The force levels required to mechanically debond ceramic brackets: an *in vitro* comparative study

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SUMMARY The *in vitro* force levels generated by four differing methods of mechanical debonding techniques for ceramic brackets, using debonding pliers, were measured. The forces generated using wide (method W) and narrow blades (method N) were compared with those generated using a diagonally opposite corner application of the wide blades (method C) and incisal-gingival application of a pair of pointed blades (method P). Chemically retained ceramic brackets (Transcend) were bonded to bovine teeth using a filled, two-paste, chemically cured composite (Concise). After 24 hours storage at 37°C in water, each specimen was subjected to one of the four mechanical debonding methods in a custom-built jig, simulating the clinical application of conventional debonding pliers.

A one-way ANÓVA with a Tukey's honestly significant difference test revealed statistically significant differences in debonding strengths between the four methods at the 0.05 level of significance. The mean debonding strength generated by method C was 40 and 25 per cent lower than that for methods W and N, respectively. Scoring of the adhesive remnant index (ARI) revealed that the predominant bond failure site was at the bracket/adhesive interface for all groups. Macroscopically, no enamel damage or bracket fractures were observed.

Introduction

The ceramic orthodontic bracket, when introduced, was considered a viable alternative to stainless steel, particularly since it offered a significant improvement in aesthetics. Unfortunately, unlike stainless steel, the material cannot be flexed slightly to aid debonding and the high initial forces that are necessarily applied in the removal of ceramic brackets at the end of orthodontic treatment have become an area of concern.

Several complications have been encountered during debonding of these brackets, such as enamel tear-outs, fractures, cracks, and bracket failure (Machen, 1990; Redd and Shivapuja, 1991; Gibbs, 1992). The reported complications have been attributed to:

- 1. The mechanical properties (brittleness and low fracture toughness) of the ceramic materials;
- 2. The high bond strength generated due to bonding characteristics of the ceramic

bracket base design (chemical, mechanical, or mechanical/chemical bonding);

3. The method employed for debonding (Bishara and Trulove, 1990a; Chaconas *et al.*, 1991; Winchester, 1992).

The various manufacturers have therefore been continuously modifying the base design of ceramic brackets and introducing new debonding techniques specifically for their particular brand of bracket. Although new techniques, including electrothermal, ultrasonic, and laser debonding, have been advocated, mechanical debonding of ceramic brackets, either with sharp-edged pliers or custom-built lifting tools engaging under the bracket wings, remains the technique of choice (Swartz, 1988; Bishara and Fehr, 1993).

Several articles in the orthodontic literature have reported on the behaviour of dental enamel during the *in vitro* use of sharp-edged debonding pliers to debond ceramic brackets (Bishara and Trulove, 1990b; Storm, 1990; Redd and Shivapuja, 1991). There have, however, been relatively few studies reporting the actual force levels generated during this procedure (Bishara and Fehr, 1993; Bishara *et al.*, 1994, 1995). Bishara and Fehr (1993), in an *in vitro* study, showed that the use of debonding pliers with narrow blades effectively debonded ceramic brackets with a significantly lower mean debonding force than pliers with wider blades. They also stated that the relatively smaller contact area of the narrow blades (2 mm) was sufficient to initiate and propagate a crack in the adhesive. This was claimed to reduce the trauma of debonding due to the reduced stress on the enamel surface.

A logical development of this is to reduce the contact area to the minimum practicable, which is, in effect, a point, and to measure the force levels created by the use of a pair of pointed debonding blades on the adhesive in the enamel/ bracket base interface.

The second aspect of debonding considered was the site of application of the force. Conventionally, debonding pliers are applied to the adhesive layer on opposing faces of the bracket (i.e. mesially and distally, or sometimes incisally and gingivally). It is postulated, however, that applying the force across the diagonally opposite corners of a bracket with conventional debonding pliers blades might be an alternative method of reducing the pliers/adhesive contact area.

The purpose of this study therefore was to determine the *in vitro* force levels required to achieve debonding by these different methods of achieving minimal contact between the debonding blades and the adhesive resin, and to compare the results with those generated by wide and narrow blades in the mechanical debonding of standardized chemically bonded ceramic brackets. The amount of adhesive remaining on the tooth surface and visible enamel damage were also investigated.

Materials and methods

Polycrystalline aluminium oxide (Al₂O₃) ceramic brackets for upper central incisors (Transcend, Unitek Corp., Monrovia, California, USA) with silane chemical coatings for retention on the bracket bases were used in the study. The brackets were bonded to bovine enamel using a chemically-cured, two-paste, highly-filled (75 per cent quartz), composite resin (Concise, 3M Dental Products, St Paul, Minnesota, USA).

Extracted primary bovine mandibular incisor teeth were obtained and stored at room temperature in 70 per cent ethyl alcohol. The teeth were taken from Yerli-Kara cattle, approximately 14–18 months old, raised and slaughtered in the same farm complex. The labial enamel surfaces of these teeth were visually inspected, using a magnifying glass, to exclude those with defects and/or caries in the labial enamel. Eighty teeth selected in this manner were used for this project.

Substrate preparation and bonding

The selected teeth were randomly assigned to one of the four test groups. Before bonding, the labial surfaces of the crowns were polished using a pumice and water slurry in a rubber cup for 10 seconds. They were then rinsed with water for 15 seconds and blown dry with oil-free compressed air. A 37 per cent solution of liquid phosphoric acid (Concise etching agent) was applied to the labial surface for 60 seconds. Finally, the teeth were washed with water for 30 seconds to remove the orthophosphoric acid and dried with compressed air. The labial surfaces of the teeth appeared chalky white in colour, as is normal after etching. The brackets were then bonded to the teeth at room temperature in accordance with the manufacturer's suggested procedure.

After bonding, excess adhesive resin around the bracket base was removed with a dental scaler. The bracketed teeth were left undisturbed to air dry for 10 minutes until the adhesive was sufficiently set. They were then stored in distilled water at 37° C for 24 hours prior to testing.

Test apparatus

In this study, debonding of ceramic brackets were carried out using debonding pliers fitted with one of three differing types of paired blades. The first pair of blades used were 3.2 mm wide stainless steel blades produced as replaceable substitutes for ETM 345–6 RT direct bond remover pliers (ETM Corporation, Monrovia, California, USA). The second pair had narrow blades (2 mm). The third pair were also the wide type, but their tips were modified in order to give a pointed edge.

A special compression jig (Figures 1 and 2) was constructed and attached to the jaws of a Lloyd M 5K testing machine (Lloyd Instruments Plc., Fareham, Hampshire, UK), in order to simulate the movement of the debonding plier blades, and to enable accurate and direct measurement of the forces created during mechanical debonding. For each test, the selected pair of plier blades were secured at the centre of each of the opposing steel cylinders by means of setscrews. The steel cylinders were removable from the compression jig to enable easy replacement of the blades. The compression jig provided a controllable and mechanically sound oppositional movement in the vertical axis of the steel cylinders carrying the blades.

Methods of debonding force application

The four methods of debonding force application compared in the study were:

- 1. Wide blades (method W) in the incisogingival plane (Figure 3a).
- 2. Narrow blades (method N) in the incisogingival plane (Figure 3b).
- 3. Pointed blades (method P) in the incisogingival plane (Figure 3c).
- 4. Wide blades (method C) applied across the mesio-incisal and disto-gingival (diagonally opposite) corners (Figure 3d).

For the tests of each method, the specimens were positioned freely between the two blades by the same operator, until the blades touched the adhesive layer from both sides. Twenty samples were debonded by each method using a new pair of blades.

During testing, the increasing force levels were monitored on the digital display on the machine. When the bond failed, the force level was automatically recorded and presented in Newtons



Figure 1 Diagrammatic illustration (side view) of the test apparatus.



Figure 2 Test apparatus (frontal view).

which was later converted into MPa by dividing by the bracket base area. The crosshead speed of the machine was 5 mm per minute.



Figure 3 Methods of debonding force application (a = method W, b = method N, c = method P, d = method C).

The bonding surface area of the bracket base was measured to the nearest 0.01 mm with a reflex microscope connected to a computerized video image analysis system. The bases of 10 brackets were measured and the mean nominal surface area was calculated as 11.32 mm².

After testing, the separated assemblies were recovered and examined under a light microscope at $\times 20$ magnification in order to classify the enamel surfaces according to the adhesive remnant index of Årtun and Bergland (1984).

Statistical analysis

The differences in the debonding strengths were investigated statistically using an analysis of variance (ANOVA). Any differences revealed by this procedure were further investigated using Tukey's honestly significant difference (HSD) test with a 95 per cent confidence interval.

Results

The descriptive statistics of the debonding strengths and the grouping of the mean values according to Tukey's HSD test for the methods used are given in Table 1. While the wide blade pairs applied from the diagonally opposite corners (method C) generated the lowest debonding strength, the wide debonding blades (method W) showed the highest mean debonding strength, followed by the narrow blades (method N) and pointed blades (method P), respectively.

Debonding method	Size (n)	Mean (MPa)	SD	Min. value	Max. value	Tukey's HSD* grouping
W	20	14.51	3.57	9.06	20.63	А
N	20	10.77	2.90	5.99	16.78	В
Р	20	10.05	2.77	7.00	14.45	В
С	20	8.37	2.72	5.17	16.49	В

Table 1 Descriptive statistics for each method and grouping of the mean debonding strengths according toTukey's HSD test.

*Grouping with different letters are significantly different at the 0.05 significance level.

Table 2 Frequency and percentage occurrence of the adhesive remnant index (ARI) for each method tested.

Method	ARI = 0	ARI = 1	ARI = 2	ARI = 3
W	3 (15%)	4 (20%)	9 (45%)	4 (20%)
Ν	1 (5%)	7 (35%)	7 (35%)	5 (25%)
Р	0 (0%)	3 (15%)	11 (55%)	6 (30%)
С	1 (5%)	3 (15%)	8 (40%)	8 (40%)
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Adhesive remnant index (ARI) scores: 0 = no adhesive left on the tooth. 1 = less than half of the adhesive left on the tooth. 2 = more than half of the adhesive left on the tooth. 3 = all adhesive left on the tooth.

The one-way analysis of variance, which was used to test the hypothesis that there was no significant difference between the debonding strengths of the four methods, showed a highly significant difference (P < 0.001) between the methods. A further examination of the results by Tukey's HSD test indicated that the mean debonding strength for method W (14.51 MPa) was significantly higher than those for method N (10.77 MPa), method P (10.05 MPa), and method C (8.37 MPa) at the 5 per cent significance level (Table 1).

The adhesive remnant index (ARI) scores 2 and 3 applied to the majority of the teeth indicate that the predominant failure site was the bracket/adhesive interface for all the methods (Table 2). In method C, 40 per cent of the specimens had an ARI score of 3 (all adhesive resin remained on the enamel surface). None of the teeth debonded with the pointed blades (method P) exhibited an ARI score of 0.

None of the specimens showed any macroscopic evidence of bracket fracture or visible enamel damage.

Discussion

Sources of error

Although technique inconsistencies are minimized by the use of standardized bonding and reproducible direct methods of testing, subtle differences in enamel prism micro-morphology, thickness of adhesive layer, and porosities within the adhesive could cause variation in the debonding strengths for each group (Regan and van Noort, 1989; Lew *et al.*, 1991). There are two further sources of error, which might have had an effect on the results.

Since the thickness of the adhesive layer is small, the tips of the blades could not be accurately placed on it when the force was applied. However, even though the tips of the blades may have deviated towards either the joint between the adhesive and the bracket base, or that between the adhesive and the enamel, these would not significantly affect the results in a clinical application, as long as the tips are kept away from the ceramic bracket itself. Blunting during use of the blades, particularly the pointed ones, would have an increasing effect on the force level applied to later specimens. However, because the number of the specimens tested (20) with each type of blade was not excessive (Bishara and Fehr, 1993), this was ignored.

Debonding strengths

No attempt was made to compare the debonding strengths of the groups of chemically bonded Transcend ceramic brackets by *in vitro* tensile and shear bond strengths as reported by previous studies because, as Bishara and associates (1995) emphasized, the forces generated by debonding pliers applied to both sides of the bracket are not directly comparable to the shear and/or tensile forces.

The mean applied debonding strength for the narrow blade pairs (method N) was approximately 25 per cent lower than that of the wide blade pairs (method W). This essentially corroborates the findings of Bishara and Fehr (1993). It should, however, be noted that they used a different adhesive and a different type of ceramic bracket (which had a combination of mechanical and chemical retention on the base) to those in this study.

Method P caused a 30 per cent lower mean debonding strength than method W. The mean debonding strength for method C was about 40 and 25 per cent lower than those of method W and method N, respectively. This means that when a pair of debonding pliers, fitted with wide (or even narrow) blades, is applied to the diagonally opposite corners of chemically bonded ceramic brackets, the stresses on the enamel surface may be expected to be lower than those occurring when both wide and narrow flat blades are applied, during debonding, in an incisogingival plane.

Failure sites

The results from this study show that the predominant bond failure site for the chemically bonded ceramic brackets under test was at the bracket/adhesive interface in all groups. This finding is supported by Storm (1990) who also found, in most cases, that failure occurred at the bracket/adhesive interface when debonding Transcend ceramic brackets with a hard wire cutter.

Although previous authors (Gwinnett, 1988; Ødegaard and Segner, 1988) found bond failure for Transcend ceramic brackets to be more prevalent at the enamel/adhesive interface, others (Baron *et al.*, 1990; Forsberg and Hagberg, 1992; Sam *et al.*, 1993) reported that the predominant failure site for the same bracket was at the bracket/adhesive interface. However it is important to note that the type of force (shear) applied to the brackets in these studies is not normally used for the debonding of ceramic brackets and differs from those used in this investigation.

The results of no visible enamel damage observed in this study is in line with the findings of Storm (1990), Redd and Shivapuja (1991), and Bishara *et al.* (1995) who also found no visual enamel damage after debonding different types of ceramic brackets. However, under light microscopy two specimens, one from method P, and one from method N, were found to exhibit slight surface damage in the form of surface roughening.

Because of the increased ARI score of 3, it is reasonable to suggest that the diagonally opposite corner application of the debonding blades (method C) might reduce the probability of bond failure at the enamel/adhesive interface, further minimizing the risk of enamel damage.

Clinical implications

Extrapolation of laboratory data to the clinical situation should always be undertaken with care because of the complex oral environment. The changes in temperature, humidity, and acidity (pH), and the mechanical and masticatory stresses placed on a bracket in the oral cavity have a deteriorating effect on the adhesive bond, and are impossible to simulate in a laboratory (Øilo, 1993). Furthermore, moisture control *in vitro* is much more accurate than that pertaining during orthodontic bonding *in vivo*. For the above reasons it is conceivable that clinical debonding

strength values would be lower than those reported in this study. Nevertheless, it may reasonably be suggested that comparison between standardized *in vitro* studies may be extrapolated to predict clinical results and that laboratory testing can be used as a screening mechanism for predicting clinical performance.

It has been stated that bond strengths larger than 138 kg/cm² (13.53 MPa) during removal of brackets with conventional debonding pliers should be avoided (Bishara et al., 1994). This might be interpreted as implying that applying significantly lower forces would be a safer and more satisfactory method of debonding. This effect may be achieved by conventional debonding pliers placed on the diagonally opposite corners of ceramic brackets since this rarely produces a force higher than 13 MPa. It is also worthy of note that, when used for the removal of canine and premolar ceramic brackets (which have relatively more curved bases than incisor brackets), this application method would eliminate the blades inevitably resting in part on the brittle ceramic bracket (Figure 4).

During debonding, the continued presence of the archwire is a useful safety factor in controlling the bracket subsequent to release. Applying the pliers across the bracket corner obviates the need to remove the archwire before debonding, as is normally necessary if pliers are used in a mesio-distal application.

The results tend to confirm the hypothesis that for debonding of ceramic brackets, because of their rigid nature, a tenable method of initiating the procedure is to produce a crack in the adhesive at the bracket/adhesive/enamel interface and then to extend this crack until the bracket is free. The use of conventional debonding pliers may in theory produce two cracks, one on either side of the bracket, but in practice it may well be that the first is propagated before the second has time to form. The results support the suggestion that the force required to initiate debonding is directly related to the contact area between the pliers tips and adhesive, and that reducing the contact area to a minimum reduces the force necessary to initiate debonding.

It is additionally suggested that, in order to make the applied force more easily controllable,

Figure 4 Diagrammatic illustration of the impingement of the wide blades on curvature of bracket base (Thick arrows indicate the possible impingement points).

instead of relying on hand pressure on a pair of levers, as with conventional debonding pliers, the force should be applied by means of a screw (as in a hand vice). This would mean the degree of 'excessive force application', which is unpleasant for the patient, may be significantly reduced.

Conclusions

The forces required to initiate debonding of ceramic brackets are related to the contact area between the tips of the pliers and the adhesive. This can be minimized by either using pointed plier tips or placing a conventional pair of debonding pliers diagonally opposite the corners of the bracket. It is suggested that the latter technique may also offer a safety bonus in that the archwire may be left attached to the brackets whilst they are removed.

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