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ORIGINAL ARTICLE

# Effect of simulated debracketing on enamel damage

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**KEYWORDS**
debracketing;
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squeeze;
tensile

*Background/Purpose:* A smooth enamel surface after the removal of a bracket from a tooth is essential for both esthetic demands and the prevention of plaque accumulation. The purpose of this study was to evaluate enamel damage caused by three standardized debracketing techniques.
*Methods:* We established three standardized test devices based on the principles of the squeezing, shearing, and tensile testing methods, which were simulated using a How Plier (TASK 60-306), a Direct Bond Bracket Remover (TASK 60-335 T), and a Lift-Off Debracketing Instrument (3 M-Unitek 444-761), respectively. Thirty teeth in each group were evaluated after debracketing. An optical stereomicroscope and a CCD camera with a computerized image analysis system were used to ascertain the proportion of remnant adhesive area (RAE) on the enamel surface. Fractography was analyzed using a scanning electron microscope.
*Results:* The squeezing debracketing method exhibited the highest debonding force (54.3 ± 7.0 N) and the least damage to the enamel surface (RAE = 99.5% ± 2 .4%). The tensile debracketing method preserved most of the adhesive on the enamel surface (RAE = 98.7% ± 3.3%) and required the least debonding force (6.8 ± 1.2 N). However, the shearing debracketing method exhibited a significantly higher debonding force (32.0 ± 8.2 N) and smaller RAE (77.3% ± 33.5%) compared to the tensile debracketing method ($p < 0.05$). Three specimens appeared to have vertical fractures on their enamel prisms when using the shearing method.

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*Conclusion:* With the proposed method, we conclude that the squeezing and tensile methods are acceptable for clinical use when debracketing, whereas the Direct Bond Bracket Remover may cause shearing failure, leading to a risk for enamel damage.


## Introduction

During conventional orthodontic therapies, bands and brackets are adhered to the teeth to apply the energy stored in the wires directly to the teeth. In 1955, Buonocore[1] introduced acid-etch bonding technology into orthodontics. Unlike the original bonding technology, acid-etch bonding is based on the theory of applying phosphoric acid or another weak acid onto the tooth surface and creating a rough surface to which the brackets are adhered. After orthodontic treatment using fixed appliances, orthodontic clinicians and researchers want to avoid cohesive enamel failures during bracket debonding to obtain adhesive-free tooth surfaces.[2–4]

The success of bracket debonding relies on keeping the enamel structure intact without producing iatrogenic damage. In addition, removing the adhesive remnants is necessary to eliminate any potential plaque retention and obtain an aesthetically pleasing enamel surface appearance. Improper bracket debonding will injure the enamel, result in cracks in its surface, cause enamel prism fracture and potentially cause additional aesthetic problems, such as tooth sensitivity, an increased risk of caries and pulp inflammation.[5,6] Therefore, it is important to evaluate the structure of the tooth surface after debonding.

Newman and Facq[7] were the first to evaluate the enamel surface after bracket debonding during orthodontic research. The debonding procedure consists of debracketing and clearing the residual adhesive from the tooth surface. Two major areas in the field of orthodontic research are debracketing analysis and residual adhesive clearance. In response to aesthetic demands, an abundance of studies regarding ceramic brackets have been performed; however, the use of metal brackets is still the gold standard for orthodontic treatment. To obtain clear enamel appearance after debracketing, many studies have recommended numerous finishing and polishing methods, including the following: the use of tungsten carbide burs at a low speed followed by pumice and/or polishing cups; the use of a tungsten carbide bur at a high speed and finishing with graded medium, fine and superfine Sof-Lex (3M Corporate Headquarters, St. Paul, MN, USA) discs at a low speed with final finishing using a rubber cup and Zircate (DENTSPLY Limited, Addlestone, Surrey, UK) paste; the use of stainless-steel finishing burs; the use of a low-speed tungsten carbide bur; and most recently, polishing tool kits with silicon silicone carbide, silicone dioxide, or diamond particles.[8–10]

The cleanup of adhesive materials and the enamel structures associated with various debracketing procedures have been studied less frequently due to difficulties in creating a standardized debracketing testing device. These studies have been performed using manual debonding, which does not standardize the consistency of the force magnitude or the initiation direction. Thus, the individual variation compromises the validity of the quantitative analysis. Thus, fewer conclusions were drawn from the current studies on these various debracketing procedures, and no compliance rule is available for clinicians. The aims of this study were to establish three kinds of debracketing test methods that simulate three contemporary debracketing techniques in the orthodontic clinic and to qualitatively and quantitatively evaluate enamel surface damage after debracketing using standardized test devices.

## Materials and methods

### Specimen preparation for debracketing

A total of 90 extracted premolars with undamaged surfaces were collected and stored in a 0.2% thymol solution at 4 °C. The teeth were rinsed and coated with 37% phosphoric acid for 30 seconds. The acid-treated teeth were then rinsed with distilled water for 20 seconds and dried with compressed air until the enamel became frosty. A light-curing adhesive, ENLIGHT (Ormco 740-0198, Orange, CA, USA), was used to adhere the bracket (Dentaurum 790-010-80, GmbH & Co. KG, Ispringen, Germany) to the enamel surface after acid-etching and polymerized with a halogen light-curing machine (Optilux 501, Kerr, Orange, CA) for 10 seconds. The premolars were randomly assigned into three groups (squeezing, shearing, and tensile testing groups). We embedded each tested bracket-tooth (along with its adhered bracket) in plaster within an aluminum ring. The ring (with its embedded tooth) was fixed in a customized debracketing device attached to a universal testing machine (Instron 5566, Instron Corporation, Norwood, MA, USA) as a standardized bracket removal procedure.

The proposed debracketing devices were fabricated according to the principles of three commonly used bracket removal technologies (the squeezing, shearing and tensile testing methods), which are described in the paragraphs below.

### Standardized debracketing techniques

#### Squeezing method

A How Plier (TASK 60-306, Ortho-Care Ltd., West Yorkshire, UK) was used and placed onto a mechanical fixer, with its beaks holding the bracket (Fig. 1). The crosshead speed of the load cell was set at 1.0 mm/minute. Force was applied onto the arms of the pliers until the bracket was removed.

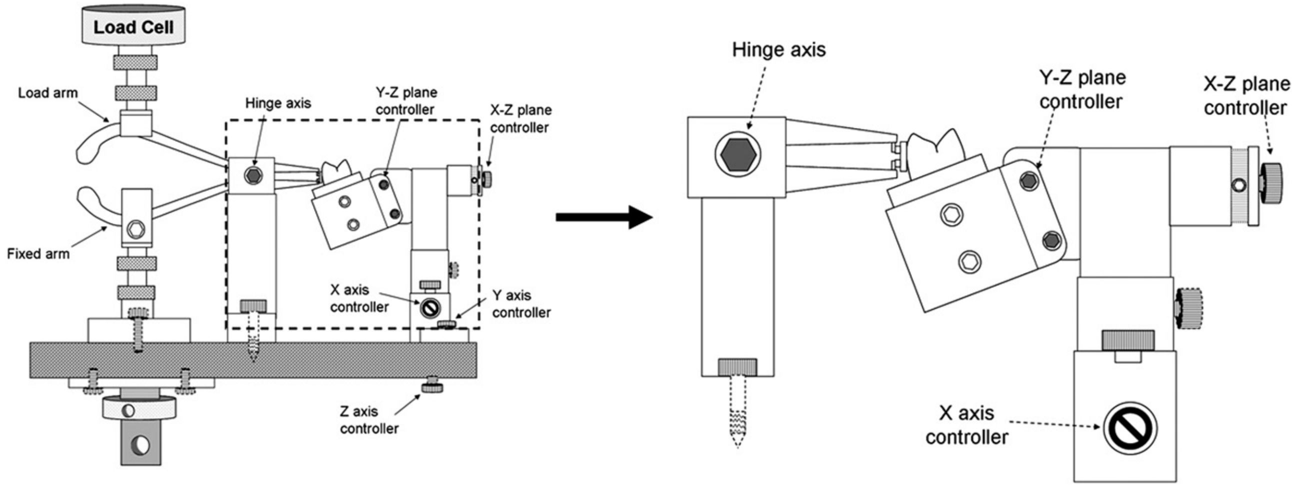


**Figure 1** Illustrations of the standardized squeezing method for simulated debracketing that was set up using a How Plier (TASK 60-306).

**Shearing method**
A Direct Bond Bracket Remover (TASK 60-335 T, Ortho-Care Ltd., West Yorkshire, UK) was set up on a mechanical fixer, with its blades inserted between the bracket and the enamel, where the adhesive zone resides (Fig. 2). The load cell was set at a crosshead speed of 1.0 mm/minute, and the force was applied to the blades of the remover until the bracket was severed off.

**Tensile testing method**
A Lift-Off Debracketing Instrument (3M Unitek Orthodontic Products 444-761, Monrovia, CA, USA) was positioned on a mechanical fixer, with its loop holding the tie-wings of the bracket (Fig. 3). The crosshead speed of the load cell was set at 2.0 mm/second. Force was applied to the loop until the bracket was pulled off.

All of the debonding forces and displacement data from the three aforementioned debracketing methods were collected and recorded using the commercial software associated with the Instron 5566 Universal Testing Machine (Merlin Software Suit, Instron Corporation, Norwood, MA, USA).

## Fractography analysis

The debonded surfaces of the brackets and the enamel were examined under stereoscopic microscopes (Olympus Optical Co., Ltd., Tokyo, Japan) and magnified by a factor of 25. We defined the proportion of remnant adhesive area on the enamel surface as the remnant adhesive area (RAE) = (adhesive remnant area/bonding area) $\times$ 100%.

The evaluated microscopic images were captured by a charge-coupled device (CCD) camera (Olympus Optical Co.) and transmitted to a computerized image analysis system (Leica Quantinet 500 MC Plus Image Analysis System, Leica Cambridge Ltd, Cambridge, England) to determine the RAE (Fig. 4).

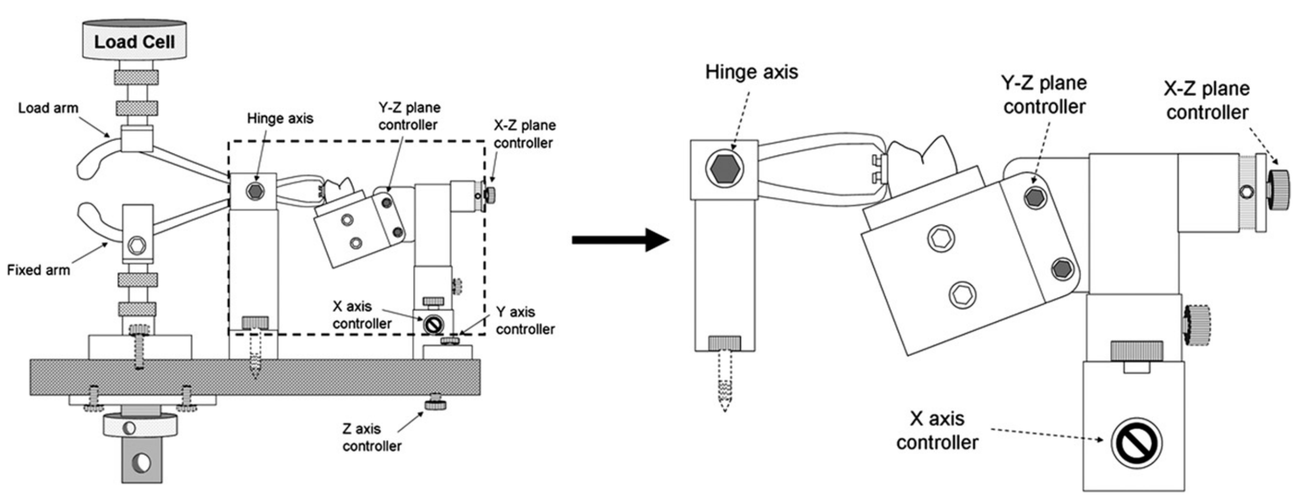


**Figure 2** Illustrations of the standardized shearing method for simulated debracketing that was set up using a Direct Bond Bracket Remover (TASK 60-335 T).

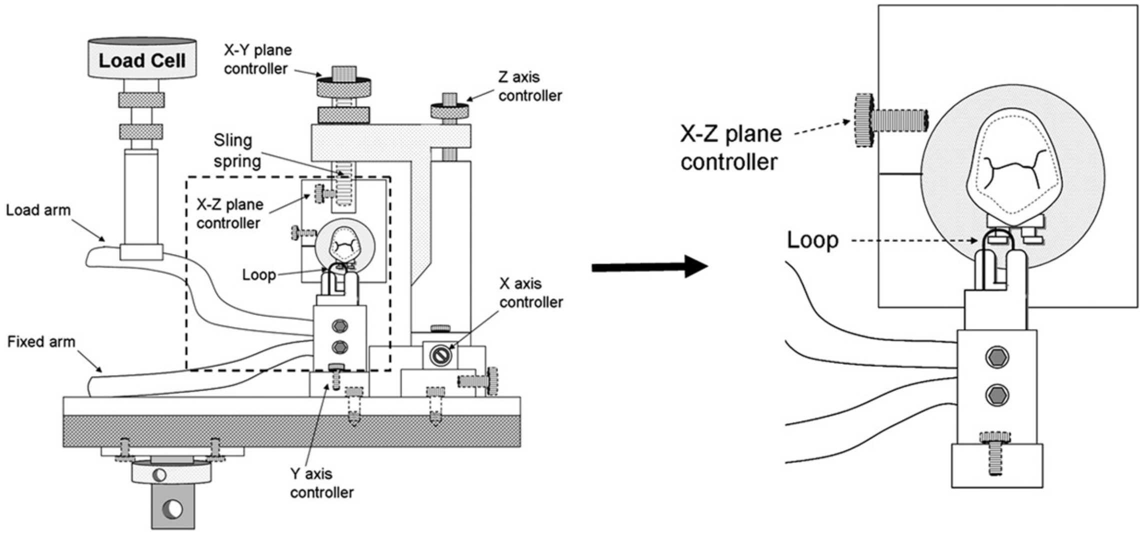


**Figure 3** Illustrations of the standardized tensile method for simulated debracketing that was set up using a Lift-Off Debracketing Instrument (3 M-Unitek 444-761).

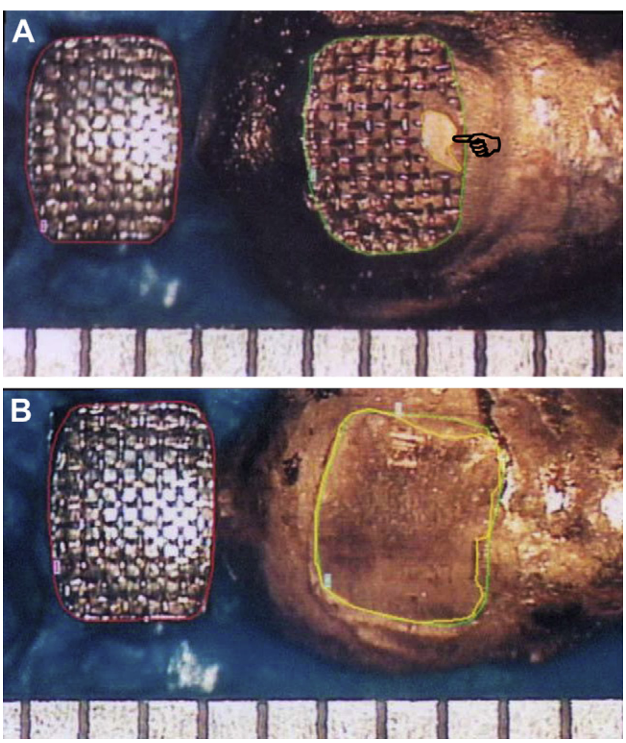


**Figure 4** Determination of the proportion of remnant adhesive area on the enamel surface (RAE) using stereoscopic microscopy and a computerized digital image analysis system. (A) A representative specimen subjected to the squeezing debracketing method reveals that most of the adhesive remained on the enamel surface. The pointer indicates the yellow circled area of the lost adhesive on the tooth side; (B) a representative specimen subjected to the shearing debracketing method exhibits debonding between the adhesive and the tooth that may damage the enamel surface. RAE = [(green circle area - yellow circle area)/green circle area] × 100%.

Any sample in which the debonding adhesive was not intact were coated with gold film and then observed under a scanning electron microscope [(SEM) JEOL Ltd., JSM-T100, Tokyo, Japan] to determine the size and fracture pattern of the damaged area on the enamel surface.

## Statistical analysis

The results were evaluated using one-way analysis of variance (ANOVA) and Tukey's test ($\alpha = 0.05$) using the SAS software (SAS® 8.2, SAS Institute Inc., Cary, NC, USA). The independent factor was the debracketing method (Sq = squeezing, Sr = shearing, and Tn = tensile testing), and the dependent factors were the debonding force and the proportion of the RAE on the enamel surface. The null hypothesis was that no differences exist among the three debracketing groups.

## Results

The means, standard deviations, and descriptive differences of the debonding forces and RAEs were calculated and summarized in Table 1. In the one-way ANOVA, the *f*-value was 12.42, and the *p*-value was less than 0.0001; these values showed that the three simulated debracketing methods had very significant effects. Hence, the null hypothesis was rejected.

In general, the debonding force can be sorted into the following order: "squeezing group" > "shearing group" > "tensile testing group." The rank order of the RAE was as follows: "squeezing group" > "tensile testing group" > "shearing group." The squeezing debracketing group exhibited the highest debonding force (54.3 ± 7.0 N) but the least damage to the enamel surface (RAE = 99.5% ± 2.4%). It is interesting to note that the tensile debracketing group also preserved the most of the adhesives on the enamel surface (RAE = 98.7% ± 3.3%) and required the lowest debonding force (6.8 ± 1.2 N) of the

**Table 1** Statistical analysis of the three common debracketing techniques simulated in this study.

| Group ($N$ = 30) | Mean of debond force (SD), $N$ | CV of debond force (%) | Mean of RAE (SD), % | CV of RAE (%) |
|---|---|---|---|---|
| Squeezing | 54.3 (7.0)[a] | 12.6 | 99.5 (2.4)[b] | 2.4 |
| Shearing | 32.0 (8.2)[a] | 25.5 | 77.3 (33.5)[c] | 43.4 |
| Tensile | 6.8 (1.2)[d] | 17.0 | 98.7 (3.3)[a,b] | 3.5 |

[a,b,c,d]Results of the one-way analysis of variance and Tukey's test. In each column, the groups labeled by the various superscripts exhibit significant differences ($p < 0.05$).
CV = coefficient of variation; RAE = remnant adhesive area; SD = standard deviation.

three groups ($p < 0.05$). However, the shearing debracketing group exhibited a higher debonding force (32.0 ± 8.2 N) and the lowest RAE (77.3% ± 33.5%) among the three groups.

## Fractography analysis

Based on stereoscopic microscopy and computerized image analysis, our raw data revealed that the squeezing and tensile debracketing methods retained at least 85% of the adhesive on the enamel surface (Fig. 4). However, in some specimens (in which the shearing debracketing method was used), the RAE was only 6%–12%. The failures often occurred in the adhesive resin or between the adhesive resin and the enamel surface. The SEM observations revealed enamel damage in only one specimen in the tensile testing group and in three specimens in the shearing group. The fractography appeared to be vertical with respect to the enamel prism and appeared to be keyhole- and cone-shaped (Fig. 5).

# Discussion

A smooth surface is very important both for aesthetic demands and for preventing biofilm accumulation. Thus, the outermost enamel layer should be as intact as possible because compared to the deeper zones, it has higher microhardness and a higher mineral and fluoride content. A rougher enamel surface may favor dental biofilm/plaque retention, which produces superficial staining and gingival inflammation. In addition, the acidic byproduct initiated by the bacterial biofilm will result in a lower pH, leading to the chemical dissolution of the mineralized hard tissue; this results in dental caries.[11] Enamel surface damage and the associated exposure of the enamel prism endings to the oral environment may decrease the enamel's resistance to organic acids, rendering it more prone to demineralization and caries.[3,11,12]

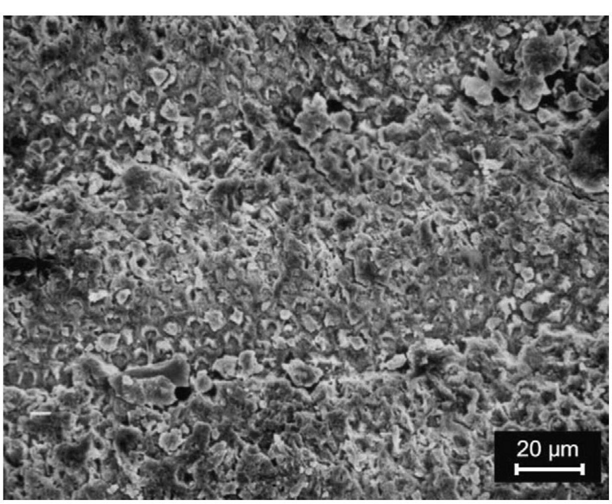


**Figure 5** Scanning electron micrograph of the enamel surface with a vertical prism fracture. This surface was debracketed using the shearing method (Direct Bond Bracket Remover). Fractography is shown as a keyhole- or cone-like shape on the enamel fracture surface.

Thus, numerous studies and clinical techniques have been developed to maintain pristine enamel after debracketing. Examples include finishing and polishing procedures, debracketing techniques, laboratory evaluation methods, various bracket base designs, cementation techniques, and adhesive composition.

## Standardized debracketing technique

In this study, we established three standardized bracket removal methods to simulate techniques that are commonly used in the clinic. Based on the central trend of the statistical analysis (Table 1), the means of the debonding forces in the three groups were as follows: squeezing = 54.3 N, shearing = 32.0 N, and tensile testing = 6.8 N. The debonding forces of the three debracketing methods differed from one another because of the various loading methods and the distinct designs of the moment arms of the three pliers. The selected debracketing pliers were three of the most widely used pliers that represented three different debracketing forces: squeezing, shearing and tension. The ratios of the lengths of the loading force and resistance arms of the How Plier, Direct Bond Bracket Remover, and Lift-Off Debracketing Instrument were 6.1/4.1, 7.0/3.0, and 8.3/0.8, respectively. The forces that the three pliers exerted on the bracket were parallel to the direction of force of the compression strut of the Instron device. Based on the mechanics formula, Moment = Force × Distance, the average forces of the How Plier, Direct Bond Bracket Remover, and Lift-Off Debracketing Instrument were calculated as 80.4 N, 74.6 N, and 71.3 N, respectively. These similar moments demonstrate the reliability of our standardized debracketing device. In addition, it is plausible that, in this study, the tensile testing method required the least force to remove the bracket (Table 1). Moreover, successful clinical bonding to a bracket normally requires 6–10 MPa of shear bond strength.[13,14] In this study, a bracket base with an area of 3 mm × 4 mm was used. For such a bracket, 72–96 N (1 MPa = 1 × $10^6$ N/$m^2$ = 1 N/$mm^2$) of shear bond strength are needed for debonding. This correlates well with the data (74.6 N) from this experiment.

Some reports have suggested that the minimum debonding force should be 3.6–9.1 kg, which is equivalent to 35.3–89.2 N.[15,16] In this study, the debonding forces of the three standardized methods fell into the suggested range and match actual clinical needs. Furthermore, in this study, the coefficients of variation ranged between 12.6% and 25.5% (Table 1), indicating that this method is quite reproducible, especially when comparing these the coefficients of variation to those that have been found for shear bond strength (40%–360%) and tensile bond strength (65%–111%) in other current studies on restorative materials.[17–19] Although the precautions in fabricating these three debracketing methods may not ensure a pure shear or tensile test, they do standardize the testing methods and render them more reproducible.

### Fractography analysis

For the proportion of RAE on the enamel surface, the squeezing and tensile testing methods retained higher RAEs (99.5% and 98.7%), while the shearing method exhibited an RAE of 77.3%.

During an operation in an orthodontic clinic, the optimal consequence of debracketing is to completely strip (debond) the bracket from the interface between the bracket and the adhesive, (i.e., the RAE should be 100%). As long as the RAE is less than 100%, the fracture surface may occur in the adhesive zone or at the adhesive/enamel interface (Figs. 4 and 5). Next, the fracture surface should be observed using SEM to determine whether such a result harms the enamel and/or fractures the enamel prism. In addition to qualitative analyses using a stereomicroscope and an SEM, data from digital image analysis software provide a quantitative measure for comparing the various groups.

Regarding the fractography, Fowler and colleagues[20] proposed the failure modes of the fracture surfaces based on the following principle: at least 75% for adhesive failure, 25%–75% for adhesive-cohesive failure, and less than 25% for cohesive failure. In addition, previous adhesive remnant index (ARI) calculation methods were mainly determined using the naked eye and were only classified into scores of 0, 1, 2, and 3, which were based on the remnant adhesive area on the tooth surface.[9,21] In this study, we determined the RAE using a computerized image system and pooled the real percentage of the remnant adhesive into statistical analysis, which provided a more reliable database for both investigators and clinicians as a critical guideline. This study found that 28 out of the 30 sample teeth from the squeezing group remained intact, and two teeth exhibited 12.9% and 3.6% surface damage due to a cohesive failure mode. Based on the SEM observations, no evidence for a fractured enamel prism was found, and the fracture surface resulted from the adhesive resin falling into the mode of cohesive resin failure. In the shearing group, 20 out of the 30 sample teeth were undamaged, while four teeth appeared to have a damaged area of more than 75%. Two teeth exhibited vertical fractures in the enamel prism; however, even this area was rather small (less than 25%). This result also demonstrates why we defined the setup of Direct Bond Bracket Remover as shearing. Van Noort and colleagues[22] and Versluis and others[23] have pointed out that shear-bond tests can pull out the dentin. Although the elastic modulus of the enamel is larger than that of the dentin, the tooth structure may still be cut due to massive stress concentrations.

In conclusion, our results provide orthodontic clinicians with a principle for bracket removal and avoiding damage to the enamel surface. We found that the How Plier (or the Weingart Plier) and the Lift-off Debracketing Instrument are acceptable for clinical use (squeezing and tensile testing methods, respectively), while the Direct Bond Bracket Remover (or ligature cutter) may cause shearing failure and lead to a risk of enamel damage. In the future, with these proposed methods, we can also quantitatively and qualitatively evaluate the effects of various adhesives, bonding techniques and bracket designs on the debracketing failure mode.

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