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A comparative investigation into relative bond strengths of Damon3, Damon3MX, and APC II brackets using different primer and adhesive combinations

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SUMMARY This investigation measured and compared shear bond strength (SBS) and adhesive remnant indices (ARIs) of Damon3 and Damon3MX brackets bonded with their recommended primer/adhesive combination or Transbond XT primer/adhesive, with APC II brackets bonded using Transbond XT. Sixty non-carious human third molars were collected and randomly divided into six equal groups of 10. Amongst these, one group was used to standardize the testing methodology, with the remainder constituting the five experimental groups. Upper right central incisor brackets represented each bracket type. Specifically, Damon3 brackets were bonded using either OrthoSolo primer/Blugloo (recommended) or Transbond XT primer/adhesive; Damon3MX brackets were bonded using OrthoSolo primer/Grengloo (recommended) or Transbond XT primer/adhesive, and APC II brackets were bonded with Transbond XT primer. Brackets were debonded by shear force using an Instron machine and the SBS measured. Scores for ARI were determined for all groups after bracket failure by magnified inspection of the tooth surface. Logrank tests showed a significantly higher SBS with Damon3 brackets bonded with OrthoSolo/Blugloo compared with Transbond XT, but no significant differences between the SBS of Damon3MX brackets bonded with OrthoSolo/Grengloo compared with Transbond XT. There were no significant differences in SBS of all three bracket types when bonded with Transbond XT. Pearson's chi-square test showed no difference in the locus of debond. All three adhesive systems are reliable when bonding Damon3 and Damon3MX brackets. Some caution should be taken when using Damon3 brackets bonded with OrthoSolo/Blugloo due to the higher SBS, although no enamel fractures were noted in this study.

Introduction

To enable controlled three-dimensional orthodontic tooth movement, good bond strength between bracket, adhesive, and tooth enamel is required. This ensures that forces are transmitted effectively throughout the bracket base to the tooth (Eliades and Brantley, 2000). Bond strength should be strong enough to withstand the oral environment, forces of mastication, and those generated by the treatment mechanics but should also allow subsequent bracket removal without enamel damage.

The Damon bracket system has the two-way colour change adhesive resins Blugloo and Grengloo (Ormco, Glendora, California, USA) for use in conjunction with OrthoSolo primer to bond Damon3 (which has an aesthetic composite resin base) and Damon3MX (stainless steel) brackets, respectively. The manufacturer claims higher bond strengths when Damon brackets are bonded with their own resins compared with Transbond XT adhesive (www.ormcoeurope.com).

A number of laboratory investigations have been carried out to measure the shear bond strength (SBS) and adhesive remnant index (ARI) associated with Damon brackets (Chalgren *et al.*, 2007; Northrup *et al.*, 2007; Reicheneder *et al.*, 2009; Tükkahraman *et al.*, 2010; Sfondrini *et al.*, 2011). In particular, comparison of the SBS and ARI of different self-ligating and conventional brackets has shown Smartclip and Damon brackets to have a significantly higher SBS compared with conventional. All brackets tested showed an ARI score of 1 or 2, indicating mixed mode failure (Sfondrini *et al.*, 2011). The SBS of three different colour change adhesives Grengloo, Blugloo, and Transbond Plus have also been tested in the laboratory, with no significant differences being detected and a mode of failure mainly at the adhesive interface (Tükkahraman *et al.*, 2010). Comparison of the SBS associated with eight adhesive systems used in conjunction with Damon3 brackets (including Blugloo and Transbond) demonstrated Blugloo to have the highest SBS. Overall, the authors concluded that Blugloo, Fuji Ortho LC, Light Bond, and Enlight LV were among the materials of choice for bonding fixed orthodontic appliances (Reicheneder *et al.*, 2009). The SBS of Damon3 brackets has also been tested using various enamel and bracket preparations, with self-ligating etching primer, gel etchant, and liquid etchant producing equal and sufficient bond strengths in combination with composite (Chalgren *et al.*, 2007). The SBS of Damon2 brackets bonded with either the Transbond XT system or the Blugloo adhesive system has also been compared with that of conventional stainless steel brackets. This investigation showed a higher SBS associated with the Damon2 bracket using either bonding system compared with the conventional stainless steel brackets bonded with Transbond XT primer and adhesive (Northrup *et al.*, 2007). Thus, laboratory studies have generally found high SBS associated with the Damon bracket system.

A wide variety of dental composite materials are currently available for orthodontic bonding; however, it is not practical for the clinician to maintain a selection of bracket-specific adhesives. Ideally, a universal adhesive system should be available, which works successfully on a variety of bracket types. Bracket failure rates in randomized control trials range from 6.6 to 9.4 per cent when bonding conventional stainless steel adhesive pre-coated (APC) brackets with Transbond XT primer and resin (Sunna and Rock, 1998; Littlewood *et al.*, 2001). These figures are clinically acceptable and therefore, the SBS of different adhesive systems can be compared with those of APC brackets bonded with Transbond XT adhesive, using this as a baseline standard.

The aims of the present investigation were to measure the SBS and ARI of Damon3 and Damon3MX brackets bonded either with their recommended adhesive systems or with their Transbond XT and compare the SBS and ARI values obtained from these combinations with those of conventional APC brackets bonded with Transbond XT. The null hypothesis was that no differences exist in SBS values and ARI among the various groups.

Materials and methods

Unrestored, non-carious, erupted, human maxillary, and mandibular third molars, extracted in the Oral Surgery Department at Guy's Hospital, UK, were collected following consent. The teeth were cleaned and stored in distilled water for less than 6 months at a temperature of 4°C (ISO TS 106 SC 11405, 2003). Teeth were selected at random, mounted in acrylic, and allocated to one of six groups. The first group of teeth was used only to standardize the testing methodology and ensure that all subsequent groups were bonded and sheared in the same way. The remaining five constituted the experimental groups. The buccal surfaces of these teeth were cleaned using oil-free pumice, with a rubber polishing cup in a slow handpiece. The teeth were washed with water, dried with an airstream, and etched with 37 per cent *o*-phosphoric acid for 30 seconds. This was rinsed off for 20 seconds and then dried until the enamel showed a uniform white frosted appearance. Depending on the group, Transbond XT or OrthoSolo primer was applied to the enamel surface with an applicator and air thinned. A thin film of Transbond XT, Blugloo, or Grengloo adhesive was then dispensed onto the bracket base and the bracket placed onto the enamel surface with bracket tweezers. Damon3 brackets have as a high-retention polycarbonate mechanical bonding base, while Damon3MX brackets have a metal base. For both brackets, different primer and adhesive combinations were placed by hand. For APC II brackets, the adhesive is already placed on the metallic bracket base. For consistency, only upper right maxillary central incisor brackets were used. The bracket was placed in position and firm pressure was applied with a dental probe and excess adhesive removed. These were then cured mesially and distally for 10 seconds per side with a conventional quartz halogen light-curing unit (Optilux 501 SDS Kerr).

SBS was measured using an Instron Universal Testing Machine (Model No 1193; Instron Limited), using 50 kg (tension load cell type: 2511/111) and a custom-made jig (Ireland and Sherriff, 1988). The shearing blade was in the upper movable jaw. The acrylic blocks were placed in the lower static jaw of the testing machine. The base of the bracket was lined up parallel with the base of the shearing blade. The blade moved up in a gingivo-occlusal direction between the base and the wings of the bracket, exerting a shear force. The Instron machine was calibrated using a 10 N dead load at the start of each testing session, and the calibration repeated after every 10 tests. The crosshead speed was 1 mm minute. The failure load (Newton) was recorded electronically with a computer connected to the testing machine. After debonding, the locus of failure for each tooth was determined by viewing them under a magnifying lens (×10) with an external light source. The amount of adhesive left on the tooth surface was scored according to the modified ARI (Årtun and Bergland, 1984).

Statistical analysis

Data were analysed using the package Stata version 10.1 (StataCorp. 2005 Stata statistical software, release 10, College Station, TX, USA: StataCorp LP). The significance level was predetermined at $\alpha = 0.05$ for all statistical tests. Kaplan–Meier survival curves were determined for each group and groups were compared using the non-parametric logrank test. The distribution of failure modes was analysed using Pearson's chi-square test.

Results

A summary of the bracket and adhesive combinations tested is shown in Table 1. Descriptive statistics for all the experimental groups are shown in Table 2. The data distribution for all five groups is shown in Figure 1. The logrank test demonstrated statistically significant differences in bond strength within the five groups ($P < 0.005$). A significantly higher bond strength was found when the Damon3 bracket was bonded with OrthoSolo™ primer and Blugloo™

adhesive (D3/B) when compared with Transbond XT primer and adhesive (D3/T; $P < 0.005$). No statistically significant difference was found in SBS of the Damon3MX bracket when bonded with either OrthoSolo primer and Grengloo adhesive (D3MX/G) or Transbond XT primer and adhesive (D3MX/T; $P > 0.5$). No statistically significant differences in bond strength were found when Damon3 (D3/T), Damon3MX (D3MX/T), and APC II brackets (APC/T) were bonded with Transbond XT primer and adhesive ($P > 0.3$).

Table 1 Groups tested.

Group number	Group code	Materials being tested
1	D3/B	Damon3 bracket bonded with OrthoSolo primer and Blugloo adhesive
2	D3/T	Damon3 bracket bonded with Transbond XT primer and adhesive
3	D3MX/G	Damon3MX bracket bonded with OrthoSolo primer and Grengloo adhesive
4	D3MX/T	Damon3MX bracket bonded with Transbond XT primer and adhesive
5	APC/T	APC II bracket bonded with Transbond XT primer and adhesive

Table 2 Descriptive statistics for all experimental groups. SBS, mean shear bond strength; SD, standard deviation; D3, Damon3 bracket; D3MX, Damon3MX bracket; APC, adhesive pre-coated bracket; T, Transbond XT primer and adhesive; B, OrthoSolo primer and Blugloo adhesive; G, OrthoSolo primer and Grengloo adhesive.

Group	Sample number	SBS (N)	SD	Range
D3/B	10	69.16*	5.96	61.57–79.93
D3/T	10	42.96	16.54	21.42–75.52
D3MX/G	10	62.08	20.01	39.36–107.23
D3MX/T	10	51.52	16.04	20.49–84.20
APC/T	10	42.59	12.35	30.92–67.36

*Significant.

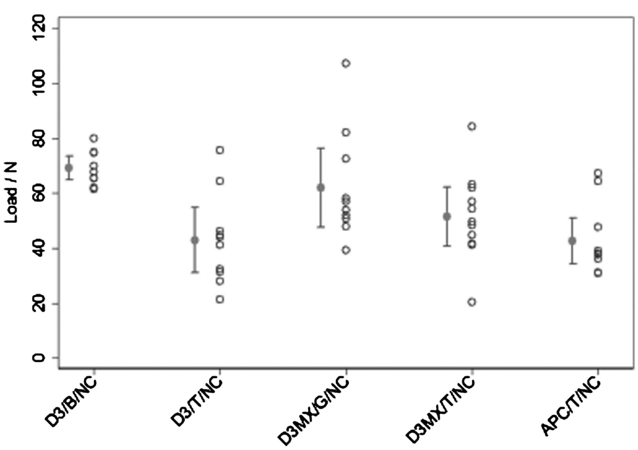

Figure 1 Data distribution, mean, and 95% confidence intervals of all groups. This graph shows the probability of a bond failing as a function of the applied load.

Pearson's chi-square test showed no statistically significant difference ($P > 0.5$) between the modified ARI scores of all five groups (Figure 2, Table 3), with bond failure occurring mostly by mixed mode failure (i.e. at the adhesive). The scores obtained were mostly 2 and sometimes 1. Occasionally, the failure mode was at the bracket–bonding agent interface, leaving behind the impression of the bracket mesh. Bond failure rarely occurred at the enamel–bonding agent interface. No enamel cracks or detachments were noted under a magnification of ×10.

Discussion

To date, relatively few studies have analysed bond strengths associated with Blugloo and Grengloo adhesives used in conjunction with OrthoSolo primer. This study demonstrated higher SBS values with Damon3 brackets bonded using OrthoSolo primer and Blugloo in comparison to Transbond XT. This could be due to better molecular interaction between resins of the Blugloo adhesive and Damon3 bracket base. This result is comparable with previous work, which has shown that Blugloo has a higher SBS than Transbond LR when bonded to Damon3 brackets (Reichenede *et al.*, 2009). In contrast, no statistically significant difference was

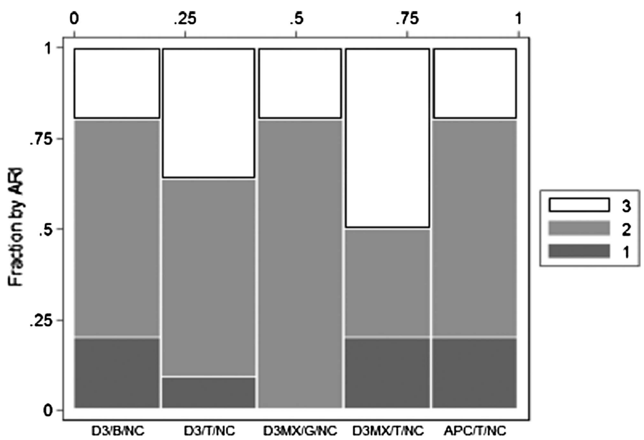

Figure 2 Distribution of adhesive remnant index scores.

Table 3 Adhesive remnant index (ARI) scores.

Group	*N*	ARI 0	ARI 1	ARI 2	ARI 3
D3/B	10	0	2	6	2
D3/T	10	0	1	5	4
D3MX/G	10	0	0	8	2
D3MX/T	10	0	2	3	5
APC/T	10	0	2	6	2

After Årtun and Bergland (1984).

found in SBS when Damon2 brackets bonded with Blugloo were compared with Transbond XT (Northup *et al.*, 2007). However, the Damon2 bracket is metal and therefore, these results are not directly comparable to this study.

The trend for relatively higher bond strengths associated with Blugloo may be due to the OrthoSolo sealant, a fluoride-releasing universal sealant and bond enhancer. It is claimed that OrthoSolo incorporates a bond-enhancing property that improves adhesion to the tooth and therefore bond strength. Indeed, a significant increase in SBS has been found when brackets are bonded with OrthoSolo primer compared with Transbond XT primer or All-Bond2 primer with Transbond XT adhesive (Vicente *et al.*, 2005). Grengloo also contains a patented ingredient, which increases traumatic impact resistance by 118 per cent and has a chemical affinity for metal brackets, which ensures reliable bond strength. This study showed no statistical difference in SBS when Damon3MX brackets were bonded with Grengloo compared with Transbond XT. This is in contrast to other studies, which have shown higher SBS when using Grengloo compared with Transbond (Türkkahraman *et al.*, 2010).

The most suitable SBS for an orthodontic bracket is the minimum bond strength above which no improvement in retention of the bracket is achieved *in vivo* and not simply maximum or high bond strengths. The force should be at a level that allows bracket debonding without causing damage to the enamel surface. APC II brackets used in conjunction with Transbond XT primer and adhesive have a low clinical bond failure rate (Sunna and Rock 1998; Littlewood *et al.*, 2001). It can be argued from the results that Damon3 and Damon3MX brackets when bonded with Transbond XT primer and adhesive also show clinically acceptable bond strengths as no significant difference in SBS of the Damon3, Damon3MX, and APC II brackets were found when bonded with Transbond XT. The clinician should be aware of the higher bond strengths found in this study when bonding Damon3 brackets with OrthoSolo primer and Blugloo adhesive. Caution needs to be exercised as debond may result in enamel damage, although no cracks were observed in this study. Care is especially needed for patients with enamel defects.

The ARI was used to quantitatively define the locus of bond failure, although a criticism of this method is that it is largely subjective (O'Brien *et al.*, 1988). The most common mixed mode failure is representative of ARI scores between 1 and 2, which are likely due to a complex distribution of stresses within the adhesive and its junctions with tooth and bracket. Failure at the bracket–adhesive interface was also common, which may be because of difficulties with the viscous adhesive entering the mesh layer or the grooves of the bracket base, trapping air in the process. There is disagreement in the literature as to the ideal site of bond failure. The failure of the bond at the bracket–bonding agent interface slows up the debonding process. The remaining composite has to be removed with a tungsten carbide debonding bur in a slow handpiece, which can also remove up to 56 μm of enamel surface (Fitzpatrick and Way, 1977) where fluoride concentration is at its greatest (Jenkins, 1978). However, adhesive failure at the enamel–bonding agent interface increases the probability of enamel fracture (Yapel and Quick, 1994) due to the micro-mechanical nature of the bond between the resin and the enamel (Hosein *et al.*, 2004). Cracks encourage plaque accumulation and staining. Cracks or fractures, however, are not recorded using the ARI scoring method. It would be sensible to say that the ideal bond failure should occur at the interface between enamel and the bonding agent, without producing enamel fractures. Enamel fracture is more likely in extracted teeth, which have been stored in distilled water as they are more desiccated than vital teeth (Theodorakopoulou *et al.*, 2004). No enamel fracture was noted in this study when teeth were observed at a magnification of ×10.

Strengths of this study include the fact that one operator (MI) conducted all bonding procedures to standardize this variable, although it was not possible to blind the operator to the primer and the adhesive being used. The brackets were also debonded within half an hour from the time of initial bonding to approximate the timing of initial archwire placement. However, valid clinical conclusions cannot be made from an entirely laboratory-based study for many reasons. Clinically, masticatory forces and those generated from orthodontic mechanics differ from the type of load applied to the brackets by an Instron machine and, also, the oral environment cannot be reproduced in the laboratory (Eliades and Brantley, 2000). Furthermore, biodegradation of materials takes place over time when exposed to the oral environment, which can alter the composition and the mechanical properties of orthodontic materials and hence the bond strength (Eliades and Bourauel, 2005). *In vitro* testing, therefore, only provides a clinical guide for the initial evaluation and selection of bracket–bonding agent combinations (O'Brien *et al.*, 1989). One possible weakness of this investigation was the use of bovine third molar teeth and brackets designed for human upper central incisors, which might have influenced the SBS. An alternative choice might have been to use bovine incisor teeth, which have a microstructural similarity to human tooth enamel (Oesterle *et al.*, 1998) and a more acceptable adaptability to upper human incisor brackets.

Conclusions

1. Damon3 brackets bonded with OrthoSolo primer and Blugloo showed a higher SBS when compared with those bonded using Transbond XT primer/adhesive. No enamel fracture was noted in either group.
2. Damon3MX brackets bonded with Grengloo showed no difference in SBS when compared with those bonded with Transbond XT primer/adhesive.

3. No significant differences were found in SBS of Damon3, Damon3MX, and APC II brackets bonded with Transbond XT primer and adhesive. This primer/adhesive combination can be used for successful bonding of Damon3 and Damon3MX 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

Chalgren R, Combe EC, Wahl AJ 2007 Effects of etchants and primers on shear bond strength of a self-ligating esthetic orthodontic bracket. American Journal of Orthodontics and Dentofacial Orthopedics 132: 577.e1–e5

Eliades T, Bourauel C 2005 Intraoral aging of orthodontic materials: the picture we miss and its clinical relevance. American Journal of Orthodontics and Dentofacial Orthopedics 127: 403–412

Eliades T, Brantley W A 2000 The inappropriateness of conventional orthodontic bond strength assessment protocols. European Journal of Orthodontics 22: 13–23

Fitzpatrick D A, Way D C 1977 The effects of wear, acid etching, and bond removal on human enamel. American Journal of Orthodontics 72: 671–681

Hosein I, Sherriff M, Ireland A J 2004 Enamel loss during bonding, debonding and cleanup with the use of a self-etching primer. American Journal of Orthodontics and Dentofacial Orthopedics 126: 717–724

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)

ISO TS 106 SC 11405 2003 Dental materials—testing of adhesion to tooth structure. International Organization for Standardization

Jenkins G 1978 The physiology and biochemistry of the mouth. Blackwell Scientific Publications, Oxford

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

Northrup R G, Berzins D W, Bradley T G, Schuckit W 2007 Shear bond strength comparison between two orthodontic adhesives and self-ligating and conventional brackets. Angle Orthodontist 77: 701–706

O'Brien K D, Read M J, Sandison R J, Roberts C T 1989 A visible light activated direct bonding material: an in vivo comparative study. American Journal of Orthodontics and Dentofacial Orthopedics 95: 348–351

O'Brien K D, Watts D C, Read M J 1988 Residual debris and bond strength—is there a relationship? American Journal of Orthodontics and Dentofacial Orthopedics 94: 222–230

Oesterle L J, Shellhart W C, Belange G K 1998 The use of bovine enamel in bonding studies. American Journal of Orthodontics and Dentofacial Orthopedics 114: 514–519

Reicheneder C A, Gedrange T, Lange A, Baumert U, Proff P 2009 Shear and tensile bond strength comparison of various contemporary orthodontic adhesive systems: an in-vitro study. American Journal of Orthodontics and Dentofacial Orthopedics 135: 422.e1–e6

Sfondrini M F, Gatti S, Scribante A 2011 Shear bond strength of self-ligating brackets. European Journal of Orthodontics 33: 71–74

Sunna S, Rock W P 1998 An ex vivo investigation into the bond strength of orthodontic brackets and adhesive systems. British Journal of Orthodontics 26: 47–50

Theodorakopolou L P, Sadowsky P L, Jacobson A, Lacefield W Jr. 2004 Evaluation of the debonding characteristics of 2 ceramic brackets: an in vitro study. American Journal of Orthodontics and Dentofacial Orthopedics 125: 329–336

Türkkahraman H, Adanir N, Gungor A Y, Alkis H 2010 In vitro evaluation of shear bond strengths of colour change adhesives. European Journal of Orthodontics 32: 571–574

Vicente A, Bravo L A, Romero M, Ortiz A J, Canteras M 2005 Adhesion promoters: effects on the bond strength of brackets. American Journal of Dentistry 18: 323–326

Yapel M J, Quick D C 1994 Experimental traumatic debonding of orthodontic brackets. Angle Orthodontist 64: 131–136