An *Ex Vivo* Investigation into the Bond Strength of Orthodontic Brackets and Adhesive Systems

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Abstract. *The aim of this study was to compare the shear bond strength of Adhesive Precoated Brackets (APC) with that of two types of uncoated bracket bases, Straight-Wire and Dyna-Lock.*

Two types of orthodontic adhesives were used, Transbond XT and Right-On. Three different curing times were evaluated with the APC brackets in order to find the best. Adhesive remnants on the enamel surface following debond were evaluated using the Adhesive Remnant Index (Artun and Bergland, 1984).

Bond strengths ranged from 11·00 to 22·08 MPa. For both types of brackets Transbond produced a significant increase in bond strength compared to Right-On. The Dyna-Lock/Right-On combination produced the poorest results. APC brackets cured for 40s had similar bond strengths to uncoated brackets fixed by means of Transbond. Overall, 79 per cent of specimens had less than half the tooth surface covered with adhesive following debond. Significantly more adhesive remained on tooth surfaces following debond of the Straight-Wire/Right-On group than any other bracket/adhesive combination.

Bond strengths were higher with light-cured Transbond than with chemically-cured Right-On. When Transbond is used in association with APC brackets a 40-second cure time is recommended.

Index words: Adhesive Precoated Brackets, Bond strength, Bracket base.

Refereed Paper

Introduction

The acid etch technique (Buonocore, 1955) and development of modern adhesive materials has lead to the widespread use of bonded attachments in fixed appliances. Several factors influence the strength of the bond obtained, including the nature of the enamel surface, enamel conditioning procedures, the type of adhesive used, and the shape and design of the bracket base.

Composite resins are the most popular orthodontic adhesives. Early self-polymerizing materials were two-paste systems, one paste containing an activator and the other an initiator. Two-paste systems were time-consuming and multiple mixes were often required for a full mouth ‘bond-up’. Another disadvantage was that air bubbles incorporated into the adhesive during mixing could have adverse effects if entrapped under bracket bases (Mitchell, 1994), No-mix systems were therefore developed to improve the handling properties of orthodontic adhesives.

Light-cured composite resin systems provide clinicians with virtually unlimited working time, thus allowing more accurate bracket placement and easier removal of excess adhesive before setting is initiated. There are, however, the potential disadvantages of increased bonding time and the possibility of incomplete polymerization under metallic brackets due to insufficient exposure to the curing light. This may result in reduced bond strength (Sargisson *et al.*, 1995). However, other reports that have examined this variable have produced conflicting results (Wang and Meng, 1992; Pearson, 1995).

Three main bracket base designs are commercially available: mesh, integral bases with undercut channels, and micro-etched. Mesh bases are generally made by the lamination of a fine mesh to a foil. The bracket body and the base are assembled with a light weld tack, after which a paste containing brazing alloy is applied to the joint (Matasa, 1996). The first integral bases available were Dyna-Lock (3M Unitek, P.O. Box 1, Bradford, BD5 9UY) brackets in which retention is provided by horizontal undercut channels open at the mesial and distal extremities, with a V-grooved pattern running vertically on the surface of the base.

Adhesive Precoated Brackets (APC) (3M Unitek, P.O. Box 1, Bradford, BD5 9UY) are available as both metallic and ceramic types. The precoated composite used is a version of Transbond (3M Unitek, P.O. Box 1, Bradford, BD5 9UY), modified to give increased viscosity (Bergstrand, 1996, personal communication). Cooper *et al.* (1992) listed the following advantages of APC over conventional light-cured systems:

(1) consistent quality and quantity of light-cured adhesive;
(2) easier clean-up following bonding;
(3) reduced waste;
(4) improved asepsis;
(5) better inventory control.

In addition, improved control of both the bracket and composite resin-associated with the use of APC is claimed to improve bond strength and thereby reduce clinical failure rate (3M Unitek product literature, 1997; F. Bergstrand, 1996, personal communication).

0301-228X/99/010000+00$02.00

Only a few studies have evaluated the bond strength of APC brackets. Bearn *et al.* (1995) compared the *ex vivo* shear bond strength of metallic APC brackets with that of identical brackets bonded with Transbond and found no significant differences between the two.

Objectives of the Present Study

1. To compare the shear bond strength of two orthodontic adhesive systems, Transbond XT and Right-On (TP Orthodontics, 2 Bruntcliffe Way, Morley, Leeds LS27 0JG.)
2. To compare the shear bond strength of Dyna-Lock APC brackets with uncoated Dyna-Lock and also mesh-backed brackets.
3. To identify an optimum light curing time for APC brackets.
4. To compare the amount of adhesive remaining on tooth surfaces following debond for precoated and standard brackets.

Materials and Methods

Brackets and Adhesives

Two types of orthodontic brackets were used: metallic Dyna-Lock Torque-in-Base brackets, available in adhesive precoated and non-precoated versions, and Straight-Wire Twin brackets (Orthologic, Summit House, Summit Road, Potters Bar, EN6 3EE) with foil mesh bases (Figure 1). Three types of resin adhesive systems were used: Right-On chemically-cured adhesive paste, Transbond XT light-cured adhesive paste, and a modified version of Transbond XT precoated onto bracket bases.

Specimen Preparation

Sound upper first premolar teeth extracted for orthodontic purposes, from patients aged 11–15 years, were collected. After extraction, teeth were stored individually in plastic tubes containing distilled water as suggested by Fox *et al*. (1994).

The study design required specimens to be divided into seven groups, with 10 in each group. All of the tubes containing collected teeth were mixed together thoroughly and 10 specimens were allocated to each group by a process of physical randomization.

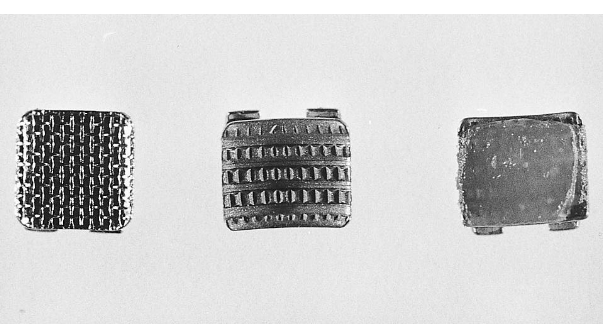

FIG. 1 The fitting surfaces of Dyna-Lock precoated and non-coated brackets and a mesh base.

Using a hand-held fret-saw, each tooth was sectioned about 1 mm below the cemento-enamel junction.

The crowns were then mounted in cold cure acrylic contained within brass cylinders, so that the buccal surfaces were parallel to and projected slightly above the rim of the cylinder as described by Bin Abdullah and Rock (1996).

Enamel preparation and bracket bonding was standardized as follows:

1. Polishing with pumice in a rubber cup using a slow speed handpiece for 5 seconds.
2. Rinsing with an air/water spray for 5 seconds.
3. Drying with oil-free compressed air for 10 seconds.
4. Etching with 35% w/w phosphoric acid for 30 seconds.
5. Rinsing with an air/water spray for 15 seconds.
6. Drying with oil-free compressed air for 5 seconds.

The appropriate primer was then applied to the etched enamel surface and bracket base, and the tooth was lightly blown with air to ensure that only a thin layer of primer remained. APC brackets were already precoated with adhesive, and therefore were applied directly to the etched and primed enamel surfaces. For the other two bracket types the appropriate adhesive was loaded onto the bracket base which was then placed on the LA point as in the clinical situation (Andrews, 1976). Brackets were seated with firm pressure to minimize the thickness of the resin film and a probe was used to remove excess resin from around the bracket before it had set. Light curing of Transbond was achieved with an Ortholux XT light unit (3M Unitek, P. I. Box 1, Bradford, BD5 9UY, U.K.) directed for 10 seconds mesially and then 10 seconds distally at each bracket. Three groups of APC brackets were evaluated with 10, 20, and 40 light curing. Following bonding, all specimens were stored in distilled water in darkness for 24 hours.

Bond Strength Testing

During testing, a brass cylinder with its embedded tooth was assembled in a special jig manufactured to fit the lower crosshead of the Instron machine (Extra, model 1185). A looped 0·018 × 0·025-inch stainless steel wire was attached to the fixed upper crosshead and passed beneath the bracket wings (Fox *et al*., 1994; Figure 2). The jig allowed

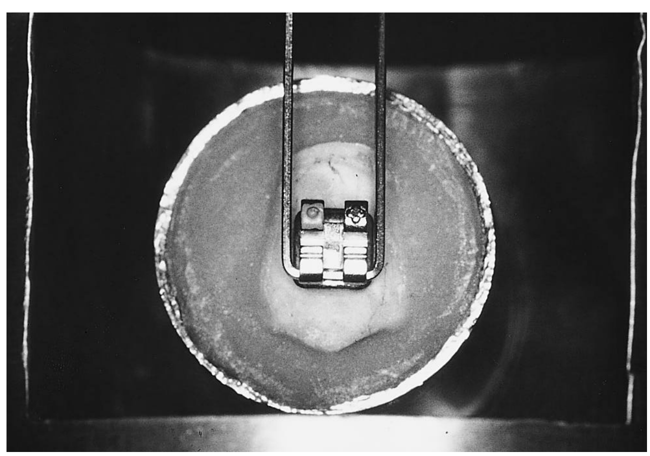

FIG. 2 A specimen on the Instron showing the position of the wire used to apply shear force.

the brass cylinder to be adjusted so that the shear forces were at right angles to the long axis of the bracket body. Specimens were mounted so that the direction of force application was occlusogingival. During testing, the lower crosshead was moved down at 5mm/min., and measurements were read on a scale of 5:1.

Assessment of Adhesive Remnants

After debonding, specimens were examined under a stereomicroscope (Leica Zoom 2000) at ×20 magnification in order to assess adhesive remnants on tooth surfaces using the Adhesive Remnant Index (Artun and Bergland, 1984).

Statistical Analysis

Data relating to bond strengths for various bracket/adhesive combinations were analysed using two-way ANOVA, followed by paired t-tests to investigate differences between groups. The effect of curing time on APC bond strength was studied by means of one-way ANOVA and Tukey's pairwise comparisons.

Results

Results of shear bond strength testing for the various bracket/applied adhesive combinations are presented as the first four rows of Table 1. Units are Newtons for Load and MegaPascals (Newtons per mm^2) for stress. Two-way ANOVA showed highly significant differences between both brackets and adhesives ($P < 0{\cdot}01$). Bonds were stronger with Straight-Wire brackets than with Dyna-Lock, 19·48 MPa against 16·66 MPa. Transbond produced better bonds than Right-On, 21·94 MPa against 14·20 MPa.

Analysis of the effect of varying cure time with APC brackets using one-way ANOVA showed that cure time was a significant variable. A 40-second light curing time gave a significant increase in the bond strength over the 10- and 20-seconds groups.

The results of Adhesive Remnant Index scoring for the various groups are shown as Table 2. The most frequent ARI score for most groups was 1, with the exception of the Straight-Wire/Right-On combination which had a majority of ARI 2 scores. None of the specimens tested scored 3.

TABLE 1 *Results of shear bond strength testing*

Bracket/adhesive combination	Load (N)		Stress (MPa)	
	Mean	SD	Mean	SD
Dyna-Lock/Transbond	300·70	20·26	22·32	1·60
Dyna-Lock/Right-On	148·25	25·79	11·00	2·02
Straight-Wire/Transbond	290·00	42·84	21·56	3·32
Straight-Wire/Right-On	231·75	24·85	17·40	1·97
APC 10-second cure	233·50	38·47	17·33	3·01
APC 20-second cure	240·50	19·58	17·82	1·57
APC 40-second cure	297·50	43·60	22·08	3·41

Discussion

The nature of the forces exerted onto orthodontic brackets *in vivo* and the nature of the stress distribution generated within the adhesive is complex, and likely to combine shear, tensile, and compressive force systems. In the present study a shear/peel method of testing was chosen as this was most likely to represent the clinical situation (Tavas and Watts, 1979). The method for specimen preparation and testing followed the guidelines recommended by Fox *et al.* (1994). Care was taken to adhere to the protocol and so minimize intra-group variation. This is evident by the low standard deviations for stress values in Table 1 and gives assurance that the number of specimens per group was adequate. Although Fox *et al*. recommended a minimum of 20 specimens per group, their survey of 66 studies revealed 10 to be the group size most often employed.

Results of shear bond strength testing are presented in units of Newtons (N) for load and MegaPascals (MPa) for stress to allow for comparison with other studies. The conversion of Newtons to MegaPascals (N/mm^2) was made by dividing load by the bracket base area of 13·47 mm^2 for Dyna-Lock brackets and 13·38 mm^2 for Straight-Wire brackets. This was calculated by measuring 10 brackets with a digital calliper and taking the mean. Shear bond strengths ranged from 11·00 to 22·32 MPa. This is larger than the 6–MPa recommended by Reynolds (1975) and Whitlock *et al.* (1994) as adequate for orthodontic purposes. The Dyna-Lock/Transbond combination produced the highest bond strength, while Dyna-Lock/Right-On gave the lowest.

It is apparent that for both types of brackets light-cured Transbond consistently produced significantly higher bond strengths than the chemically-cured adhesive Right-On. The data therefore does not support the findings of Sargisson *et al.* (1995) who found no significant differences between the *ex vivo* shear bond strengths of Transbond and Right-On.

Transbond performed equally well with the two types of bracket bases. Right-On adhesive, however, gave significantly inferior results with Dyna-Lock brackets, in agreement with the work of Ferguson *et al.* (1984) who suggested that the poor performance of Dyna-Lock brackets with Right-On adhesive was due to incomplete blending of the two dissimilar phases of Right-On in association with undercut-case brackets.

A 40-second light curing time significantly increased bond strength with APC brackets. This is in agreement with

TABLE 2 *The adhesive remnant index score frequency for each group*

Bracket/adhesive combination	Adhesive Remnant Index score			
	0	1	2	3
Dyna-Lock/Transbond	0	9	1	0
Dyna-Lock/Right-On	2	6	2	0
Straight-Wire/Transbond	2	6	2	0
Straight-Wire/Right-On	1	2	7	0
APC 10 seconds	0	9	1	0
APC 20 seconds	2	7	1	0
APC 40 seconds	1	8	1	0

*ARI score 0 = no adhesive left on the tooth; 1 = less than half the adhesive left on the tooth; 2 = more than half the adhesive left on the tooth, 3 = adhesive covering the whole area of the bracket base.

the findings of Wang and Meng (1992) who reported higher bond strengths with Transbond XT when light curing was increased from 20 to 40 seconds. In the present study no significant differences were detected between the bond strengths of the APC-10- and 20-second groups, respectively. After a 40-second cure APC brackets produced similar bond strengths to Dyna-Lock brackets when adhesive was applied by the operator. This finding agrees with the conclusions of Bearn *et al.* (1995).

The Adhesive Remnant Index (Artun and Bergland, 1984) provides an easy method of evaluating adhesive remnants following debond. Almost 80 per cent of all specimens had less than half the tooth surface covered with adhesive. The Straight-Wire/Right-On group, however, had a preponderance of 2 scores (more than 5 per cent tooth coverage). It is difficult to explain why this occurred as the combination of a mesh base with a lightly filled composite resin should provide a strong base/adhesive interlock so that the majority of the adhesive would come away with the bracket.

Conclusions

1. The use of Transbond XT light-cured adhesive significantly increased the shear bond strength of Dyna-Lock and Straight-Wire brackets compared to Right-On chemically-cured adhesive.
2. Both types of brackets performed similarly when Transbond XT was used. The Dyna-Lock/Right-On combination produced inferior results.
3. Precoating Dyna-Lock brackets with adhesive did not increase bond strength. In fact, APC-10- and APC-20-second specimens displayed reduced bond strengths compared to the Dyna-Lock/Transbond XT combination.
4. A 40-second light cure time significantly increased the shear bond strength of APC and is therefore recommended.
5. Significantly more adhesive remained on the tooth surface following debond of the Straight-Wire/Right-On group than any other bracket/adhesive combination.

Results of *ex vivo* studies should be interpreted with care. A prospective randomized clinical trial is currently under way to test the clinical performance of the materials used in this study using the same bonding technique. It is hoped that this will also give some indication of the clinical applicability of *ex vivo* bond strength testing.

Acknowledgements

We are grateful to 3M Unitek for help with this study and to Dr John Rippin for statistical assistance.

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