and the monocrystalline ceramic brackets (Mann-Whitney test; P < .0001). Of the monocrystalline ceramic brackets, 95% (18/19) were removed in one piece without any fractures (Table 4). One monocrystalline ceramic bracket (5%) fractured in two pieces. Of the polycrystalline ceramic brackets, 35% (6/17) fractured in four or more pieces, and 65% (11/17) fractured in two pieces. More polycrystalline ceramic brackets left fragments on the teeth after debonding than did monocrystalline ceramic brackets: 24% and 5%, respectively.

DISCUSSION

Usually, enamel loss from debonding orthodontic brackets is assessed only after cleanup. However, debonding is a procedure that consists of two steps:

Table 2. Adhesive Remnants Remaining on the Tooth Surface After Bracket Debonding and After Cleanup (Mean ± Standard Deviation)

	Metal-Reinforced Polycrystalline Ceramic Brackets		Clear Monocrystalline Ceramic Brackets	
Adhesive Remnant	Post-debond	Post-cleanup	Post-debond	Post-cleanup
Number of samples with adhesive remnant	16	2	19	1
Volume, µm ³	$1467 \pm 685^{*}$	97 ± 78	1711 ± 516*	198
Thickness, μm	188 ± 113**	16 ± 5	$120 \pm 37^{**}$	15

* P = .2381 (t-test); ** P = .0164 (t-test).

	Number of Teeth With Each ARI Score			
ARI Score and Description	Metal-Reinforced Polycrystalline Ceramic Brackets	Clear Monocrystalline Ceramic Brackets		
0: No adhesive left on tooth	2	0		
1: Less than half of the adhesive left on tooth	6	0		
2: More than half of the adhesive left on tooth	1	2		
3: All adhesive left on tooth	8	17		

Table 3. Number of Teeth With Adhesive Remnant Index (ARI) Scores After Bracket Debonding Prior to Cleanupa

^a The ARI scores for the two ceramic bracket types are significantly different (Mann-Whitney test, P = .016).

bracket removal and resin cleanup.⁸ Each of these steps can affect the final enamel loss outcome. Therefore, we evaluated the debonding conditions and the enamel surface after each of these steps.

Using the 3D scans, we were able to guantify and compare enamel loss between the debonding and cleanup steps (Table 1). For both systems, we found minor enamel loss after debonding, which slightly increased after cleanup. Similar results have been reported for metal brackets after debonding and cleanup.^{13,15,16} Both volume (product of area and depth) and mean depth were determined for ceramic brackets in this study, but depth is more clinically relatable. Since enamel thickness is in the range of 1500 to 2000 µm and a prophylaxis procedure using bristle brush or rubber cup causes enamel loss between 7 and 14 µm,20 enamel loss of about 20- to 30 µm mean depth may be considered comparable with prophylaxis after dental cleaning. Other studies also reported little to no enamel damage but are usually based on qualitative analyses such as scanning electron microscopy and did not separate the enamel loss due to debonding and cleanup.²¹ It should be noted that the surface enamel that is removed by bracket debonding contains the highest amount of fluoride.22 Clinicians should be aware that although the amount of enamel loss may be small, permanent damage is introduced.

Besides measuring enamel loss between debonding and cleanup, the 3D analysis also allowed a quantifying of differences between the two bracket systems. Enamel loss after cleanup was significantly higher with the metalreinforced polycrystalline ceramic bracket system compared with the clear monocrystalline ceramic bracket system. This difference may be the consequence of the thicker remnant layer that was left on the tooth after debonding of the polycrystalline ceramic brackets (mean thickness, Table 2; Figure 2). If brackets fracture during debonding and fragments remain adhered to the teeth, removal of those fragments can be an arduous task.^{5,8} The removal procedure creates mental stress on both the patient and provider because it can be lengthy and cumbersome, and the cleanup procedure often leads to enamel damage.^{23,24} The latter observation is confirmed by the quantitative results in our study that show a significantly higher enamel loss for the polycrystalline ceramic bracket system that left more fragments attached after debonding.

Cohesive ceramic fracture occurred predominantly with the polycrystalline ceramic bracket (Table 4). All polycrystalline ceramic brackets fractured in two or more fragments, while only one of the monocrystalline ceramic brackets (5%) fractured (in two pieces) during debonding. This contradicts another study in which the polycrystalline ceramic brackets fractured less often than the monocrystalline ceramic brackets.²⁵ It is well documented that as the debonding forces increase, so does the frequency of enamel cracks and bracket fracture.5,8,26 The monocrystalline ceramic bracket system required a lower debonding force,26 which supports our finding of less enamel loss and fewer bracket fragments with this system. According to the manufacturer, fracture in two pieces is the preferred fracture characteristic for the polycrystalline ceramic brackets. The bracket design incorporates a vertical debonding slot that concentrates stresses at the base of the bracket so that it fractures along the vertical

 Table 4.
 Number and Percentage of Samples With a Certain Number of Bracket Fragments Following Debonding and Number of Teeth With

 Bracket Fragments Remaining^a
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	Metal-Reinforced Polycrystalline Ceramic Brackets		Clear Monocrystalline Ceramic Brackets	
Number of Fragments	Number	Percentage	Number	Percentage
0	0/17	0	18/19	95
2	11/17	65	1/19	5
4	3/17	18	0/19	0
>4	3/17	18	0/19	0
Teeth with bracket fragments	4/17	24	1/19	5

^a The number of fragments for the two ceramic bracket types are significantly different (Mann-Whitney test, P < .0001).



Figure 1. (A) Post-debond and post-cleanup scans were aligned with the baseline scan using the occlusal, proximal, and lingual surfaces as unchanged reference (fitting) areas, shown in yellow. (B) The volume and depth of enamel loss (area 1) and adhesive remnants (area 2) were measured separately at the bracket area to avoid loss and gain from canceling each other out. (For interpretation of colors the reader is referred to the web version.)

slot.²⁵ We found that most of the polycrystalline ceramic brackets (65%) fractured into two fragments. However, 6 of the 17 polycrystalline ceramic brackets (35%) fractured in four or more pieces, with four (24%) leaving fragments of the brackets bonded to the teeth. The monocrystalline ceramic brackets, on the other hand, are designed to peel off the tooth in one piece when debonded with special plastic pliers.¹² This debonding characteristic is attributed to the zirconia microspheres (40-µm diameter) that are embedded in the bracket base. Only one monocrystalline ceramic bracket (5%) left a fragment on a tooth. This finding is consistent with a previous study that found approximately 20% of the polycrystalline ceramic brackets fractured in four or more pieces.²¹ 3M Unitek offers special debonding pliers for their polycrystalline ceramic metal-reinforced ceramic brackets but claims that Weingart or Howe pliers can also be safely used.27 However, the conventional Weingart or Howe pliers may result in more bracket fragments,²⁸ which could explain our results.

It can be argued that brackets ideally debond from the adhesive and leave most or all adhesive on the tooth. The ARI, which characterizes the amount of adhesive left on the tooth, was significantly different between the two bracket systems. The monocrystalline ceramic brackets showed a more consistent debonding pattern. Of the 19 monocrystalline ceramic brackets, 18 (95%) left all adhesive on the teeth with a well-defined outline. This made the adhesive more visible and easier to cleanup (Figure 3). For the polycrystalline ceramic brackets, the ARI scores imply an inconsistent pattern of debonding. About half of the polycrystalline ceramic bracket group (47%) had all adhesive left on the teeth after debonding, while the other half (47%) had half or less of the composite remaining, indicating partial adhesive failure. This finding is consistent with another study that tested



Figure 2. (A) Post-debond scan of a tooth with partially debonded polycrystalline ceramic bracket, showing a bracket fragment left on the tooth (black, meaning out of the range of the ± 250 -µm color scale) with adjacent area of the adhesive remnant (light blue, blue, purple). (B) Post-cleanup scan of the same tooth showing where removing the bracket fragment caused slight enamel loss (green, yellow). (For interpretation of colors the reader is referred to the web version.)

the same bracket using a similar debonding protocol and found that almost half of the samples had 50% or less resin left on the teeth.²¹

Reducing enamel damage during debonding of ceramic brackets and removing of adhesive remnant is desirable.²⁹ Although we found significant differences in the performance of the two bracket systems, it can still be concluded that both ceramic bracket systems allowed for successful debonding based on the relatively minor enamel loss. When evaluating the outcome of this study, it is important to keep in mind that debonding under clinical conditions and consequent results may differ from the in vitro conditions. Debonding forces may be applied slightly differently, while temperature, moisture, and other oral conditions could reduce the bond strength and therefore alter the amount of enamel damage during debonding. In addition, the extracted teeth used in our study may have had undetected surface or subsurface cracks caused by the extraction forceps that increased the likelihood of further enamel damage. Nevertheless, the results of this in vitro study are still clinically very relevant. The 3D



Figure 3. (A) Post-debond scan of a tooth with monocrystalline ceramic bracket showing a clear outline of the adhesive remnant (blue, purple, black). (B) Post-cleanup scan of the same tooth showing no enamel loss after the cleanup procedure (gray). (For interpretation of colors the reader is referred to the web version.)

measurement technology allowed quantification of very small changes in the enamel surfaces that are clinically difficult to detect. This study showed that cleanup after bracket removal should be performed with much care. With fast-developing digital technology, a future clinical study using an intraoral scanner could verify and expand the findings of our study and provide further insights into what happens to the tooth surface following orthodontic bracket debonding.

CONCLUSIONS

- Enamel loss following ceramic bracket debonding can be quantified in vitro using an accurate 3D scanner.
- Both polycrystalline and monocrystalline ceramic bracket systems can be debonded successfully with little to no enamel damage. The polycrystalline ceramic brackets had slightly more enamel loss post-cleanup, which was attributed to the debonding process that left more resin and bracket fragments on the teeth and resulted in a more demanding cleanup.
- The final enamel loss after cleanup with a multi-fluted carbide bur was 20–30 μm for either ceramic bracket system.

ACKNOWLEDGMENTS

The authors are grateful to Dr Ralph DeLong, University of Minnesota, for the use of the Cumulus software and Dr Edward F. Harris for his mentorship and advice. We also thank Ormco and 3M Unitek for donating the bracket systems used in this study.

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