European Journal of Orthodontics 28 (2006) 400–404
doi:10.1093/ejo/cji107
Advance Access publication 22 February 2006

Bonding characteristics of a self-etching primer and precoated brackets: an *in vitro* study

Sunil Hirani* and Martyn Sherriff**
Departments of *Orthodontics and **Biomaterials Sciences, Dental Institute of King's College London, UK

SUMMARY Little is known about the performance of Transbond™ Plus Self-Etching Primer (TPSEP), especially when used with Adhesive Precoated Brackets™ (APC 1 and APC 2). The aim of this study was to compare the shear bond and rebond strengths and failure sites of APC 1 and APC 2 with a non-coated bracket system [Victory Series (V)] using Transbond XT™ light-cured adhesive and TPSEP or 37 per cent phosphoric acid as the conditioner.

The results demonstrated that on dry testing of 120 brackets when applying an occluso-gingival load to produce a shear force at the bracket–tooth interface, there was no statistically significant difference in the shear bond strength (SBS) of APC 1 (68.4 N), APC 2 (74.9 N), and V brackets (75.4 N, control group). There was also no significant difference in bond failure sites of the APC 1 and APC 2 when compared with the non-coated bracket system using Transbond XT light-cured adhesive and TPSEP, with bond failure for all groups occurring mainly at the adhesive–enamel interface. There was a significant difference in the SBS of the V brackets when using TPSEP and 37 per cent phosphoric acid as the conditioners. The latter was lower (60.6 N) and the bond failure site changed from the enamel–adhesive interface to the bracket–adhesive interface.

The shear rebond strengths of all bracket types were statistically significantly lower ($P < 0.05$) than their initial SBS (APC 1, APC 2, and V: 35.9, 36.7, and 34.1 N, respectively) and the locus of bond failure altered from the adhesive–enamel interface to the bracket–adhesive interface. A clinical trial using TPSEP as a conditioner would be useful as the time taken to remove the adhesive from the enamel surface may be reduced following debond.

Introduction

The application of visible light-cured composites for bonding was first described by Tavas and Watts (1979) and subsequent *in vitro* studies have confirmed that adequate bond strength can be achieved with visible light-curing systems when using metal brackets (Bearn *et al.*, 1995).

A number of ways of ascertaining the success of a bond are available, including measurement of bond strength *in vitro*, measurement of the failed proportion of brackets *in vivo*, and *ex vivo* studies utilizing finite-element analysis. The easiest of these methods is to record *in vitro* shear bond strength (SBS). Reynolds (1975) stated that successful clinical bonding can be achieved with bond strengths from 6–8 MPa and above. The adhesive remnant index (ARI; Årtun and Bergland, 1984) can be used to determine the nature of bond failure and it allows the clinician to subjectively determine the sites of fracture when a bracket debonds.

Adhesive Precoated Brackets (APCs) were introduced in 1991 and were designed to reduce the steps in the bonding procedure, thereby reducing the number of bonding variables. The composite used on precoated brackets is a version of Transbond XT, modified in viscosity, and this adhesive can be used in conjunction with Transbond™ Plus Self-Etching Primer (TPSEP), a combination of etchant and primer.

Conventional adhesive systems may use three different agents (an enamel conditioner, a primer solution, and an adhesive resin) in the process of bonding orthodontic brackets to enamel. TPSEP allows etching, priming, and bonding of enamel in one simple step.

Rebonding brackets may result in a decrease in base mesh diameter with a consequent reduction in shear and tensile bond strengths (Mascia and Chen, 1982). However, the bond strength of rebonded brackets has been reported to exceed the minimum force requirement of 6–8 MPa (Egan *et al.*, 1996). There is no agreement on how rebond strength compares with original bond strength. Some authors have reported that rebond strength is lower (Ireland and Sherriff, 1994), while others have reported it to be comparable (Egan *et al.*, 1996) or greater (Leas and Hondrum, 1993) than original bond strength.

The ideal bond should fail during debond at the adhesive–enamel interface for faster debond (Kinch *et al.*, 1989; Ireland and Sherriff, 1994). Failure is usually cohesive within the adhesive, leaving behind material which has to be removed. This is preferable to a situation where the bond is such that the enamel becomes the weakest link and fractures during debonding (Retief, 1974).

Previous studies suggest that metallic APCs have a lower SBS than Transbond XT on uncoated brackets (Bishara *et al.*, 1997; Sunna and Rock, 1999). The manufacturer has addressed this by modifying the adhesive used for precoating (APC 1 to APC 2). Self-etching primers (SEPs) have also been shown to have lower SBSs and more adhesive remaining on the teeth following debond (Bishara *et al.*, 2001). However, recent studies by Cacciafesta *et al.* (2003) and Sfondrini *et al.* (2004) have reported that the bond strengths associated with APC and SEP are adequate for clinical use. The purpose of the present study was to:

1. Compare the shear bond and rebond strengths of two types of precoated brackets, APC 1 and APC 2, with a non-coated bracket system using Transbond XT light-cured adhesive and TPSEP as the conditioner;
2. Compare the SBSs of Victory Series (V) brackets manually coated with Transbond XT adhesive using TPSEP and 37 per cent phosphoric acid as the conditioners;
3. Study the sites of failure of each system.

The null hypothesis was that there is no difference in the SBSs of APC 1, APC 2, and manually coated light-cured Transbond XT adhesive on V brackets when using TPSEP as the conditioner.

Materials and methods

One hundred and twenty sound premolar teeth extracted for orthodontic reasons at a Community Dental Clinic, Luton, UK, were collected and stored in distilled water (age range of patients between 11 and 15 years). The water was changed weekly to avoid bacterial growth.

The bond-testing apparatus consisted of a universal testing machine (Model 1193, Instron Limited, High Wycombe, Bucks, UK, using 50-kg tension load cell type: 2511/111) using a custom-made jig (Ireland and Sherriff, 1988). The products and light-curing unit used in this study were produced by 3M Unitek (Monrovia, California, USA) and their instructions were followed. These were APC 1, APC 2, V brackets, Transbond XT primer, Transbond XT light-cured adhesive, TPSEP, and 37 per cent phosphoric acid. The light-curing unit was an Ortholux XT.

Each tooth was carefully embedded in cold cure acrylic with the crowns exposed and the flattest expanse of buccal enamel just above the acrylic surface. The numbered and mounted specimens were divided into four equal groups to be used with their respective conditioners: group A (APC 1 and TPSEP), group B (APC 2 and TPSEP), group C (V brackets, Transbond XT adhesive, and TPSEP; control group), and group D (V brackets, Transbond XT adhesive, and 37 per cent phosphoric acid). The rebonded brackets and tooth surfaces were prepared using a tungsten carbide bur to remove residual adhesive.

Three groups of brackets (A–C) were randomly allocated to two different operators. The authors of this study were unaware of which brackets had been used on the numbered mounted specimens. This information was revealed following the study.

The shear and rebond strengths and sites of failure of APC 1, APC 2, and V brackets using TPSEP were recorded (groups A–C). Following this, the SBS and site of failure of V brackets, light-cured with Transbond XT adhesive (group D), conditioned with conventional 37 per cent phosphoric acid and unfilled resin primer were recorded.

Bond strength testing to failure was performed with a crosshead speed on the Instron of 2 mm min^{-1} and at a room temperature of 20°C. The load at which bond failure occurred was noted for each specimen tested, together with the ARI. The latter observation was undertaken by examining the fractured joint surfaces with an objective lens from a stereomicroscope (×30 magnification).

The results were analysed with Stata 7.0 (Stata Statistical Software, College Station, Texas, USA, Release 7.0.). In all analyses, significance was predetermined at $P < 0.05$. Univariate summary statistics were calculated. Data were tested for normality using the Shapiro–Francia test. Kaplan–Meier survival estimates were calculated and the survival curves compared using a log-rank test. The ARI were analysed as a single ordered table using the Kruskal–Wallis test. Table 1 shows the bond strength summary statistics of all groups.

Results

The Kaplan–Meier technique estimates an empirical hazard and survival function, and as such requires no underlying data distribution. The resulting survival curves can then be compared using a non-parametric technique such as the log-rank test.

Figure 1 shows the probability of a bond failing as a function of applied load. At a survival probability of 1 all bonds remain intact, and at a probability of 0 all bonds fail. The four groups can be directly compared with the probability that a bond will fail at a given load.

Table 1 Univariate summary statistics for all experiments. Bond strength has been rounded to one significant figure and the probability to two significant figures.

Experiment	Bracket	*n*	*X*	SD	P_{SF}
Shear bond strength with TPSEP and conventional etchant and primer (V2)	APC 1	28	68.4	19.1	0.94
	APC 2	28	74.9	17.2	0.93
	V1	30	75.4	21.3	0.14
	V2	30	60.6	16.1	0.06
Rebond strength with TPSEP	APC 1	30	35.9	9.9	0.01
	APC 2	29	36.7	10.2	0.01
	Victory	30	34.1	8.9	0.01

X, mean bond strength in newtons; SD, standard deviation; P_{SF}, probability associated with the Shapiro–Francia test; APC, Adhesive Precoated Brackets; TPSEP, Transbond Plus Self-Etching Primer; V1, Victory Series brackets with light-cured Transbond XT (using TPSEP); V2, Victory Series brackets with light-cured Transbond XT (using 37 per cent phosphoric acid and primer).

The ARI is a four-point scale where 0 represents no adhesive left on the tooth surface, implying that bond failure occurred purely at the adhesive–enamel interface; 1 represents less than half the adhesive left on the tooth, implying that bond failure occurred mainly at the adhesive–enamel interface; 2 represents more than half the adhesive left on the tooth, implying that bond failure occurred mainly at the bracket–adhesive interface; and 3 represents all adhesive left on the tooth, with a distinct impression of the bracket, implying that bond failure occurred purely at the bracket–adhesive interface.

The most common mode of failure when using TPSEP for APC 1, APC 2, and V brackets was ARI 1 (Figure 2). There was no significant difference in the distribution of failure scores ($P = 0.06$).

The most common mode of bond failure occurred at ARI 3 in group D (Figure 3). Therefore, the site of bond failure changed when using Transbond XT and phosphoric acid to the bracket–adhesive interface.

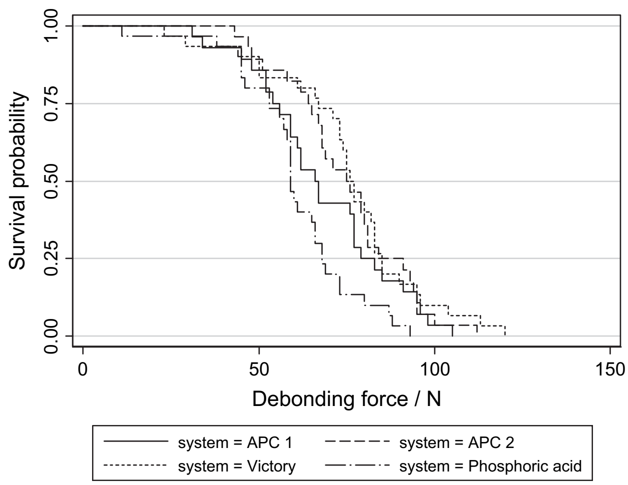

Figure 1 Kaplan–Meier survival estimate curves.

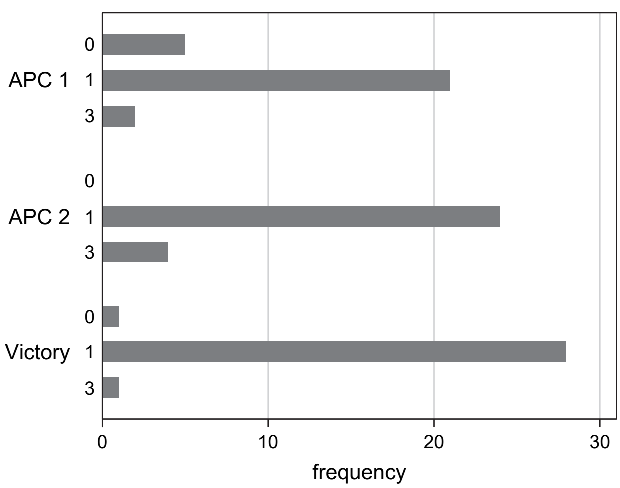

Figure 2 Distribution of the adhesive remnant index following initial debonding using Transbond Plus Self-Etching Primer as the conditioner.

The rebond strengths were lower than their original bond strengths by approximately 50 per cent (Table 1). The Shapiro–Francia test showed that the data were not normally distributed ($P_{SF} = 0.01$). There was a significant difference in ARI scores for the bracket types ($P = 0.01$), and the locus of bond failure moved from ARI 1 to ARI 3 on rebond (Table 2).

Discussion

The findings concerning the bond strengths of the precoated and non-coated brackets are in agreement with those of Bearn *et al.* (1995). There was no significant difference in the SBS of groups A and C (Table 1).

The Kaplan–Meier survival estimate curves (Figure 1) showed little difference between APC 1, APC 2, and V bracket types, indicating similar probabilities of failure. On further analysis with a log-rank test, there was no significant difference ($P = 0.38$) between the curves. The most common mode of bond failure when using TPSEP was ARI 1 (Figure 2), implying that the type of bracket has little effect on bond failure and is most likely to be associated with the use of the combination of etchant and primer. There was no significant difference in the distribution of failure scores; however, as this was $P = 0.06$, caution needs to be applied.

The mean SBS for the V brackets coated with Transbond XT and conditioned with TPSEP was 74.4 N. When using phosphoric acid and unfilled resin as the conditioner and primer, respectively, the mean SBS was 60.6 N. This is in agreement with Buyukyilmaz *et al.* (2003). It was interesting to note that the average bond strength when using TPSEP was significantly higher than that of the two-stage conventional method. This increased bond strength of TPSEP may be due to the simultaneous etching and priming that occurs, allowing the primer to penetrate the entire depth of the etch ensuring a mechanical interlock. Figure 1 shows a difference in the survival probabilities of both groups especially at a debonding force range of 50–100 N. When further analysed using a log-rank test, there was a significant difference ($P = 0.01$) between the groups. These findings are contrary to those of Bishara *et al.* (2001), Aljubouri *et al.* (2003), Cacciafesta *et al.* (2003), and Sfondrini *et al.* (2004). Bishara *et al.* (2001) reported that the converse occurred, i.e. when using TPSEP with brackets bonded with Transbond XT adhesive, a significantly lower SBS was obtained when compared with phosphoric acid as the conditioner. Cacciafesta *et al.* (2003) found no significant difference between the two conditioners when using bovine mandibular incisors. Aljubouri *et al.* (2003) stored the bonded samples in a humidor at 37°C for 24 hours prior to bond strength testing in a gingivo-occlusal direction. Possible reasons for the differences in observations between studies could relate to the differences in conditioner, the types of teeth used, and the methods of storage. The

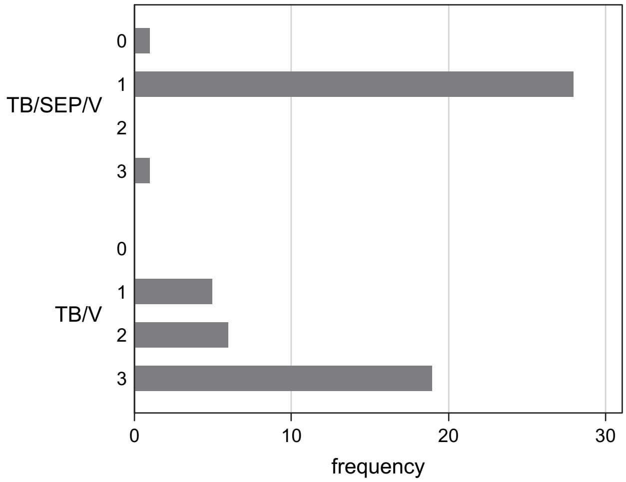

Figure 3 Distribution of the adhesive remnant index for the Victory Series brackets when using light-cured Transbond XT adhesive with Transbond Plus Self-Etching Primer (TB/SEP/V) and 37 per cent phosphoric acid (TB/V) as the conditioners.

Table 2 Adhesive Remnant Index (ARI) and rebond ARI scores when using Transbond Plus Self-Etching Primer

ARI	Frequency	Percentage	Rebond ARI	Frequency	Percentage
0	6	7.1	0	0	0
1	72	84.7	1	4	4.5
2	0	0	2	2	2.3
3	7	8.2	3	83	93.3

conditioner used by Bishara *et al.* (2001) was Prompt L-Pop, which is an acidic primer used for restorative dentistry and requires the tooth to be conditioned for 15 seconds compared with TPSEP, an orthodontic conditioner that requires the tooth to be conditioned for only 3 seconds. The teeth used by Bishara *et al.* (2001) were molars as opposed to premolars, which were used in the present investigation. Direct comparison of studies using different tooth types may not be possible. Hobson *et al.* (1999) examined variations in SBS between different tooth types. Their results indicated that significant differences in SBS exist between different tooth types and opposing dental arches. Different teeth show biological variation in their etch pattern after acid priming (Hobson and Mattick, 1997, 1998; Mattick and Hobson, 2000) and it has been stated that these differences between tooth types may influence the bond strength achieved. Linklater and Gordon (2001) studied whether significant differences in SBS existed between different tooth types *ex vivo*. They concluded that there are significant differences in mean bond strength between different tooth types, and hence that *ex vivo* bond strength is not uniform across all teeth.

When using the two conditioners TPSEP and phosphoric acid with the three bracket types, a difference in bond failure site was noted (Figure 3). With TPSEP, this was predominantly ARI 1 and with phosphoric acid ARI 3. The increased frequency of ARI scores of 3 when using phosphoric acid is in agreement with Buyukyilmaz *et al.* (2003), Cacciafesta *et al.* (2004), and Sfondrini *et al.* (2004). The potential importance of this may be observed at the time of debond when removal of large amounts of debris can be time consuming and may cause enamel surface damage (Zachrisson and Årtun, 1979). When using TPSEP as the conditioner, the results of this investigation suggest the opposite to the findings of Bishara *et al.* (2001), Buyukyilmaz *et al.* (2003), and Cacciafesta *et al.* (2003), i.e. in the present study, there was less residual adhesive remaining on the teeth treated with TPSEP than on those bonded with the conventional adhesive system. The possible reasons for this have already been mentioned.

The rebond strengths of all bracket types were significantly lower than their initial bond strengths (Table 1). Bishara *et al.* (2000) also reported that the highest values for SBS were obtained after initial bonding and that rebonded teeth had a significantly lower SBS.

Bond failure sites changed from ARI 1 to ARI 3 on rebond when using TPSEP (Table 2) and the rebond strength was significantly lower compared with the initial SBS. The importance of this is that rebonding brackets may not be clinically worthwhile due to the reduced bond strength, its ease of debond, and increased time required to remove the adhesive.

Conclusion

1. When using TPSEP, there was no significant difference in the SBS of two types of precoated brackets, APC 1 and APC 2, compared with the non-coated bracket system (control group). The most common mode of bond failure for the three bracket types was at the adhesive–enamel interface.
2. There was a significant difference in the SBS of V brackets when using TPSEP and 37 per cent phosphoric acid as the conditioners: the latter was lower. Bond failure site changed from the enamel–adhesive interface to the bracket–adhesive interface.
3. The shear rebond strengths of all bracket types were significantly lower than their initial SBS. The locus of bond failure changed from the adhesive–enamel interface to the bracket–adhesive interface.
4. When using TPSEP, adhesive removal time from the enamel surface may be reduced following debond as there is less residual adhesive remaining on the tooth surface when compared with the two-stage conventional system.

Acknowledgements

We would like to thank Mr Dirk Bister, Mr Robert Evans, and Mr David Young for their assistance and 3M Unitek for the generous supply of the materials required for this project and their advice.

Address for correspondence

Sunil Hirani
Department of Orthodontics
Floor 22, Guy's Tower
Guy's Hospital
London Bridge SE1 9RT
UK
E-mail: sunilhirani@aol.com

References

Aljubouri Y D, Millett D T, Gilmour W H 2003 Laboratory evaluation of a self-etching primer for orthodontic bonding. European Journal of Orthodontics 25: 411–415

Årtun J, Bergland S 1984 Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pre-treatment. American Journal of Orthodontics 85: 333–340

Bearn D R, Aird J C, McCabe J F 1995 *Ex vivo* bond strength of adhesive precoated metallic and ceramic brackets. British Journal of Orthodontics 22: 233–236

Bishara S E, Olsen M, VonWald L 1997 Comparisons of shear bond strength of precoated and uncoated brackets. American Journal of Orthodontics and Dentofacial Orthopedics 112: 617–621

Bishara S E, VonWald L, Laffoon J F, Warren J J 2000 The effect of repeated bonding on the shear bond strength of a composite resin orthodontic adhesive. Angle Orthodontist 70: 435–441

Bishara S E, VonWald L, Laffoon J F, Warren J J 2001 Effect of a self-etch primer/adhesive on the shear bond strength of orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 119: 621–624

Buyukyilmaz T, Usumez S, Karaman A I 2003 Effect of self-etching primers on bond strength—are they reliable? Angle Orthodontist 73: 64–70

Cacciafesta V, Sfondrini M F, De Angelis M, Scribante A, Klersy C 2003 Effect of water and saliva contamination on shear bond strength of brackets bonded with conventional, hydrophilic, and self-etching primers. American Journal of Orthodontics and Dentofacial Orthopedics 123: 633–640

Cacciafesta V, Sfondrini M F, Scribante A, De Angelis M, Klersy C 2004 Effects of blood contamination on shear bond strengths of conventional and hydrophilic primers. American Journal of Orthodontics and Dentofacial Orthopedics 126: 207–212

Egan F R, Alexander S A, Cartwright G E 1996 Bond strength of rebonded orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 109: 64–70

Hobson R S, Mattick C R 1997 A quantitative *in-vivo* study of the acid etch patterns on the buccal surfaces of teeth. Journal of Dental Research 76: 1046 (abstract)

Hobson R S, Mattick C R 1998 *In vivo* acid etch patterns on tooth buccal surfaces. Journal of Dental Research 77: 979 (abstract)

Hobson R S, McCabe J F, Hogg S D 1999 Orthodontic bond strength on different teeth. Journal of Dental Research 78: 547 (abstract)

Ireland A J, Sherriff M 1988 The use of an adhesive composite for the bonding of orthodontic attachments. Journal of Dental Research 67: 661 (abstract)

Ireland A J, Sherriff M 1994 Use of an adhesive resin for bonding orthodontic brackets. European Journal of Orthodontics 16: 27–34

Kinch A P, Taylor H, Warltier R, Oliver R G, Newcombe R G 1989 A clinical study of amount of adhesive remaining on enamel after debonding, comparing etch times of 15 and 60 seconds. American Journal of Orthodontics and Dentofacial Orthopedics 95: 415–421

Leas T J, Hondrum S 1993 The effect of rebonding on the shear bond strength of orthodontic brackets—a comparison of two clinical techniques. American Journal of Orthodontics and Dentofacial Orthopedics 103: 200–201

Linklater R A, Gordon P H 2001 An *ex vivo* study to investigate bond strengths of different tooth types. Journal of Orthodontics 28: 59–65

Mascia V E, Chen S R 1982 Shearing strengths of recycled direct-bonding brackets. American Journal of Orthodontics 82: 211–216

Mattick C R, Hobson R S 2000 A comparative micro-topographic study of the buccal enamel of different tooth types. Journal of Orthodontics 27: 143–148

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

Sfondrini M F, Cacciafesta V, Scribante A, De Angelis M, Klersy C 2004 Effect of blood contamination on shear bond strength of brackets bonded with conventional and self-etching primers. American Journal of Orthodontics and Dentofacial Orthopedics 125: 357–360

Sunna S, Rock W P 1999 An *ex vivo* investigation into the bond strength of orthodontic brackets and adhesive systems. British Journal of Orthodontics 26: 47–50

Tavas M A, Watts D C 1979 Bonding of orthodontic brackets by transillumination of a light activated composite, an *in vitro* study. British Journal of Orthodontics 6: 207–208

Zachrisson B U, Årtun J 1979 Enamel surface appearance after various debonding techniques. American Journal of Orthodontics 75: 121–137