Debonding forces applied to ceramic brackets simulating clinical conditions

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At the end of orthodontic treatment, bonded metal brackets are usually removed mechanically with orthodontic pliers and other devices. These instruments either deform the bracket and break the bond at the bracket-adhesive interface, or stress the adhesive to its ultimate strength and cause cohesive failure within the composite resin. An optimal method of removing metal brackets involves the application of a force that peels the bracket base away from the tooth causing bond failure at the adhesive-bracket interface. This method of debonding is advocated because it is consistently atraumatic.[1,2]

Complications such as enamel fractures, cracks and flaking have been reported during mechanical debonding of ceramic brackets.[3] As a result, the potential for tooth damage is a major concern among clinicians using these brackets. The possibility of enamel damage during debonding is a function of two main variables: the brittleness of ceramic and the bond strength at the bracket-adhesive interface.[4]

Applying debonding pressure on the bracket base often results in partial or complete bracket failure (fracture). The bracket remnants are usually removed with a diamond bur in a high-speed handpiece, which can cause both the patient and the clinician significant apprehension. As a result, manufacturers have developed new debonding techniques specifically designed for ceramic brackets. One of the first instruments marketed for this use requires the application of heavy shear-torsion forces to the already sensi-

Abstract

Debonding ceramic brackets is an area of concern to clinicians. Reports of enamel fractures and cracks have raised questions about the safety of the procedures used to remove these attachments.

The purpose of this study was to compare the differences between the actual forces generated during bracket removal in the clinical setting and the shear forces applied during laboratory testing. Adhesive Remnant Index (ARI) scores are presented as a percentage of the total number of teeth tested and are compared between the two types of debonding methods. The ARI scores quantitatively express where the bond failure occurs during bracket removal.

The results indicate that there is a significant difference between the mean bond strengths of the shear (107.8 kg/cm^2) and the modified diametral compression (67.8 kg/cm^2) forces. Debonding ceramic backets with pliers requires the application of 30% less force to the enamel surface than debonding with the shear forces as tested in the laboratory. There were no significant differences in the ARI scores of the two groups—i.e. where the bond failures occured.

Key Words

Debonding forces • Ceramic brackets • Pliers • Shear test

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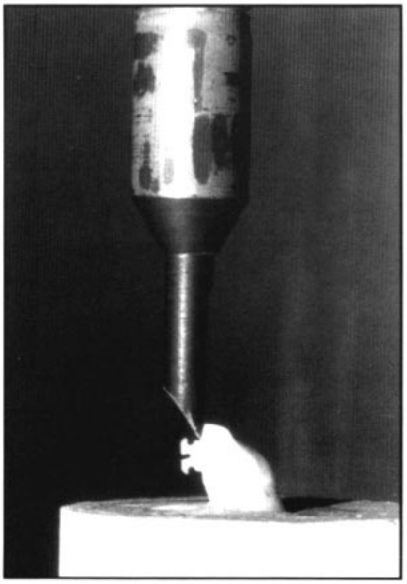

Figure 1

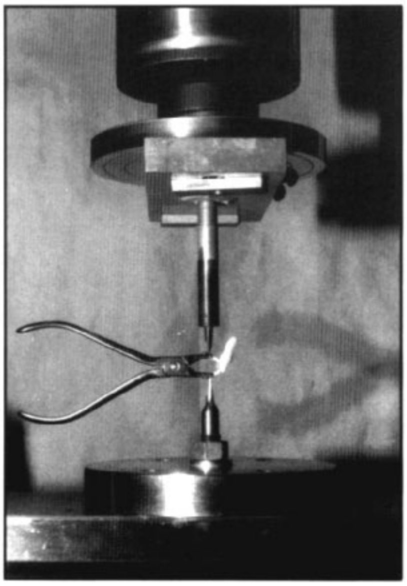

Figure 2A

Figure 1
Shear bond testing using the Instron Machine.

Figure 2A-B
Diametral compression testing using the debonding pliers simulating clinical conditions.

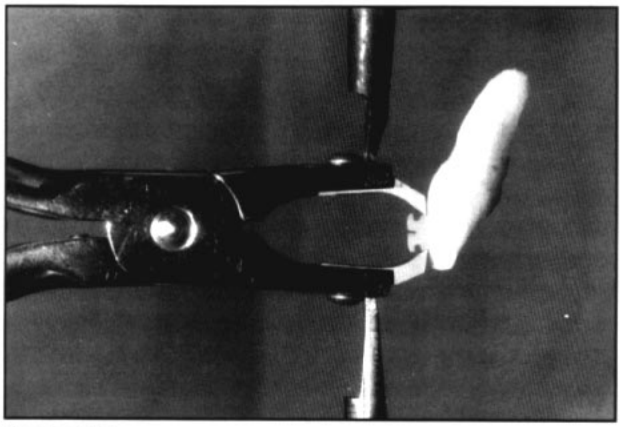

Figure 2B

tive and mobile teeth. The sudden nature of bracket failure in this approach has the potential of causing enamel fracture or cracks.[5]

Most ceramic brackets are removed with specially designed pliers that apply some form of tensile or shear force to the tooth surface.[5] Swartz recommended that ceramic brackets should be debonded with a sharp-edged debonding instrument placed at the enamel-adhesive interface. A gradual squeezing force should be applied until bracket failure occurs. Attempting to twist one piece from the other requires great force while wedging a chisel at the interface of the two will usually be less destructive and require significantly less force.[4]

Alternative debonding methods: New debonding methods are constantly being tried in an attempt to reduce trauma to the tooth structure while increasing the efficiency of cleanup of the enamel surface.

Brackets can be removed with an ultrasonic device with minimal damage to tooth structure but this approach significantly increases debonding time and results in considerable wear on the ultrasonic tip.[3]

Electrothermal procedures have also shown promising results with minimum damage to the enamel structure. Bishara and Trulove[3] found that the incidence of bracket failure during debonding was significantly greater with conventional debonding methods (10-35%) than with electrothermal methods (0%). However, an inflammatory pulpal response is possible.[6]

While the shear and tensile bond strengths for ceramic brackets *in vitro* have been reported,[7-16] the actual force applied when using a sharp-edged debonding plier to debond a bracket has not. The debonding plier is unique in that it applies force at the bracket-adhesive interface on both sides of the bracket base simultaneously. This method of debonding is a modified diametral compression test for tension. The diametral compression test is used for materials that have very little plastic deformation, such as ceramics, composites and enamel. This is an indirect way to measure the tensile strength.[17] This compressive force introduces a tensile stress perpendicular to the force application. In such a situation, the tensile stress is directly proportional to the compressive load applied, thus simulating a bilateral load. This type of compressive force simulates the clinical application of debonding force transmitted by the sharp edges of a debonding plier.

The purpose of this study was to compare the differences between the actual forces generated during bracket removal in the clinical setting and the shear forces applied during laboratory testing.

Materials and methods

Teeth: Fifty-one extracted human teeth were obtained and stored in an aqueous solution of thymol (0.1% wt/vol) to prevent dehydration and bacterial growth. The teeth were free of large restorations or caries which may affect the enamel strength. Each tooth was thoroughly scaled and rinsed to remove calculus, soft tissue remnants, and debris. The age, sex, race, and other population distributions of the patients supplying the teeth were unknown.

Brackets: The Transcend 2000 bracket (Unitek Corporation/3M, Monrovia, California) was used in this study. It is made from a polycrystal aluminum oxide. The bracket has an opaque color, is mechanically retained and has an average base surface area of 11.88 mm^2.

Table 1
Results of Student t-test comparing the debonding strengths for diametral compression and shear forces.

Force Group	N	Mean£	Standard Deviation	Standard Error	Range£	D.O.F.§	Prob.
Diametral	30	67.8	74.2	13.62	9.5-331.3	47.8	.02*
Shear	21	107.8	43.6	9.56	42.0-211.3	47.8	

£Kg/Cm² §Degrees of Freedom N = number in each group Prob. $p \leq 0.05$ t-value = -2.41

Surface preparation technique: Each tooth was given a 15-second prophylaxis consisting of a rubber cup and pumice on a slow speed contra-angle handpiece. Then the teeth were rinsed thoroughly and dried.

The teeth were etched for 30 seconds with a 37% phosphoric acid solution and rinsed for 20 seconds. The teeth were again thoroughly dried and the ceramic brackets were bonded using Endur adhesive (Ormco Corporation, Glendora, California) following the manufacturer's instructions. All excess adhesive was removed from around the bracket periphery. The teeth were left undisturbed for 48 hours in distilled water.

The teeth were randomly assigned so that there were equal numbers of incisors and molars in the two groups to be tested.

Methods of debonding: An Instron Model Universal Testing Machine (Instron Corporation, Canton, Massachusetts) was used to assess debonding strengths. A 500 kg capacity load cell, set on the 100 kg scale, was used to determine bond strength. The load cell was calibrated prior to data collection checked at regular intervals during testing. A cross head speed of 0.2 inches per minute (0.5 cm/min) was used for all debonding strength determinations. The load required to break each bond was quantified using a strip chart recorder with a speed of 5 inches per minute.

Two methods of debonding were tested. In the first group, a special jig positioned the tooth so that the ceramic bracket was perpendicular to the knife-edged blade at the incisal dimension at the bracket-adhesive interface (Figure 1). The Instron machine applied a shear force until bond failure occurred. One blade was used throughout the entire sample of the shear force group, which included a total of 21 teeth. The force values generated by this method of debonding have been previously reported,[7-13] but no attempt was made to compare such force values to those generated when using the debonding pliers.

In the second group 30 brackets were debonded using an ETM 346 debonding plier (ETM corporation, Monrovia, California). The bonded brackets were positioned freely between the ETM plier blades in the incisal-gingival dimension at the bracket-adhesive interface (Figure 2A and B). Force was applied to the flat surface of the plier to minimize the chance of it slipping. The Instron machine slowly applied a squeezing force to the plier until bond failure occurred. Two sets of ETM 346 debonding plier blades were used to debond the 30 teeth. After debonding 15 teeth the plier blades were replaced.

The debonding forces recorded by the Instron machine with this method are not equal to the actual debonding forces applied at the bracket-adhesive interface. This is because the force was applied at a predetermined distance on the plier beaks. However, these forces are directly proportional and can be expressed in the following ratio: the actual force equals the measured force multiplied by "a" divided by "b" (a/b), where (a)

Table 2
Distribution of Adhesive Remnant Index for the diametral compression and shear forces.

	ARI£ Scores				
Type of force	1	2	3	4	5
Compression	0.0%	3.3%	73.3%	10.0%	13.3%
	0/30	1/30	22/30	3/30	4/30
Shear	0%	0%	38.1%	42.8%	19.0
	0/21	0/21	8/21	9/21	4/21

£ARI = Adhesive Remnant Index
1 = All adhesive remains on tooth.
2 = More than 90% of the adhesive remains on the tooth.
3 = More than 10% but less than 90% of the adhesive remains on the tooth.
4 = Less than 10% of the adhesive remains on the tooth.
5 = No adhesive remains on the tooth.

is the distance from where the measured force is applied to the fulcrum of the pliers and (b) is the distance from where the actual force is applied to the fulcrum of the plier. The actual debonding strengths were calculated by taking the measured debonding strength, in kg/cm^2, and multiplying it by 0.77.

In addition to the debonding forces, the other variables evaluated were the amount of residual adhesive remaining following debonding using the Adhesive Remnant Index (ARI)[2], the incidence of bracket failure (fracture), and the presence of visible enamel damage. The ARI is one method of visually determining where bond failure occurred (see details in Table 2). Such a determination is of clinical importance because the greater the incidence of failure at the enamel-adhesive interface the greater will be the stresses applied to the enamel surface.

Statistical Analysis: The debonding strengths for the shear and diametral compression force groups were recorded in kg/cm^2 and compared using the Student's t-test[18] to determine if there was a significant difference between these two groups. The level of significance was established at the 0.95 level of confidence.

The Adhesive Remnant Index (ARI) scores were presented as a percentage of the total number of teeth tested and compared using a X^2 test.

Results

Comparison of debonding strength between two methods of debonding: A student t-test was performed to compare the debonding strengths of two types of force application, shear strength and a modified diametral compression strength using debonding pliers. The results of the comparisons are presented in Table 1 and indicate that there was a significant difference ($p < 0.05$) in debonding strengths between the modified diametral compression (67.8 kg/cm^2) and the shear force (107.8 kg/cm^2) applied by the Instron machine.

Comparisons of the Remnant Adhesive Index: Frequency distributions of the ARI scores for both types of force applied are presented in Table 2. No significant differences were present between the two groups. The results indicate that the distribution of the ARI scores range between 3 and 5 and indicate that failure occurs mostly within the adhesive or at the adhesive-enamel interface.

Presence of visible enamel damage: None of the debonded teeth showed any visible enamel damage in either of the two groups tested.

Discussion

The shear and tensile bond strengths for ceramic brackets have been measured in previous studies.[7-16] Until recently, however, no attempt has been made to measure the force applied by a sharp-edged plier during debonding.[19] The latter method of debonding is frequently used by clinicians when removing ceramic brackets at the end of treatment. Unlike the typical shear and tensile bond strength setups, the debonding plier is unique in that it applies force to the adhesive interface with the enamel and/or bracket, on both sides of the bracket simultaneously. This type of force is similar to the force applied during a diametral compression test for tension.

The diametral compression test is a way of indirectly measuring the tensile strength of materials that exhibit very limited plastic deformation, i.e. ceramics, composites, and enamel. The test uses a compressive load that is applied on the diameter of a short cylindrical specimen. Unlike a typical shear or tensile test where the load is unilateral, the modified diametral compression test simulates a bilateral load.[17]

From the review of the literature, it was not possible to determine an optimal upper bond strength limit. Retief's[19] research on bond failure at the enamel-adhesive interface indicated that enamel fractures can occur with bond strengths as low as 138 kg/cm^2. This is comparable with the mean linear tensile bond strength of enamel reported by Bowen and Rodriguez[20] of 148 kg/cm^2. Therefore, it would be best to avoid bond strengths larger than 138 kg/cm^2.

The findings indicate that when using the pliers to debond ceramic brackets, the debonding forces are significantly lower than the shear debonding forces reported during *in vitro* testing. These differences are encouraging since they indicate that clinicians are applying forces of significantly lower magnitudes during debonding than previously perceived.

It seems that applying the load to the two sides of the bracket increases the chances of starting a crack and propagating it in the brittle adhesive allowing for debonding to occur at a lower debonding force. Furthermore, Bishara and Fehr[21] in an earlier study recommended the use of the narrow blades (2.0 mm) on the debonding pliers instead of the wide blades, since the narrower blades effectively debond the ceramic brackets with 20-25% less force than the wider blades.

The findings from the ARI scores indicate that both mechanical debonding methods tested resulted in a bond failure either within the adhesive or at the adhesive-enamel interface. The latter site of bond failure is not very desirable since it places debonding stresses directly on the enamel surface. This in turn may increase the probability of damaging the enamel surface.

Another finding that deserves to be noted is the wide range of debonding forces that occurred. From a clinical perspective, the lower end of the range implies that a bond might fail and the bracket would need to be replaced. On the other hand, the higher end of the range indicates that the debonding forces are of such large magnitude they can result in significant enamel damage. As a result the clinician should be careful to remove any excess adhesive from around the bracket and place the edges of the debonding pliers carefully at the bracket-adhesive interface.

Conclusions

The results of the present investigation indicate that there is a significant difference between the mean bond strengths of the shear force (107.8 kg/cm^2) and a modified diametral compression force (67.8 kg/cm^2). When debonding brackets with pliers, 30% less force is applied to the enamel surface than when debonding with shear forces. The clincian is advised to remove any excess adhesive around the ceramic brackets and place the sharp edges of the debonding pliers carefully at the bracket adhesive interface to minimize stress at the enamel surface.

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