Debonding characteristics of a polymer mesh base ceramic bracket bonded with two different conditioning methods

Selma Elekdag-Turk, Devrim Isci, Nurhat Ozkalayci and Tamer Turk Department of Orthodontics, Faculty of Dentistry, University of Ondokuz Mayıs, Samsun, Turkey

SUMMARY The aim of this study was to compare the shear bond strength (SBS) and debonding characteristics of a polymer mesh base ceramic bracket bonded with two different surface conditioning methods. InVu Readi-Base ceramic brackets were bonded to 100 human premolars with different etching protocols. With conventional method (CM), the teeth were etched with 37 per cent phosphoric acid for 30 seconds, while Transbond Plus self-etching primer (SEP) was applied as recommended by the manufacturer. SBS testing was performed on 25 samples of each group while the remaining 25 samples of each group were subjected to plier or machine debonding after thermocycling for 1000 cycles. The adhesive remnant index (ARI) was used to determine the amount of composite resin on the enamel. Statistical analysis included Kruskal–Wallis and Mann–Whitney *U*-tests and Weibull analysis.

No significant difference was observed between the CM (9.22 MPa) and SEP (9.04 MPa) groups (P = 0.684). ARI scores of machine and plier debonding for both groups showed a significant difference ($P \le 0.0001$). Debonding with pliers showed a pronounced number of ARI scores of 3 for both groups. Polymer mesh base fractures were observed for both groups. Nevertheless, no significant differences were observed between the groups ($\chi^2 = 4.304$, P = 0.230).

The results of this *in vitro* study are encouraging, since, for the majority of specimens, all of the residual adhesive remained on the enamel surface. This type of debonding pattern has the advantage of protecting the enamel surface. Nevertheless, the base fractures at the ceramic/polymer interface might necessitate modifications in debonding strategy.

Introduction

Ceramic orthodontic brackets were introduced in the 1980s. The superior aesthetics they offer compared with conventional stainless steel appliances make them sought after brackets by many patients.

Nevertheless, numerous unfavourable clinical characteristics have been reported with ceramic brackets. The possibility of irreversible enamel surface damage at debonding has been and still is a concern to clinicians, patients, and manufacturers (Machen, 1990; Bishara and Fehr, 1997; Øgaard *et al.*, 2004; Russell, 2005). The rigid, brittle nature of both the ceramic brackets and the underlying enamel results in a poor environment for absorption of stress during debonding (Swartz, 1988). Thus, a number of modifications were made in the design of ceramic bracket bases in an attempt to make the debonding procedure safer for the patient and less stressful for the clinician (Devanathan, 2003; Olsen *et al.*, 1997).

One such modification for the facilitation of debonding was the introduction of a thin, flexible polycarbonate laminate base attached to the ceramic bracket wings (Ceramaflex). With this type of second-generation ceramic bracket, the bond to the enamel was not through adhesive to the ceramic but to the smooth, flexible polycarbonate laminate. This thin, smooth, plastic backing bends and allows for easy separation between the brittle ceramic and the enamel during debonding (Bordeaux *et al.*, 1994). *In vitro* studies with this type of bracket reported no enamel damage during debonding (Fox and McCabe, 1992; Bordeaux *et al.*, 1994; Olsen *et al.*, 1997).

There is some controversy regarding the bond strengths of the Ceramaflex bracket when compared with other brackets (Fox and McCabe, 1992; Bordeaux et al., 1994; Olsen et al., 1997). Fox and McCabe (1992) compared this polycarbonate base ceramic bracket with metal edgewise brackets and reported that the two brackets had similar mean bond strengths. Bordeaux et al. (1994) assessed shear bond strengths (SBS) of four second-generation ceramic brackets and a foil-mesh base stainless steel bracket. They reported that the mean SBS of the polycarbonate base ceramic bracket was significantly lower than all other brackets tested. The findings of Olsen et al. (1997), which supported the results of Bordeaux et al. (1994), demonstrated that this type of bracket had a significantly lower bond strength than a comparable ceramic bracket without a polycarbonate base.

Moreover, polycarbonate base delamination has been observed (Fox and McCabe, 1992; Bordeaux *et al.*, 1994; Olsen *et al.*, 1997). Bordeaux *et al.* (1994) reported that in 90 per cent of the sample, the plastic wafer, i.e. the flexible polycarbonate laminate, remained on the tooth with the adhesive after debonding. Olsen *et al.* (1997) found that the bond failure location was between the ceramic material and polycarbonate base in 17 out of 20 debondings.

The concept of a base providing plastic deformation during debonding led to the design of a ceramic bracket (MXi) incorporating a flexible polymeric base with a mesh architecture for the enhancement of bond strength. Furthermore, the ceramic/polymer interface of this bracket was reinforced with an amorphous glass layer, which is formed integrally on the smooth ceramic surface through a high-temperature sintering process (Devanathan, 1998).

The findings of Bishara *et al.* (1999) indicated that the SBS of a collapsible ceramic bracket with a metal insert was greater than that of the MXi ceramic bracket; yet, the SBS of both brackets were more than the minimal force levels suggested by Reynolds (1975) as being clinically acceptable for orthodontic purposes (5.9–7.8 MPa). When debonding with the appropriate pliers, most of the adhesive remained on the enamel surface for both brackets. The authors concluded that such a debonding pattern has the advantage of protecting the enamel surface. No fractures of the bracket bases were noted.

The InVu bracket is an injection-moulded ceramic bracket with a flexible polymer mesh base. This polycrystalline bracket has been designed to optimize various parameters, such as ease of debonding and good bond strength. The brackets require no special tools in the clinician's armamentarium for safe and easy debonding at the end of fixed appliance treatment (Russell, 2005).

The rapid pace of advancement in dental materials science has led to the simplification of clinical procedures with the introduction of self-etching primers (SEPs). This singlestep etch/primer bonding system combines the etching and priming steps into one, eliminating the need for rinsing. It is reported that bonding brackets with SEP results in less damage to the enamel surface than bonding with a conventional multi-step method, i.e. etching with phosphoric acid (Hosein *et al.*, 2004; Øgaard *et al.*, 2004; Vilchis *et al.*, 2007). Moreover, some recent studies have concluded that adequate bond strength is obtained with SEPs when compared with the conventional system (Turk *et al.*, 2007a,b).

The aim of this *in vitro* study was to compare the SBS and debonding characteristics of pre-applied adhesive InVu brackets bonded to teeth with different surface conditioning methods, i.e. SEP and phosphoric acid etching.

Materials and methods

One-hundred human maxillary premolar teeth obtained from patients requiring extractions were included in this study. The teeth were stored in 0.1 per cent thymol solution until use. The selection criteria for the teeth were as follows: intact buccal enamel, absence of pre-treatment with chemical agents (such as hydrogen peroxide), and absence of cracks and caries. Each tooth was embedded in a cold-cure acrylic resin (Orthocryl; Dentaurum, Ispringen, Germany) cylindrical block. A jig was used to align the buccal surface of each tooth parallel to the base of the cylinder. The teeth were cleansed and polished with pumice and rubber prophylactic cups for 10 seconds.

InVu Readi-Base ceramic brackets (TP Orthodontics Inc., La Porte, Indiana, USA) with 0.022 inch slots were used. The mean area of each bracket base, according to the manufacturer, was 16.3 mm².

The 100 samples were randomly divided into two groups; one group was bonded using the conventional method (CM) and the other with SEP. The pre-coated brackets were bonded according to one of the following two protocols.

Group CM: The teeth were etched with 37 per cent phosphoric acid for 30 seconds, washed for 20 seconds, and dried for 10 seconds until the buccal surfaces of the etched teeth appeared chalky white in colour. After etching, a thin uniform coat of primer (Transbond XT Primer; 3M Unitek, Monrovia, California, USA) was applied. The precoated bracket was firmly positioned on the enamel surface. Excess adhesive surrounding the periphery of the bracket was meticulously removed with an explorer. The adhesive resin was polymerized for 10 seconds from above the bracket using a visible curing unit (Hilux 200; Benlioglu Dental Inc., Ankara, Turkey) with an output power of 600 mW/cm².

Group SEP: Transbond Plus SEP (3M Unitek) was used according to the manufacturer's instructions, namely, the SEP was applied to the enamel surface and rubbed for 3 seconds. A gentle burst of dry air was then delivered to thin the primer. The bonding procedure with the precoated brackets was performed as for group CM. Both bonding procedures were carried out by one author (SE-T).

Two minutes after bonding, the samples were placed in distilled water (37°C) for 24 hours to prevent dehydration. Subsequently, the samples were subjected to thermocycling testing of 1000 cycles. Thermocycling was performed between 5 and 55°C with a dwelling time of 30 seconds as recommended by the International Organization for Standardization (2003).

SBS testing

Twenty-five samples from each group were subjected to SBS testing which was performed with a universal testing device (Lloyd LRX; Lloyd Instruments Ltd., Fareham, Hants, UK). Each specimen was secured in the lower part of the machine so that the bracket base paralleled the direction of the shear force. The specimens were stressed in an occluso-gingival direction with a crosshead speed of 1 mm/minute. The bond strengths, in megapascals, were determined by dividing the surface area of the bracket (mm²) into the debond load (N).

Debonding the brackets with pliers

Twenty-five InVu brackets of each group were debonded according to the manufacturer's recommendations. The mesiodistal edges of the flexible polymer mesh base were gently squeezed with ligature cutters (Figure 1). According to the manufacturer, the mesh base will undergo plastic deformation and reportedly release intact from the tooth. For each group, a brand new ligature cutter was used.

Evaluation of the residual adhesive

The enamel surfaces were examined with a stereomicroscope (Stemi 2000-C; Carl Zeiss, Göttingen, Germany) at a magnification of $\times 10$ to determine the amount of composite resin remaining according to the adhesive remnant index (ARI; Årtun and Bergland, 1984). The ARI scale has a range from 0 to 3, with 0 indicating no composite left on the enamel; 1, less than half of the composite left; 2, more than half of the composite left; and 3, all composite left on the tooth surface.

Statistical analysis

A Mann–Whitney U non-parametric test was applied to determine whether there were any significant differences in SBS (P < 0.05).



Figure 1 Contact areas between the cutting edges of the pliers and bracket base.

A Weibull analysis was performed, and the Weibull modulus, characteristic bond strength, correlation coefficient, and the stress levels at 5 and 10 per cent probability of failure were calculated.

Kruskal–Wallis and Mann–Whitney U non-parametric tests were used to determine whether there were any significant differences in the ARI scores and bracket base fracture values (P < 0.008).

Results

The mean SBS and standard deviations (SD) for each group and analysis of the results of the Mann–Whitney *U*-test are presented in Table 1. No significant difference was observed between the CM (9.22 MPa) and SEP (9.04 MPa) groups (P = 0.684).

The parameters of the Weibull analysis for each group are given in Table 1. The Weibull distribution plots of the probability of failure at a certain shear stress level for the two groups are depicted in Figure 2.

The median, mean, SD, and range of the ARI scores are given in Table 2. The Kruskal–Wallis test indicated that there were significant differences between the groups ($\chi^2 = 32.683$, P = 0.0001). The Mann–Whitney *U*-test showed a significant difference between the ARI scores for machine and plier debonding for both groups ($P \le 0.0002$). Debonding with pliers showed a pronounced number of ARI scores of 3 for both groups.

The median, mean, SD, and range of scores for bracket base fractures are presented in Table 3. Bracket base fractures are shown in Figures 3a,b. The Kruskal–Wallis test indicated that there were no significant differences between the groups ($\chi^2 = 4.304$, P = 0.230).

Discussion

Ceramic brackets, compared with their metal counterparts, are sought after by an ever-increasing number of patients. Nevertheless, these aesthetic brackets have generated discussion due to the challenge they might present during the debonding process (Øgaard *et al.*, 2004). To circumvent

Table 1 Mean shear bond strengths, standard deviations (SD), minimum and maximum values, and Weibull parameters for each group (n = 25).*

Groups	Mean	SD	Minimum	Maximum	Weibull analysis					
					Weibull modulus	Correlation coefficient	Characteristic bond strengths (MPa)	Shear stress at the 5% probability of failure (MPa)	Shear stress at the 10% probability of failure (MPa)	
Conventional method Self-etching primer	9.22 9.04	1.80 2.17	5.85 5.30	14.20 13.75	7.11 5.13	0.913 0.972	9.80 9.80	6.45 5.50	7.14 6.32	

*Mann–Whitney U-test did not show any significant difference (P = 0.684).

the complications associated with ceramic bracket debonding, a bracket with a flexible polymer mesh base (InVu) has been introduced. With this type of bracket, the bond to the enamel is not through the adhesive to the ceramic base, but to the thin flexible polymer mesh base.

The findings from the current study indicate that there was no significant difference in SBS between the CM (9.22 MPa) and SEP (9.04 MPa) groups. The SBS values for both groups were higher than the force levels (5.9–7.8 MPa) advised by Reynolds (1975) as being sufficient for clinically effective bonding. The upper limit for bond strength has also been investigated. Retief (1974) pointed out that enamel fractures can occur with bond strengths as low as 13.8 MPa. The SBS values in the present study were within the 'safe' range.

The Weibull analysis conveys information concerning the probability of bracket failure and presents the



Figure 2 Cumulative failure probabilities versus shear bond strength for the groups bonded using the conventional method (CM) and self-etching primer (SEP).

orthodontist with an indication of how the material or bracket is likely to perform in a clinical situation, i.e. the oral environment (Fox *et al.*, 1994). Littlewood *et al.* (2001) suggested the 5 per cent chance of failure as an appropriate level to assess bond strength. According to those authors, the bond strength of a material with a 5 per cent chance of failure should be at least 5.4 MPa. In the present study, SBS showed shear stress levels higher than 5.4 MPa at the 5 per cent probability of failure for both groups. This result suggests acceptable SBS for both groups in the oral environment.

For both groups, careful debonding with pliers, namely ligature cutters, resulted in a pronounced number of ARI scores of 3. Such a pattern, i.e. the tendency for all adhesive to remain on the enamel surface, has the advantage of protecting the enamel surface during debonding (Bishara *et al.*, 1999). Machine debonding, even though abrupt and unilateral in nature, displayed a marked number of ARI scores of 2, i.e. more than half of the composite left on the enamel surface.

When brackets fail at the enamel/adhesive interface, the enamel surface can be damaged (Bishara *et al.*, 2007). It should be noted however that teeth stored in 1 per cent thymol solution, as in this study, are much drier than vital teeth and, therefore, are more susceptible to enamel damage (Mundstock *et al.*, 1999). Nevertheless, no enamel damage was observed in the present research.

The debonding procedure was strictly performed according to the manufacturer's instructions, namely, the mesiodistal edges of the mesh base of the brackets were squeezed with ligature cutters. The bracket reportedly releases intact from the tooth with this type of debonding. However, 14 brackets in the CM group and 10 brackets in the SEP group displayed partial base fractures. These fractures were located at the corners of the polymer mesh bases. In fact, these corners were the first contact areas of the cutting edges of the ligature cutter. High localized stress concentration may have induced this particular type of fracturing. Interestingly, the line of fracture was through the ceramic/polymer interface for all samples.

Groups	Debond method	ARI scores†								
		0	1	2	3	Median	Mean	SD	Range	
Conventional method	Machine§	_	_	18	7	2	2.28	0.46	2–3	
	Pliers§	_		3	22	3	2.88	0.33	2-3	
Self-etching primer	Machine [‡]		_	20	5	2	2.20	0.41	2-3	
	Pliers‡	_	—	7	18	3	2.72	0.46	2–3	

 Table 2
 Frequency distribution of the adhesive remnant index (ARI).*

 $\chi^2 = 32.683, P = 0.0001$

†ARI scores: 0, no composite left on enamel surface; 1, less than half of composite left; 2, more than half of composite left; and 3, all composite left. §A significant difference was observed between the groups ($P \le 0.0002$).

A significant difference was observed between the groups ($P \le 0.0002$).

Groups	Debond method	Base fracture scores: 0, no damage on base and 1, fracture of base								
		0	1	Median	Mean	SD	Range			
Conventional method	Machine	11	14	1	0.56	0.51	0-1			
	Pliers	11	14	1	0.56	0.51	0-1			
Self-etching primer	Machine	17	8	0	0.32	0.48	0-1			
	Pliers	15	10	0	0.40	0.50	0-1			

Table 3	Frequency	distribution	of bracket	base	fractures.*
	/				

 $\chi^2 = 4.304, P = 0.230.$



Figure 3 Bracket base fractures following bonding with the conventional method (A) and with the self-etching primer (B).

Bishara *et al.* (1999) reported no fractures for MXi bracket bases following debonding with pliers. The MXi bracket is a precursor of the InVu bracket (Devanathan,

2003). However, these MXi brackets were debonded with a direct bond remover with the blades applied simultaneously on both sides between the bracket base and the enamel

surface. Bishara *et al.* (1999) concluded that the clinician should avoid applying any forces to the bracket base when debonding the MXi ceramic bracket. Bishara and Fehr (1993) compared the effectiveness of direct bond removers with narrow (2.0 mm) and wide (3.2 mm) blades in the debonding of ceramic brackets. They reported that the narrow blades resulted in a significantly lower mean debonding force (20 per cent). They concluded that it would be advantageous to use narrow blades due to the reduced force levels transmitted.

As already reported, partial polycarbonate base fractures were observed in the present study. These broken-off fragments were primarily loose, i.e. not attached to the adhesive, for both plier debonding groups. Loose fragments might pose various problems for the patient as well as the clinician. Bishara and Fehr (1997) recommended the placement of a piece of gauze behind the teeth to catch potential fragments, otherwise the risk of ingestion or aspiration might be encountered. Those researchers pointed out that some debonding pliers possess a protective sheath. Such a sheath decreases the probability of fragments becoming discharged into the patient's mouth. Protective eyewear should be worn by the clinician as well as the patient (Bishara and Fehr, 1997).

Conclusion

The results of this *in vitro* study are encouraging, since, for the majority of specimens, all of the residual adhesive remained on the enamel surface. This type of debonding pattern has the advantage of protecting the enamel surface. However, the base fractures at the ceramic/polymer interface might call for modifications in debonding, such as the use of a direct bond remover plier with narrow blades applied between the polycarbonate base and the enamel surface.

As with all *in vitro* investigations studies, the findings should be viewed with caution since laboratory testing cannot model the clinical situation. Only a comprehensive clinical study with this type of ceramic bracket will shed light on this important aspect of debonding.

Address for correspondence

Dr Selma Elekdag-Turk Department of Orthodontics Faculty of Dentistry University of Ondokuz Mayis 55139 Kurupelit, Samsun Turkey E-mail: turkset@superonline.com

Acknowledgements

The authors would like to thank TP Orthodontics for providing the InVu Readi-Base brackets.

References

- Årtun J, Bergland S 1984 Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. American Journal of Orthodontics 85: 333–340
- Bishara S E, Fehr D E 1993 Comparisons of the effectiveness of pliers with narrow and wide blades in debonding ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 103: 253–257
- Bishara S E, Fehr D E 1997 Ceramic brackets: something old, something new, a review. Seminars in Orthodontics 13: 178–188
- Bishara S E, Olsen M E, VonWald L, Jacobsen J R 1999 Comparison of the debonding characteristics of two innovative ceramic bracket designs. American Journal of Orthodontics and Dentofacial Orthopedics 116: 86–92
- Bishara S E, Ostby A W, Laffoon J F, Warren J 2007 Shear bond strength comparison of two adhesive systems following thermocycling. Angle Orthodontist 77: 337–341
- Bordeaux J M, Moore R N, Bagby M D 1994 Comparative evaluation of ceramic bracket base designs. American Journal of Orthodontics and Dentofacial Orthopedics 105: 552–560
- Devanathan D 1998 Technical brief. Debonding mechanics of the MXi bracket. M-114 Jan, TP Orthodontics, Inc., La Porte
- Devanathan D 2003 Design and development of the ultimate ceramic bracket. 996–372E Apr TP Orthodontics, Inc., La Porte
- Fox N A, McCabe J F 1992 An easily removable ceramic bracket? British Journal of Orthodontics 19: 305–309
- Fox N A, McCabe J F, Buckley J G 1994 A critique of bond strength testing in orthodontics. British Journal of Orthodontics 21: 33–43
- Hosein I, Sherriff M, Ireland A J 2004 Enamel loss during bonding, debonding, and cleanup with use of a self-etching primer. American Journal of Orthodontics and Dentofacial Orthopedics 126: 717–724
- International Organization for Standardization (ISO/TS 11405) 2003 Dental materials-testing of adhesion to tooth structure. Geneva, Switzerland
- Littlewood S J, Mitchell L, Greenwood D C 2001 A randomized controlled trial to investigate brackets bonded with a hydrophilic primer. Journal of Orthodontics 28: 301–305
- Machen D E 1990 Legal aspects of orthodontic practice: risk management concepts. Ceramic bracket update. American Journal of Orthodontics and Dentofacial Orthopedics 98: 185–186
- Mundstock K S, Sadowsky P L, Lacefield W, Bae S 1999 An *in vitro* evaluation of a metal reinforced orthodontic ceramic bracket. American Journal of Orthodontics and Dentofacial Orthopedics 116: 635–641
- Øgaard B, Bishara S E, Duschner H 2004 Enamel effects during bondingdebonding and treatment with fixed appliances. In: Graber T M, Eliades T, Athanasiou A E (eds) Risk management in orthodontics: experts' guide to malpractice. Quintessence Publishing Co., Inc., Chicago, pp. 19–46
- Olsen M E, Bishara S E, Jacobsen J R 1997 Evaluation of the shear bond strength of different ceramic bracket base designs. Angle Orthodontist 67: 179–182
- Retief D H 1974 Failure at the dental adhesive-etched enamel interface. Journal of Oral Rehabilitation 1: 265–284
- Reynolds I R 1975 A review of direct orthodontic bonding. British Journal of Orthodontics 2: 171–178
- Russell J S 2005 Aesthetic orthodontic brackets. Journal of Orthodontics 32: 146–163
- Swartz M L 1988 Ceramic brackets. Journal of Clinical Orthodontics 22: 83–88
- Turk T, Elekdag-Turk S, Isci D 2007a Effects of self-etching primer on shear bond strength of orthodontic brackets at different debond times. Angle Orthodontist 77: 108–112
- Turk T, Elekdag-Turk S, Isci D, Cakmak F, Ozkalayci N 2007b Saliva contamination effect on shear bond strength of self-etching primer with different debond times. Angle Orthodontist 77: 901–906
- Vilchis R J S, Hotta Y, Yamamoto K 2007 Examination of enamel-adhesive interface with focused ion beam and scanning electron microscopy. American Journal of Orthodontics and Dentofacial Orthopedics 131: 646–650

Copyright of European Journal of Orthodontics is the property of Oxford University Press / UK and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.