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Electrothermal Debonding of Ceramic Brackets: An *Ex Vivo* Study

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Abstract. *The shear forces necessary to remove ceramic brackets from human premolar teeth using mechanical and electrothermal debonding techniques were compared and the post-debond enamel characteristics were evaluated. The temperature rise in the pulp cavity during electrothermal debonding was recorded. The samples were tested sequentially on a shear jig attached to an Instron Universal Testing Machine®. The results indicate that removal of ceramic brackets with an electrothermal debonder requires less force than with a mechanical debonding technique. Furthermore, the associated pulp temperature rise appears to be within currently established biologically acceptable limits. However, the indices that are commonly used to define the condition of the enamel surface following debond may not be applicable to electrothermal debonding.*

Index words: Ceramics, Dental Debonding, Dental Pulp, Enamel Surface.

Introduction

The search for the ideal clear, but strong bracket has now progressed to the stage when both translucent and water-clear brackets made from ceramics are available. As the sole benefit of using ceramic brackets is improved aesthetics, it is paramount that morbidity associated with their use is on a par or below that associated with the use of brackets made of stainless steel. However, with the appearance of brackets made from ceramics, reports of enamel damage associated with their use began to appear (Jeiroudi, 1991). The fracture toughness of enamel is lower than that of ceramic (Scott, 1988) and ceramic brackets bonded to rigid, brittle enamel have little ability to absorb stress (Swartz, 1988). Enamel fracture or the appearance of fracture lines during debonding is related to the high bond strength of ceramic brackets and seems to be associated with sudden impact loading (Ghafari and Chen, 1990; Jeiroudi, 1991). Ideally, stress should be distributed primarily to the bracket and not the tooth. If the load application tends to fracture ceramic brackets, breaking the bracket/adhesive interface would probably minimize damage to the enamel surface (Swartz, 1988).

A promising approach for enamel protection is electrothermal debonding (Sheridan *et al.*, 1986a; Bishara and Truelove, 1990; Brouns *et al.*, 1993). Electrothermal debonding is the technique of removing bonded brackets from enamel with a device that generates heat. This heat is transferred to the bracket by a blade that is placed in the bracket slot. The heat deforms the bracket/adhesive interface and the bracket may then be removed without distortion or excessive forces being applied to the underlying enamel (Sheridan *et al.*, 1986a).

Materials and Methods

Upper and lower first and second human premolars (n = 90) extracted for orthodontic reasons were collected. Teeth with carious lesions, large restorations, damaged or hypoplastic enamel were excluded. The teeth were stored in 2 per cent formalin solution after extraction. The teeth were divided into three groups using random tables. Each group had a different ceramic bracket type bonded to it (Table 1, Fig. 1–3) using a proprietary orthodontic adhesive (System 1+®, Ormco Corporation).

Preparation of Teeth for Shear Testing

Each tooth was etched for 30 seconds, washed, dried, and then bonded. After bonding, each tooth was allowed to bench cure for 10 minutes. The teeth were then stored in distilled water at a temperature of 37°C for 24 hours before testing. All brackets were bonded by a single operator.

The three groups were sub-divided into mechanical and thermal debonding groups using random tables. Each tooth was embedded in a self-curing acrylic, Varidur® [a poly (methylmethacrylate)], in a customized poly (vinyl chloride) mould. One bracket was bonded to each tooth at the long axis centre of the clinical crown. This was done to ensure its relevance to the clinical situation and to achieve the best fit of the bracket base to the enamel surface. A surveyor (Degussa model) was used to orientate the tooth so that the bracket base was perpendicular to the base of the mould. This orientation was confirmed by means of a travelling microscope with cross-hairs. The specimen

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TABLE 1 *Type, characteristics, and manufacturers of brackets used*

Bracket type	Composition	Bonding mechanism	Surface area of base (mm^2)	Manufacturer
Starfire®	Monocrystalline aluminium oxide	Chemical	11·6	'A' company
Transcend 6000®	Polycrystalline aluminium oxide	Micromechanical	8·7	Unitek/3M
Fascination®	Polycrystalline aluminium oxide	Chemical	9·2	Dentaurum

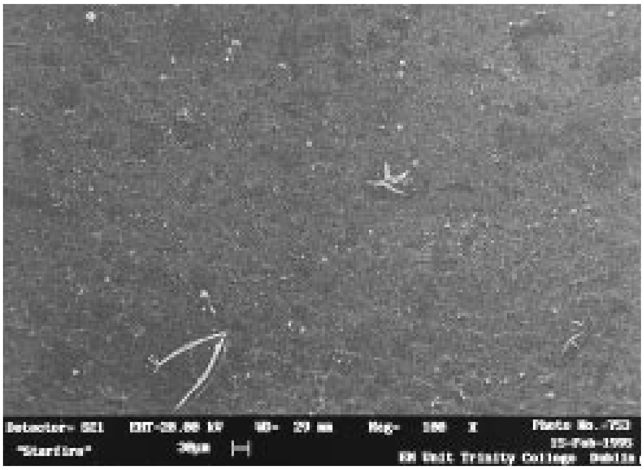

FIG. 1 Scanning Electron Micrograph of the base of the Starfire TMB®. Bracket magnification × 100.

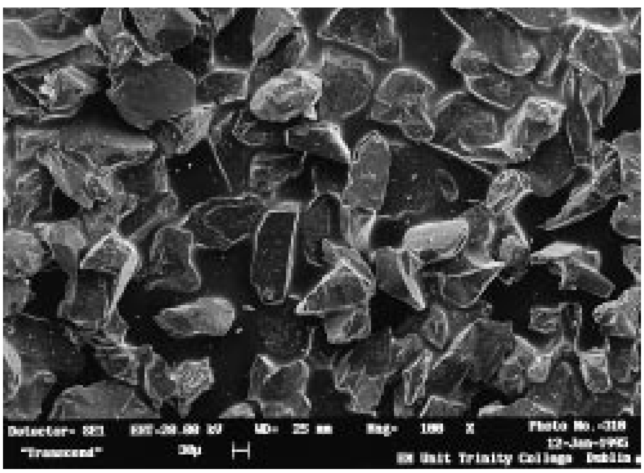

FIG. 2 Scanning Electron Micrograph of the base of the Transcend 6000®. Bracket magnification × 100.

undergoing testing was clamped to the lower member of the Instron Testing Machine®. The assembly ensured that the blade of the testing jig (Fig. 4) applied a force that was perpendicular to the upper surface of the bracket. The upper member moved in a downward direction applying force in a shear mode. Force was applied to the bracket until failure at a cross-head speed of 5 mm/minute; the value was shown on a digital display and registered on a strip chart recorder.

In the thermally debonded group the heating element of the Ceramic Debonding Unit® (Dentaurum) was placed in the bracket slot. The three second heating cycle was activated and the bracket was removed at the end of

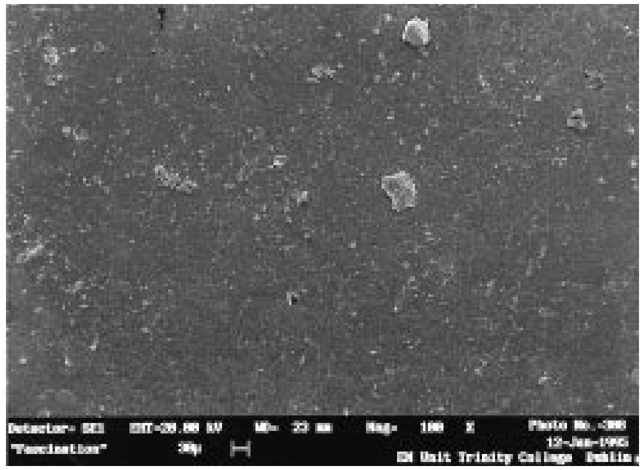

FIG. 3 Scanning Electron Micrograph of the base of the Fascination®. Bracket magnification × 100.

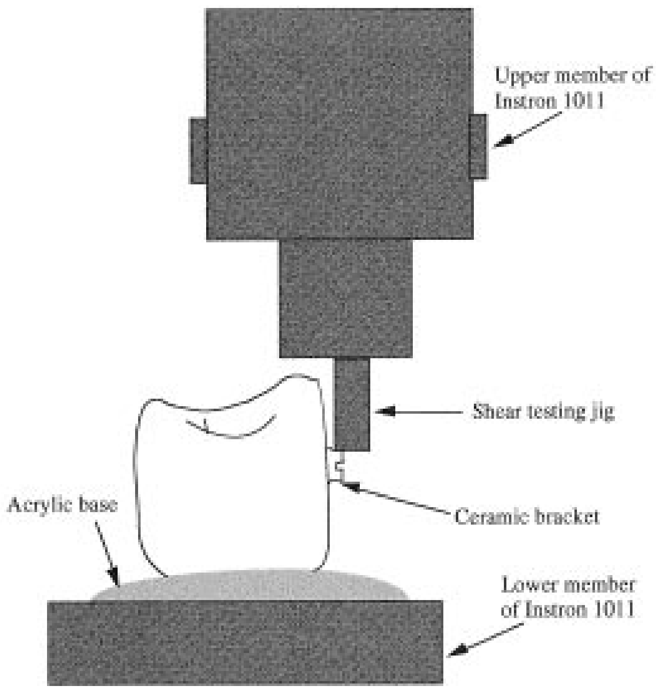

FIG. 4. A diagrammatic representation of the testing jig.

the cycle with the blade attached to the upper member of the Instron Testing Machine®. In the mechanically debonded group the brackets were removed without the use of the Ceramic Debonding Unit® by the Instron Universal Testing Machine®. The maximum shear stress at bond failure for each bracket was measured.

The bracket base surface areas were measured with a toolmaker's microscope (Mitutoyo Corporation) with a digital micrometer on the *x* and *y* axes.

Temperature Recording

The method of recording pulpal wall temperature as described by Zach and Cohen (1965), and Sheridan *et al.* (1986b) was utilized. Lingual access openings, 3 mm wide and 5 mm long, were prepared in the teeth. These were extended into the pulp chamber and pulpal material extirpated. A Type K thermocouple with a digital thermometer utilizing electronic co-junction compensation was placed next to the dentine adjacent to the bracket placement site allowing measurement of pulpal wall temperature. This thermometer was calibrated 'in-house' using a platinum resistance thermometer.

Assessment of Enamel Surface

The enamel surfaces following debond were examined under a scanning electron microscope (Stereoscope 440, Cambridge-Leica) at ×20 magnification. The specimens were examined sequentially and the images were stored on a high density optical disc. The amount of residual adhesive was evaluated for each tooth with the adhesive remnant index (ARI) as shown in Table 2 (Bishara *et al.*, 1993).

Statistical Analysis

The assumption that the population is normally distributed cannot be made in shear testing and transformation of the data is to be avoided due to the relatively small sample numbers (Fox *et al.*, 1994). Data which do not follow a normal distribution may be analysed with a distribution free or non-parametric analysis. For paired experimental data the Wilcoxon Rank Sum Test was employed. Kruskal–Wallis tests were used to compare the shear stress values within the mechanically debonded bracket groups and within the thermally debonded groups. Fishers Exact Test was used to examine the ARI data.

Results

Shear Force

The descriptive statistics for the shear testing experiments are shown in Table 3. The shear forces recorded in the mechanically debonded cohort did not differ significantly between different bracket types. There was a significant difference between the shear forces recorded when the different brackets were debonded electrothermally with the Fascination® group showing significantly lower shear force levels than the other brackets. The shear force levels recorded for the electrothermally debonded brackets were significantly lower than those recorded for mechanically debonded groups in each case. The shear force figures for all the mechanically debonded brackets were pooled and compared with the pooled shear forces of the thermally debonded brackets. The mean debonding shear force for the pooled mechanical group was 12·4 MPa and the mean debonding shear force for the thermal group was 4·6 MPa; there was a statistically significant difference between these groups ($P < 0{\cdot}05$).

Pulp Temperature Change

The mean increases in temperature recorded in the pulp cavity with the use of the electrothermal debonder are tabulated in Table 4. There were no significant differences in temperature rise associated with the different brackets ($P > 0{\cdot}05$).

TABLE 2 *Criteria for establishing the adhesive remnant index (Bishara 1993)*

ARI score	Description
1	All adhesive remains on tooth
2	More than 90%
3	More than 10%, but less than 90%
4	Less than 10%
5	No adhesive remains on tooth

TABLE 4 *Descriptive statistics for temperature rise in the pulp cavity with the use of an electrothermal debonder. None of the mean or median values differed significantly* (P > *0·05)*

Bracket type	*N*	Mean °C	SD °C	Median °C	Interquartile range
Starfire®	15	6·7	4·4	5·3	5·4
Transcend®	15	6·9	2·8	6·0	5·4
Fascination®	15	7·1	3·9	5·8	6·9

TABLE 3 *Descriptive statistics of forces recorded by debonding of brackets*

Bracket type	Debond mode	*N*	Mean MPa	SD MPa	Median MPa	Interquartile range
Starfire®	Thermal	15	12·8	7·1	11·3	10
Transcend®	Thermal	15	14·6	5·4	13·6	7·4
Fascination®	Thermal	15	9·7	5·4	9·0	7·9
Starfire®	Mechanical	15	6·4	4·6	5·2	5·2
Transcend®	Mechanical	15	5·4	4·1	3·7	6·4
Fascination®	Mechanical	15	1·8	2·4	0·7	3·1

N = sample size, MPa = megapascals, SD = standard deviation.

TABLE 5 *Adhesive remnant index for mechanically and electrothermally debonded brackets given as a percentage*

ARI	M Sf	T Sf	M Td	T Td	M Fa	T Fa
1	0	0	0	0	13·3	66·7
2	6·7	0	6·7	13·3	0	0
3	40	40	46·7	46·7	26·7	13·3
4	13·3	33·3	26·7	26·7	26·7	13·3
5	40	26·7	20	13·3	33·3	6·7

M = mechanical; T = thermal debonding; Sf = Starfire; Td = Transcend; Fa = Fascination.

Enamel Surface Characteristics

The ARI results for all brackets are shown in Table 5. There were no differences between the ARI scores for the Starfire TMB® or Transcend 6000® brackets between the differing debond methods ($P > 0{\cdot}05$). There was a significant difference for the Fascination® bracket with differing methods of debond with a shift towards an ARI score of 1 ($P < 0{\cdot}05$) for the thermally debonded teeth. Within the mechanically debonded groups there was no significant difference between bracket types ($P > 0{\cdot}05$), whereas there was a significant difference within the thermally debonded groups accounted for by the Fascination® bracket group.

Discussion

Laboratory bond strength investigations have significant weaknesses (Årtun and Bergland, 1984). Forces are difficult to standardize exactly and even then only in two directions (shear and tensile). Many factors are capable of influencing the results such as adhesive thickness and the curvature of the enamel. However, in this study the bond strength results obtained are similar to those of other workers (Gwinnet, 1988; Maskerom *et al.*, 1990; Eliades *et al.* 1991). Clinically, bonded brackets should be able to withstand forces generated by the treatment mechanics and occlusion and yet allow easy debonding without injury to the tooth. Reynolds (1975) has reported that a maximum bond strength of 5·9 to 7·9 MPa would be adequate to resist treatment forces, but added that bond strength levels of 4·9 MPa have proved clinically acceptable. In this investigation there were no significant inter-bracket differences in the shear force necessary to debond the mechanically debonded group, despite the differences in the surface areas of the bracket bases and in their retentive mechanisms. This finding may reflect an intrinsic standard bond strength employed by different manufacturers. Iwamoto (1987) found that as the mechanical retention of the bracket pad increased, the shear bond strengths decreased. One would therefore expect to find that the chemically retained brackets, Starfire TMB® and Fascination®, would give significantly higher bond strengths than the mechanically retained Transcend 6000® brackets. This is not borne out by the present work. The findings of other authors who have concluded that the bracket base surface characteristics appear to greatly influence bond strength are not supported (Osterag *et al.*, 1991).

Guidelines for adequate shear bond strength for ceramic brackets have not been reported. However, it is possible to use previous studies using metal brackets as a guide to analyse the shear bond strengths obtained in this study. Studies using metal brackets have reported bond strengths in the 12·1–20·7 MPa range (Gwinnet, 1988; Ødegaard and Segner, 1990). The ceramic brackets in this study generated mean shear bond strengths from 9·7 MPa (Fascination®) up to 14·6 MPa (Transcend 6000®). This would imply that the force on the enamel surface during debonding of a ceramic bracket is of a similar magnitude to that occurring during the removal of a metal bracket.

It is important to note that the large standard deviations obtained in this part of the study reflect the substantial spread in the data. This indicates that some of these brackets have been removed by the application of appreciably higher, as well as lower, levels of force. The clinical implication of such a finding is that some brackets will debond readily, whereas others with identical characteristics will subject the enamel surface to higher stress values and possible damage. Ghafari *et al.* (1992) have suggested that testing the debond strength of ceramic brackets is unpredictable. A number of other authors have reported wider ranges of variation around mean values of bond strength for ceramic brackets than for metal brackets (Gwinnet, 1988; Ødegaard and Segner, 1988; Viazis *et al.*, 1990).

Interpretation of the results obtained in this investigation is complicated by the limited number of investigations available on electrothermal debonding of ceramic brackets and the lack of a commonly accepted maximum 'safe' temperature increase for the living pulp. Zach and Cohen's (1965) work on primate teeth provides the most reliable guideline as to the amount of thermal activity pulpal tissue can tolerate. Thermal injury appeared to be reversible as long as the pulpal temperature increase did not exceed 5·5°C. The results of the present investigation showed a mean increase in temperature higher than those found by other workers using similar recording methods (Sander and Weinreich, 1989; Bazner *et al.*, 1991; Brouns *et al.*, 1993), and by Ruppenthal and Baumann (1992) who used infra-red thermography. No statistical differences were found between the temperature rises during electrothermal debonding of the three bracket types in this study. When comparing the observed temperature rises with thresholds in the literature, it is unclear whether irreversible damage to the pulp would occur during normal electrothermal debonding procedures. Spierings *et al.* (1985) state that the degree of heat trauma largely depends on the individual recovery capacity of the tissue. The mean temperature rises obtained in this study were similar to the 5·5°C limit commonly accepted as being the level above which some pulpal damage occurs.

Takla and Shivapuja (1995) have stated that teeth with large restorations or compromised pulp vitality could be at greater risk to the heat generated with ETD. The effect of thermal insult on pulp tissues and the equivocal nature of the results that are apparent when similar studies are compared point to the importance of further definitive investigations in this area.

No enamel tear-outs or gross enamel fractures were observed following scanning electron microscopy of debonded enamel surfaces in this study. This is in agreement with the findings of a number of workers (Guess *et al.*, 1988; Bordeaux *et al.*, 1994), but disputes those of Eliades *et al.* (1993) who reported enamel fractures with Fascination® bracket debond and those of Winchester (1992) who described enamel fractures in association with mechanical debonding of Transcend 2000® and Starfire® brackets. Furthermore, Joseph and Rossouw (1990) found enamel fractures in 40 per cent of teeth that had polycrystalline aluminium oxide brackets bonded with a chemically-cured resin.

There is some controversy regarding the optimal site of bond failure (O'Brien *et al.*, 1988). The ceramic/adhesive mode is considered by some as favourable due to the fact that it is less likely to lead to enamel fracture (O'Brien *et al.*, 1988). However, this has to be offset against dangers to the enamel incurred by removal of the remaining adhesive.

It has been argued that the ARI is a largely subjective evaluation of retained adhesive which does not accurately reflect the true situation (Årtun and Bergland, 1984). No significant difference in ARI score occurred between any of the bracket types in the mechanically debonded groups. This confirms the findings of Bishara and Truelove (1990) who found no significant differences in the ARI scores for three different types of ceramic brackets with chemical and mechanical retentive mechanisms following a mechanical debonding procedure. However, thermal debonding of Fascination® brackets led to a significant increase in the amount of residual adhesive left on the enamel surface. Thermal debonding of Transcend® and Starfire TMB® brackets did not significantly alter the amount of adhesive left on the enamel surface.

Unlike the other parameters investigated, the ARI results showed little consistency between bracket types. However, as no enamel damage was observed in any of the specimens under investigation the assumptions underlying this index may not be applicable to the electrothermal debond method.

Conclusions

These results indicate that removal of ceramic brackets with an electrothermal debonder requires less force than a mechanical debonding technique and therefore may be associated with a lower risk of iatrogenic harm. However, while the associated pulp temperature rise appears to be within currently established biologically acceptable limits, more research is required in this area before a definitive conclusion can be reached. Indices that are commonly used to define the condition of the enamel surface following debond may not be applicable to electrothermal debonding.

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