Original Article

Enamel Cracks and Ceramic Bracket Failure during Debonding In Vitro

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ABSTRACT

Objective: To test the null hypothesis that no difference in bracket failure characteristics is noted when use of a new ceramic bracket debonding instrument is compared with the use of conventional pliers.

Materials and Methods: Thirty maxillary premolars were randomly assigned to one of two groups. In group 1, Clarity collapsible ceramic brackets (3M Unitek, Monrovia, Calif) were debonded with the use of conventional Utility/Weingart (3M Unitek, Monrovia, Calif) pliers. In group 2, Clarity brackets were debonded with a new Debonding Instrument (3M Unitek). For all teeth, the same bracket bonding system was used. Following debonding, teeth and brackets were examined under 10× magnification for assessment of bracket failure (fracture) and of residual adhesive on the enamel surface. Enamel surfaces were visualized with transillumination prior to bonding and after removal of the residual adhesive, so the effect of the debonding forces could be determined.

Results: The results of Adhesive Remnant Index comparisons indicated that a statistically significant difference ($\chi^2 = 8.73$; $P = .013$) in bond failure patterns was apparent when the two groups were compared. Brackets debonded with the new instrument showed a greater tendency for the adhesive to be removed from the tooth during debonding.

Conclusions: The hypothesis is rejected. Although the incidence of enamel damage following debonding was similar in the two groups, the use of the new Debonding Instrument decreased the incidence of bracket fracture.

KEY WORDS: Ceramic brackets; Debonding; Enamel cracks

INTRODUCTION

The introduction of the direct bonding technique facilitated the construction of orthodontic appliances that are more esthetic and thus minimally obtrusive. During the early 1970s, plastic brackets were marketed as the esthetic alternative to metal brackets. These polycarbonate brackets quickly lost favor as a result of discoloration and slot distortion caused by water absorption.[1–6] This event led manufacturers to modify the plastic brackets by reinforcing the slots with metal and ceramic fillers.[7] Despite these improvements, the clinical problems of distortion and staining persisted.

In the mid 1980s, the first brackets made of monocrystalline sapphire and polycrystalline ceramic materials became widely available.[7,8] Ceramic brackets, different from plastic brackets, resist staining and slot distortion and are chemically inert to fluids that are likely to be ingested. However, several disadvantages are associated with ceramic brackets, including (1) the inability to form chemical bonds with adhesives without a coupling agent, (2) low fracture toughness[7] (ie, brittleness that can cause the bracket to fracture and fail), and (3) increased frictional resistance between metal arch wires.[9,10]

Currently, two main types of bracket adhesives are available on the market—acrylic and diacrylate resins.[11] Because of the inert composition of the aluminum oxide from which ceramic brackets are made, chemical cohesion between the ceramic base and the adhesive resin is impossible. Consequently, the early ceramic brackets used a silane coupler that was needed to act as a chemical mediator between the ceramic bracket base and the diacrylic or acrylic adhesive resin.[4,6,12,13] Chemical retention resulted in an extremely

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strong bond that caused the enamel/adhesive interface to be stressed during debonding.[6,7]

Today, three different retention mechanisms by which the base of the ceramic bracket can be made to adhere to the adhesive are available—(1) chemical, (2) mechanical, and (3) a combination of both.[11]

Ceramic materials are extremely brittle, so less energy is necessary to cause fracture (ie, failure) of the bracket.[6,14,15] In fact, even the smallest surface imperfections or cracks can significantly reduce the load that is necessary to fracture a ceramic bracket.[6,7] Fracture toughness refers to the ability of a material to resist breakage.[7] Clinically, reports of bracket fracture and enamel surface damage that occur during debonding of ceramic brackets continue to be a matter of concern to clinicians.[6,8,16–18]

To reduce the rate of irreversible enamel surface damage, several methods of debonding of ceramic brackets have been suggested. These include (1) conventional methods in which pliers or wrenches are used, (2) an ultrasonic method that requires the use of special tips, and (3) electrothermal methods that involve transmission of heat to the adhesive through the bracket.[6,19] Although all three methods have been used successfully to debond brackets, the use of pliers to apply shear or tensile force is perhaps the most convenient and the most popular method. Improvements in bracket engineering, debonding methods, and debonding instruments have been made, yet enamel damage during the debonding of ceramic brackets continues to be a matter of concern for the clinician.

Although some studies have reported no enamel damage when ceramic brackets are debonded with the appropriate pliers,[20,21] other studies have reported an increase in enamel cracks or crack length following debonding.[22–25] Studies by Liu et al,[23] Mundstock et al,[24] and Årtun[25] have reported enamel damage of up to 20% of teeth after debonding of ceramic brackets with pliers. Such damage was related to the bracket type, the bracket base design, and the adhesive system used.[23–25] Bishara et al[22] reported that 18% of teeth exhibited an increase in the number or severity of enamel cracks following debonding.

In an effort to reduce the forces placed on enamel during debonding, and thus decrease the likelihood of enamel damage, various debonding techniques performed with specific pliers have been proposed and tested.[21,26] Recently, one manufacturer (3M Unitek, Monrovia, Calif) introduced a new Debonding Instrument, in an attempt to minimize bracket failure. This manufacturer suggests that How or Weingart (3M Unitek, Monrovia, Calif) pliers can be used to debond these brackets. Little information is available on the efficacy of this recently introduced Debonding Instrument. Thus, the purposes of this study were (1) to evaluate debonding characteristics, as well as effects on the enamel surface, when the new Debonding Instrument is used to remove ceramic brackets, and (2) to compare the results with those obtained when conventional pliers are used.

MATERIALS AND METHODS

Teeth

Thirty freshly extracted human maxillary premolars were collected and stored in a solution of 0.2% (weight/volume) thymol. To meet criteria for use in the study, teeth were selected only if they had intact buccal enamel, had not been pretreated with chemical agents (eg, hydrogen peroxide [H_2O_2]), and were free of caries. The teeth were embedded in dental stone placed in phenolic rings (Buehler Ltd., Lake Bluff, Ill). After mounting, the teeth were cleaned and polished with pumice and rubber prophylactic cups for 10 seconds.

Brackets

Ceramic maxillary premolar brackets (APC Plus Clarity series; 3M Unitek) were used. These brackets are precoated with a light-cured composite adhesive. The average surface area of the bracket base was determined to be 10.3 mm^2.

Enamel Surface Evaluation

Before bonding, all teeth were carefully examined with a 10× magnifying lens for evaluation of possible enamel damage and the presence of enamel craze lines. The enamel surface was also studied under transillumination with a fiber optic light head (Kinetic Instruments, Ethel, Conn). The fiber optic light was moved back and forth over each tooth at a distance of 1 cm. Each facial tooth surface was divided into four equal vertical and horizontal zones for detailed mapping of the enamel cracks. Each tooth was evaluated twice. This method was used previously to examine the presence of cracks in the anterior and posterior teeth and was found to be superior to direct or indirect illumination of the teeth.[27] Differentiation between the orientation of cracks, whether vertical, horizontal, or oblique, as well as between weak and pronounced enamel cracks, was made. A pronounced crack was one that could be visualized with the fiber optic source and verified under normal room illumination. A weak crack was one that was not apparent under normal room illumination but could be visualized with use of the fiber optic light source.

Bonding Procedure

The teeth were then randomly assigned to one of two groups:

Group 1: Fifteen teeth were bonded according to the manufacturer's recommended protocol. Transbond Plus Self-Etching Primer (SEP; 3M Unitek) was activated and applied by continuous rubbing of SEP onto the enamel surface for 3 to 5 seconds. The SEP then was dried lightly with compressed air for 1 to 2 seconds. Each precoated maxillary premolar bracket was placed on the tooth, and a 300 g force was applied (Correx Force Gauge, Bern, Switzerland) for 10 seconds. The force gauge was used to ensure a uniform adhesive thickness between the bracket and the enamel. The bracket was light-cured with the use of a halogen curing light (Ortholux XT Curing Light; 3M Unitek) for 20 seconds (10 seconds from each proximal side). This group was debonded with conventional Utility/Weingart pliers.

Group 2: Fifteen teeth were bonded according to the same procedure that was described for group 1. This group was debonded with the new Debonding Instrument.

After bonding, all teeth were stored in distilled water for 1 week at 37°C before debonding.

Debonding Procedure

Group 1: Ceramic brackets were debonded according to the manufacturer's directions with the use of Utility pliers. The tips of the pliers were placed over the mesial and distal ends of the metal-lined arch wire slot. The tie wings were squeezed gently until the bracket collapsed. It is critical that the tips of the pliers be placed over the ends of the metal slot insert, and not over the bracket base.

Group 2: The brackets were removed with the new Debonding Instrument. Following the manufacturer's recommendations, the instrument was positioned against the mesial and distal sides of the bracket and was placed symmetrically against the labial surface of the bracket to optimize contact surface area. The instrument was squeezed until the bracket collapsed, then was gently rocked in the mesial-distal direction until the bracket became separated from the enamel.

Adhesive Remnant Index

Once the brackets were debonded, the enamel surface of each tooth was examined under 10× magnification, so the amount of residual adhesive remaining on each tooth could be determined. A modified Adhesive Remnant Index (ARI) was used to quantify the amount of remaining adhesive according to the following scale: 1 = all the adhesive remained on the tooth; 2 = more than 90% of the adhesive remained on the tooth; 3 = between 10% and 90% of the adhesive remained on the tooth; 4 = less than 10% of the adhesive remained on the tooth; and 5 = no adhesive remained on the tooth. Following evaluation of the ARI, all remaining adhesive was removed from the enamel surface with the use of a high-speed handpiece and a carbide finishing bur. The enamel surface was then reevaluated under transillumination, as described earlier.

Table 1. Frequency Distribution of Modified Adhesive Remnant Index (ARI) Scores and χ^2 Comparisons of the Two Groups Tested[a]

		Modified ARI Scores				
Pliers	n	1	2	3	4	5
Utility pliers	15	12	1	—	1	1
New Debonding Instrument	15	8	1	6	—	—

[a] $\chi^2 = 8.73$; $P = .013$. 1 indicates that all adhesive remained on the tooth; 2, more than 90% of the adhesive remained on the tooth; 3, 10% to 90% of the adhesive remained on the tooth; 4, less than 10% of the adhesive remained on the tooth; 5, no adhesive remained on the tooth; n, sample size; and *P*, probability.

Statistical Analysis

The chi-square (χ^2) test was used to compare the bond failure mode (ARI scores) between the two groups. For the purposes of statistical analysis, the ARI scores 1 and 2, as well as 4 and 5, were combined. Additionally, the chi-square test was used to compare the increase in frequency and severity of enamel cracks before and after debonding. Significance for all statistical tests was predetermined to be $P \leq .05$.

RESULTS

Adhesive Remnant Index

Results of the failure modes of the two groups are presented in Table 1. Comparison of ARI scores ($\chi^2 = 8.73$) indicates that use of the two types of pliers to debond ceramic brackets involved significantly different ($P = .013$) bracket failure modes. For both groups, most of the adhesive remained on the tooth after de-

Table 2. Changes in the Frequency and Severity of Cracks Before and After Debonding of Ceramic Brackets With Two Different Types of Pliers[a]

Pliers	n	No Change	Increase
Utility Pliers	15	12 (80%)	3 (20%)
New Debonding Instrument	15	11 (73%)	4 (27%)

[a] $\chi^2 = 0.186$; $P = .666$. n indicates sample size; *P*, probability.

Table 3. Comparison of Changes in Severity of Bracket Failure Between the Two Types of Pliers[a]

		Number of Bracket Pieces		
Pliers	n	1	2	3
Utility Pliers	15	12	1	2
New Debonding Instrument	15	15	—	—

[a] $\chi^2 = 3.33$; $P = .189$. n indicates sample size, *P*, probability.

bonding, indicating failure at the bracket/adhesive interface. Debonding with the new Debonding Instrument, however, resulted in significantly less adhesive on the tooth.

Enamel Evaluation

None of the teeth evaluated under 10× magnification showed frank enamel damage (fracture). A majority of the teeth (22/30; 73.3%) had most of the adhesive remaining on the surface following debonding, thus minimizing the likelihood of gross enamel damage. Following this evaluation, all residual adhesive was removed from the teeth with the use of a high-speed handpiece and a carbide finishing bur.

Transillumination

The teeth were reevaluated via the transillumination technique described earlier. Enamel cracks and craze lines following debonding were compared with the cracks that were apparent before bonding, and increases in number or severity were noted.

The changes observed are presented in Table 2, and results indicate that 80% of the teeth debonded with the Utility pliers and 73% of those debonded with the new instrument revealed no change in crack frequency and/or severity. Results from the statistical analysis ($\chi^2 = 0.186$; $P = .666$) also indicate that changes in enamel cracks resulting from use of the two different types of pliers were not significantly different.

Bracket Failure

The number of bracket pieces fractured during debonding was counted, to help investigators determine the severity of bracket failure (Table 3). Test results ($\chi^2 = 3.33$) revealed no statistically significant differences ($P = .189$) in bracket failure rates when the two types of pliers were compared. It is of interest to note that for all brackets that were shattered into small pieces, debonding had been done with the Utility pliers (3/15, or 20%).

DISCUSSION

The hardness and brittleness of ceramic materials have necessitated the use of special instruments to debond ceramic brackets, including wrenches, pliers with and without sharp blades, and ultrasonic and electrothermal instruments.[6,19] Recently, a new instrument was introduced that was designed to grasp the tie wings of the ceramic bracket during debonding, in an effort to hold the bracket together, thus allowing for efficient removal.

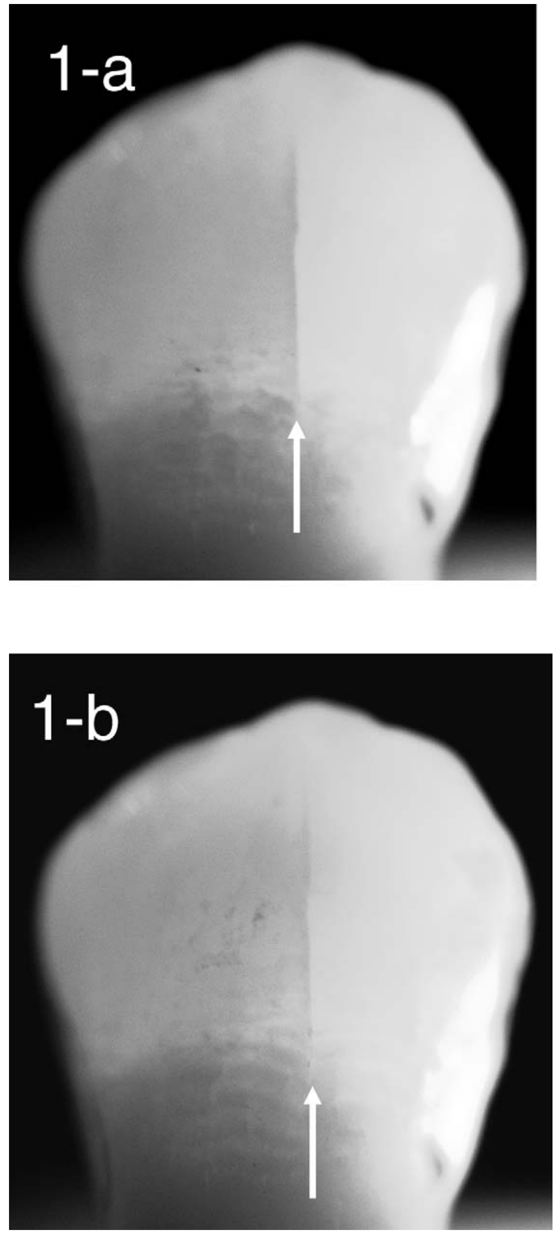

Figure 1. (A) Transillumination before bonding: Note the craze line running down the center of the maxillary premolar. (B) After debonding and adhesive removal, no increase in cracks or craze lines was observed.

Findings from the present study indicate that both types of pliers tested tended to leave a significant amount of adhesive on the enamel surface. These results are similar to those reported in previous stud-

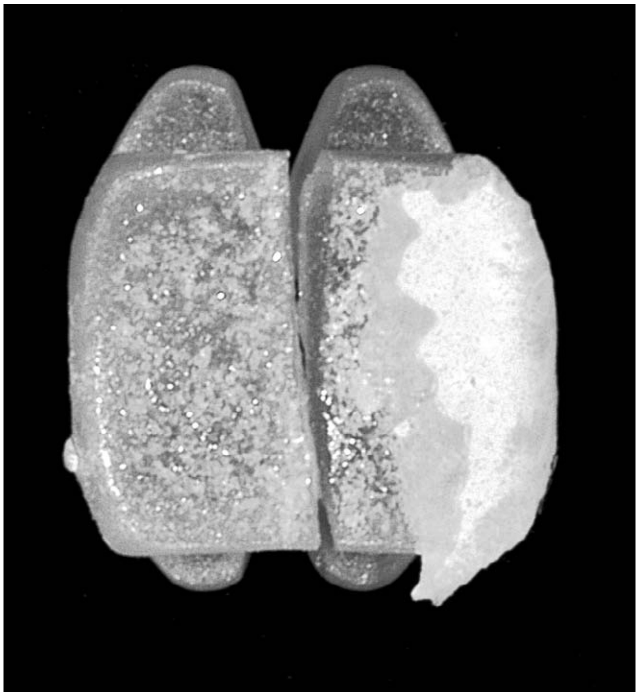

Figure 2. Clarity bracket following debonding with the new Debonding Instrument.

ies.[20,23] Such a debonding pattern has the advantage of protecting the enamel surface but the disadvantage of leaving more residual adhesive material that must be mechanically removed by the clinician after debonding. Results (Table 1) also show that the new debonding instrument left relatively less adhesive on the tooth after debonding than was left by conventional Utility pliers. Almost one half of the teeth that were debonded with the new pliers had an ARI score of 3, with ~50% of the adhesive remaining on the teeth.

The present results also reveal that changes in the enamel surface following debonding were essentially the same between the two types of pliers. Most teeth (Table 1) showed no increase in the frequency or severity of cracks (Figure 1). Other studies similarly reported no changes in 80% to 100% of teeth following removal of the ceramic brackets with pliers.[22–25]

It is important to emphasize that this is an in vitro study, and that results of debonding with new pliers might vary with conditions of the oral environment.

It is of interest to note that debonding with the new Debonding Instrument did not result in additional fracture after the bracket collapsed. This instrument is designed to adapt closely to the tie wings and engage them, minimizing bracket separation into small pieces. When the new instrument is used, the ceramic brackets collapse and crack in the mesiodistal center of the bracket (Figure 2). During this process, one half of the adhesive is removed with the bracket, and the adhesive on the other half remains on the tooth. On the other hand, with the Utility pliers, three of 15 (20%) debonded brackets fractured into two or more pieces (Figure 3). This debonding mode is clinically undesirable for two reasons: (1) It makes the remaining bracket fragments more difficult to remove, and (2) the bracket fragments may present a hazard to the patient if swallowed or aspirated.

Regardless, when ceramic brackets are used, the clinician should avoid applying significant force to the

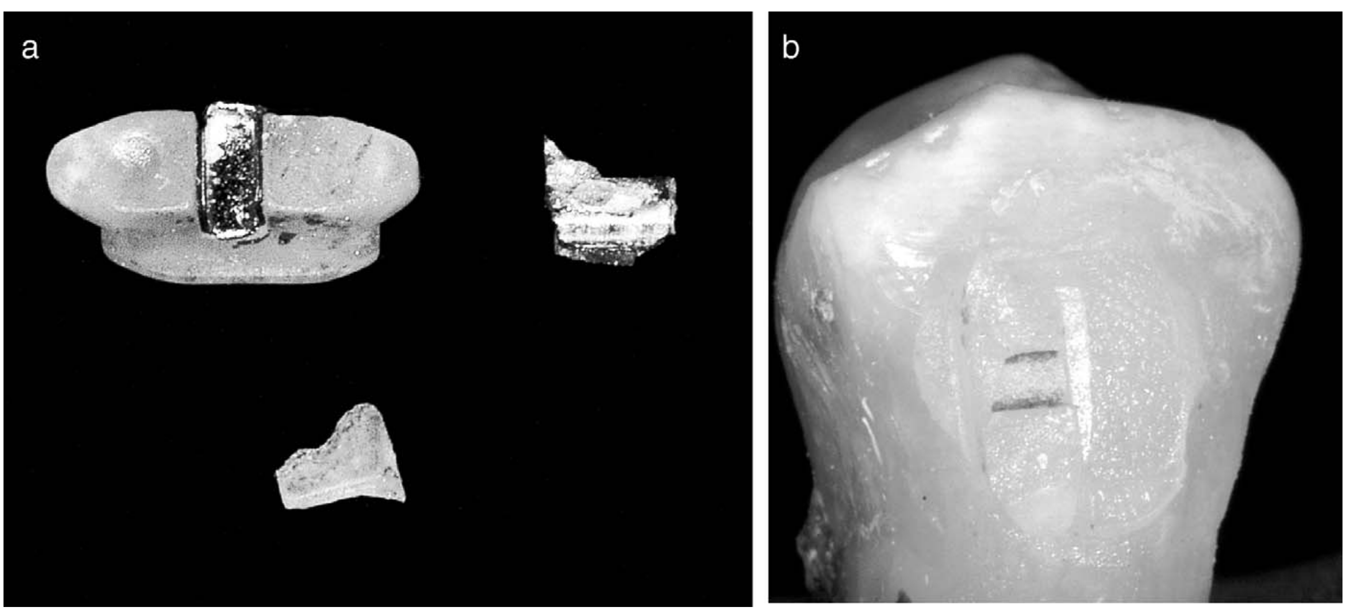

Figure 3. (a) Bracket failure that occurs during debonding with How pliers. (b) Residual adhesive remaining on the tooth with the imprints of the bracket base.

bracket base during debonding to minimize partial bracket failure.

CONCLUSIONS

- The number of enamel cracks that results from debonding was similar between the two types of pliers.
- The new pliers left less adhesive on the teeth following debonding and produced a lower incidence of bracket fracture.

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