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Original Research Article

Shear bond strength of orthodontic brackets bonded with four different orthodontic adhesives: an *in vitro* study

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ABSTRACT

Background: The fundamental requirement of an orthodontic adhesive is clinically acceptable bond strength between orthodontic brackets and tooth surface without any failure. Bond strength has a massive influence in the success of orthodontic treatment. The study aimed to evaluate and compare the shear bond strength of four different orthodontic adhesives.
Methods: This *in-vitro* study was conducted at the Department of Orthodontics and Dentofacial Orthopaedics, Dhaka Dental College & Hospital. Eighty extracted human premolars of 30 participants were randomly divided into four groups and bonded with 0.018-inch stainless steel edgewise brackets: Group 1-37% phosphoric acid + Enlight; Group 2-37% phosphoric acid + Transbond XT; Group 3 - Xeno V+ self-etch adhesive; Group 4 - ESPE universal self-etch primer + Transbond Plus color change adhesive.
Results: Transbond XT exhibited the highest shear bond strength (14.45 MPa), followed by Enlight (7.80 MPa), Xeno V+ (6.73 MPa), and Transbond Plus (4.25 MPa). ANOVA revealed a significant difference among the groups, and post hoc Bonferroni tests confirmed significant pairwise differences. Regarding adhesive remnant index (ARI) scores, score 0 was most frequent in the Transbond Plus group (35%), score 1 in Transbond XT (60%), score 2 in Xeno V+ (55%), and score 3 in Enlight (35%). Chi-square analysis showed a significant difference ($p<0.001$) in ARI distribution among groups.
Conclusions: This study showed that clinically acceptable bond strength was observed for Transbond XT, Enlight, and Xeno V+, with Transbond XT exhibiting the highest shear bond strength, followed by Enlight, Xeno V+, and Transbond Plus.

Keywords: Adhesive remnant index, Orthodontic adhesive, Self etch primer, Shear bond strength

INTRODUCTION

Bonding is a critical aspect of orthodontics, as efficient attachment between tooth and bracket is essential for successful treatment. Bond failure or loose brackets can be frustrating in practice, making optimal bond strength an important property of orthodontic adhesives to withstand masticatory and appliance forces. Bond strength refers to the adhesion between bonded surfaces, measured by the stress required to separate them. Several factors influence shear bond strength (SBS), including material-related factors (etching technique, bracket and adhesive type), tooth-related factors, tooth origin (bovine or human), curing devices and guides, pretreatment of enamel, and experimental conditions such as storage media, photopolymerization time, and crosshead speed.[1-6] According to Reynolds, a resistance of 5.9-7.8 MPa is adequate, while Newman reported orthodontic forces range from 1-3 MPa in clinical conditions.[7,8]

The acid-etch technique was first introduced by Buonocore in 1955.[9] Newman in 1965 pioneered bracket bonding, which became a standard clinical practice by the 1970s.[10-12] Early chemically cured systems were popular but limited by inadequate setting time.[13] Later, light-cured materials were introduced by Tavas and Watts.[14] Conventional adhesive systems use an enamel conditioner, primer, and adhesive resin, consisting mainly of BIS-GMA resin, TEGDMA diluents, fillers, silane coupling agents, and camphoroquinone as a photo-initiator.[15,16] Compared to restorative composites, orthodontic resins contain fewer filler particles, allowing higher bond strength.[17]

Recent advances include self-etching primers, which combine acid and primer in one step, simplifying the procedure and reducing chairside time by 65%.[18] During debonding, residual adhesive and enamel damage remain concerns. The Adhesive Remnant Index (ARI) introduced by Artun and Bergland is widely used to evaluate residual resin.[19] Bond strength can be tested both *in vivo* and *in vitro*, though in vivo methods lack standardized devices. Martell-Ramos developed a debonding device for in vivo use, but most studies rely on *in vitro* testing with a universal testing machine.[20] Pickett noted that *in-vitro* results often appear stronger than *in-vivo.* Shear bond testing remains a quick, effective *in-vitro* method for comparing adhesives.[21]

In Bangladesh, limited research has been conducted. Sardar compared SBS and ARI of Grengloo and Enlight adhesives.[22] Sultana compared self-etching primer with the conventional acid-etch system at BSMMU.[23] To date, no study in Bangladesh has evaluated the shear bond strength of four different adhesives. This research will therefore provide a new perspective on SBS in orthodontics. The aim of the present study was to evaluate and compare the shear bond strength of four different adhesives and to assess their adhesive remnant index.

METHODS

This *in vitro* experimental study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, Dhaka Dental College and Hospital, Dhaka, Bangladesh, from April 2019 and June 2020. In this study, a total of 80 extracted human premolars of 30 participants were included, divided into four groups of 20 teeth each.

Inclusion criteria

Inclusion criteria were the teeth with intact buccal enamel, morphologically sound teeth and teeth that have not undergone any previous treatment.

Exclusion criteria

Teeth were excluded if they exhibited gross enamel irregularities, such as caries or demineralization, or if they had been previously bonded with orthodontic brackets. Teeth presenting with hypoplastic areas, fractures, cracks, or fissures were also excluded. Additionally, teeth that had been pretreated with chemical agents, as well as those with cracks resulting from forceps extraction, were not included in the study.

Grouping

Each premolar was mounted in a self-cure acrylic block with the roots embedded up to the cementoenamel junction, and the blocks were color-coded according to group allocation. The samples were divided into four groups: Group 1 (Pink): Enlight, Group 2 (Blue): Transbond XT, Group 3 (Green): Xeno V+, Group 4 (Yellow): Transbond Plus.

SBS was tested using a universal testing machine (UTM) and expressed in megapascals (MPa), calculated as the force applied in Newtons divided by the bracket base surface area in mm². The ARI was used to assess residual adhesive on the tooth surface, scored from 0 (no adhesive remaining) to 3 (100% adhesive with bracket impression).

Study procedure

A data collection sheet was prepared. The force shown by the universal testing machine that caused debonding and ARI scores was entered in the data collection sheet. Twenty freshly extracted premolars were selected for each group according to the inclusion and exclusion criteria and stored in normal saline. The teeth were then mounted in self-cure acrylic blocks, embedding the roots up to the cementoenamel junction. Each block was color-coded and numbered for identification. Stainless steel Pearl premolar brackets with 0.018-inch slots and a base area of 12.95 mm² were used. All teeth were polished using oil-free polishing paste with a hand micromotor before bonding.

Bonding was carried out as follows.

In Group 1, teeth were etched with 37% phosphoric acid for 30 seconds, rinsed, and dried to a chalky white appearance. Ortho Solo primer was applied and light cured for 20 seconds. Brackets were bonded with Enlight adhesive and cured for 40 seconds using an LED curing unit.

In Group 2, Teeth were etched with 37% phosphoric acid for 30 seconds, rinsed, and dried. Transbond XT primer was applied and cured for 20 seconds. Brackets were bonded with Transbond XT adhesive and cured for 40 seconds with an LED curing unit.

Group 3: Teeth were conditioned with Xeno V+ self-etching primer, lightly air-dried for 1-2 seconds, and light cured for 10 seconds. Brackets were bonded with Te Econom Plus adhesive and cured for 40 seconds with an LED curing unit.

Group 4: Teeth were conditioned with 6th-generation self-etching primer (ESPE) for 15 seconds, lightly air-dried for 1-2 seconds. Brackets were bonded with Transbond Plus color change adhesive and cured for 40 seconds with an LED curing unit.

Following bonding, all specimens were stored in normal saline at room temperature for 1 to 7 days before testing.

Laboratory tests

Laboratory tests were conducted at the Pilot Plant and Process Development Center, Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka. Shear bond strength was measured using a universal testing machine (Hounsfield H10KS, 2013, USA). The specimens mounted in acrylic blocks were secured to the lower grip of the machine. To ensure consistent application of debonding force, a custom-made blade was attached to the upper grip connected to the load cell and positioned to contact the bracket. A crosshead speed of 1 mm/minute was maintained. The debonding force was recorded in MPa using QMat 5.51S-Series software.

Following debonding, the ARI was assessed with the naked eye under a stereomicroscope at 10× magnification, using the scoring system described by Artun and Bergland, score 0: No adhesive remaining on the tooth, score 1: Less than 50% adhesive remaining on the tooth, score 2: More than 50% adhesive remaining on the tooth, score 3: 100% adhesive remaining on the tooth with the impression of the bracket base.[19]

Statistical analysis

All data were recorded systematically in a pre-formatted data collection form. Quantitative data were expressed as mean and standard deviation, and qualitative data were expressed as frequency distribution and percentage. Descriptive statistics were used to calculate the mean shear bond strength. Comparisons among the four groups were performed using one-way ANOVA followed by Bonferroni post hoc tests. The Chi-square test was applied to evaluate the frequency and percentage distribution of the ARI. A p value <0.05 was considered significant. Statistical analysis was performed by using SPSS 19 (Statistical Package for Social Sciences).

Ethical implication

Since this was an *in-vitro* experimental study conducted on premolars extracted as part of routine orthodontic treatment, no additional teeth were removed solely for research purposes, and thus no harm was caused to any patient. There were no physical risks to participants during the study period. Informed written consent was obtained from all patients prior to the use of their extracted teeth. Ethical approval for the study was obtained from the Ethical Committee of Dhaka Dental College and Hospital.

RESULTS

In the present study, a total of 80 extracted human premolars of 30 participants were used in this study, with 20 teeth allocated to each group. Group 1 was etched with Meta Etchant and bonded using Enlight adhesive, while Group 2 was etched with Meta Etchant and bonded with Transbond XT. Group 3 was bonded with Xeno V+ self-etch adhesive, and Group 4 was bonded with ESPE universal self-etch primer in combination with Transbond Plus color change adhesive.

Table 1 shows that the majority of participants were aged 24-26 years (40.0%), followed by 21-23 years (33.3%) and 27-29 years (26.7%). The mean age of participants was 24.6±3.2 years. Regarding gender distribution, 18 participants (60.0%) were female, while 12 participants (40.0%) were male.

Table 1: Demographic characteristics of the study participants whose teeth were used in the study (n=30).

Variable	Frequency (N)	Percentage (%)
Age (years)		
21-23	10	33.3
24-26	12	40.0
27-29	8	26.7
Mean±SD (years)	24.6±3.2	
Gender		
Male	12	40.0
Female	18	60.0

Table 2 shows that all groups demonstrated clinically acceptable bond strength, as defined by Reynolds (6-8 MPa), except Transbond Plus.[7] Transbond XT (14.45±5.20 MPa) exhibited significantly higher SBS compared to Enlight (7.80±3.28 MPa), Xeno V+ (6.73±4.66 MPa), and Transbond Plus (4.25±1.79 MPa). Both conventional groups (Enlight and Transbond XT) recorded higher SBS values than the self-etch groups (Xeno V+ and Transbond Plus). Among the adhesives, Transbond XT showed the highest bond strength, followed by Enlight, Xeno V+, and Transbond Plus. Notably, Transbond Plus was the only adhesive with a mean SBS below the clinically acceptable range for orthodontic bonding.

Table 3 shows that analysis of variance (ANOVA) revealed a statistically significant difference in shear bond strength ($p < 0.001$) among the groups. The mean SBS of specimens bonded with Transbond XT (14.45 MPa) was significantly higher than those bonded with Enlight (7.80 MPa), Xeno V+ (6.73 MPa), and Transbond Plus (4.25

MPa). Thus, the adhesive system (Enlight, Transbond XT, Xeno V+, and Transbond Plus) was identified as a statistically significant factor ($p<0.001$). Transbond XT demonstrated the highest SBS, while Transbond Plus showed the lowest.

Table 2: Mean shear bond strength and descriptive statistics (n=80).

Group	Number	Shear bond strength (MPa), Mean±SD	Range (min-max)
Group 1 (Enlight)	20	7.80±3.82	2.338-14.460
Group 2 (Transbond XT)	20	14.45±5.20	4.497-23.140
Group 3 (Xeno V+)	20	6.73±4.66	1.853-22.290
Group 4 (Transbond Plus)	20	4.25±1.79	1.782-7.876

Data were expressed as Mean±SD

Table 3: Comparison of shear bond strength (Mpa) among four groups by ANOVA test (n=80).

Groups	Number	Mean±SD (MPa)	Range (min-max)	P value
Group 1 (Enlight)	20	7.80±3.82	2.338-14.460*	<0.001*
Group 2 (Transbond XT)	20	14.45±5.20	4.497-23.140*	
Group 3 (Xeno V+)	20	6.73±4.66	1.853-22.290*	
Group 4 (Transbond Plus)	20	4.25±1.79	1.782-7.876*	

*=Significant, n=Number of samples

Table 4: Comparison of shear bond strength (Mpa) between two groups by Post hoc (Bonferroni) test.

Group comparison	P value
Group 1 vs Group 2	<0.001**
Group 1 vs Group 3	1.000^{ns}
Group 1 vs Group 4	0.044*
Group 2 vs Group 3	<0.001**
Group 2 vs Group 4	<0.001**
Group 3 vs Group 4	0.347^{ns}

*=Significant, ** = Highly significant; n=Number of samples, ns=Not significant

Table 4 shows the results of the post hoc Bonferroni test, which revealed statistically significant differences between most groups, except Enlight vs. Xeno V+ ($p=1.000$) and Xeno V+ vs. Transbond Plus ($p=0.347$). A p value <0.05 was considered statistically significant. The mean SBS of Transbond XT was significantly higher than that of Enlight, Xeno V+, and Transbond Plus ($p<0.05$). In contrast, Enlight did not differ significantly from Xeno V+, and Xeno V+ did not differ significantly from Transbond Plus.

Table 5 shows the distribution of ARI scores among the four groups. ARI score 0 was most frequent in Transbond Plus (35%), indicating minimal or no adhesive remaining on the tooth. ARI score 1 was most common in Transbond XT (60%), reflecting less than 50% adhesive remaining. ARI score 2 predominated in Xeno V+ (55%), indicating more than 50% adhesive remained, while ARI score 3 was most frequent in Enlight (35%), showing that most adhesive remained on the tooth. Chi-square analysis revealed a statistically significant difference in ARI scores among the groups ($p<0.001$), highlighting differences in adhesive retention patterns for the four orthodontic adhesives.

Table 5: Distribution of frequency and percentage of ARI scores (n=80).

Groups	Number	Score 0, N (%)	Score 1, N (%)	Score 2, N (%)	Score 3, N (%)	P value
Group 1 (Enlight)	20	1 (5.0)	5 (25.0)	7 (35.0)	7 (35.0)	χ^2 = 31.52, df = 9, p<0.001*
Group 2 (Transbond XT)	20	6 (30.0)	12 (60.0)	2 (10.0)	0 (0.0)	
Group 3 (Xeno V+)	20	0 (0.0)	7 (35.0)	11 (55.0)	2 (10.0)	
Group 4 (Transbond Plus)	20	7 (35.0)	7 (35.0)	3 (15.0)	3 (15.0)	

*=Significant, n=Number of samples, X^2=Chi-square, df=Degree of freedom

DISCUSSION

In the present study, the age distribution of participants ranged from 21 to 29 years, with the majority belonging to the 24-26-year age group (40.0%). The mean age of the study population was 24.6±3.2 years. A higher proportion of females (60.0%) participated in the study compared to males (40.0%), reflecting a female predominance in the sample.

This *in-vitro* experimental study evaluated and compared the SBS and ARI of four orthodontic adhesives: Enlight, Transbond XT, Xeno V+, and Transbond Plus.

SBS

In this study, Transbond XT exhibited the highest SBS, followed by Enlight, Xeno V+, and Transbond Plus. All groups demonstrated mean SBS values above the clinically acceptable range of 6-8 MPa for orthodontic brackets, as reported by Reynolds, except Group 4 (Transbond Plus), which fell below this threshold.[7] Overall, conventional acid-etch groups (Enlight and Transbond XT) showed higher SBS compared to self-etch groups (Xeno V+ and Transbond Plus). The use of 37% phosphoric acid in conventional groups likely contributed to the higher bond strength by enhancing enamel etching.[21]

In Group 1, Enlight showed a mean SBS of 7.80±3.82 MPa. This is comparable to the 6.8±2.1 MPa reported by Owens et al, although other studies reported higher values, such as 11.97±2.42 MPa by Vasudevan et al and 13.92±3.92 MPa by Shaik et al.[24,25,16] Differences in SBS across studies may be attributed to variations in storage media and bracket types. For instance, Vasudevan used distilled water and 3M Gemini brackets, Shaik et al used 0.1% thymol and Ormco mini premolar brackets, whereas the present study used normal saline.[16]

Group 2 (Transbond XT) showed a mean SBS of 14.45±5.20 MPa. Transbond XT has been widely studied, with reported SBS values ranging from 6.2 MPa to 23.4 MPa; most studies report values between 9.6 MPa and 14.8 MPa.[26-29] The results of this study are in agreement with values reported by previous studies (14.30±4.35 MPa, 13.71±3.54 MPa, and 15.49±3.28 MPa).[8,30,31] Lower values have been reported by Yonekura et al (8.9 MPa) and Abdelnaby et al (11.2 MPa), while higher values were observed by Saleh et al (18.6 MPa) and Scougall Vilchis et al (19.0±6.7 MPa), likely due to differences in experimental conditions.[32-35]

Group 3, bonded with Xeno V+, showed a mean SBS of 6.73±4.66 MPa. Few studies are available for this adhesive, which is an updated version of Xeno V and requires only 10 seconds of light curing. Sharma et al reported SBS of 13.51±2.45 MPa for Xeno V, which is higher than the present study, possibly due to differences in experimental protocols.[36]

In Group 4, Transbond Plus showed the lowest mean SBS (4.25±1.79 MPa). Melissa Cerone et al evaluated universal self-etch one-step adhesives and found that none achieved clinically acceptable SBS for orthodontic bonding, reporting 3.8±2.0 MPa for a single-bond system.[37] Similarly, Rameez et al compared color-changing adhesives including Transbond Plus, Blugloo, and Grengloo, and reported lower SBS for Transbond Plus than for other adhesives.[38]

Overall, comparison among the four groups confirmed that the adhesive system (Enlight, Transbond XT, Xeno V+, and Transbond Plus; $p<0.001$) was a statistically significant factor affecting SBS. Transbond XT consistently showed the highest bond strength, whereas Transbond Plus was the lowest, highlighting the influence of adhesive type on clinical performance.

ARI

Analysis of ARI scores further highlighted differences in adhesive behavior. In Group 1 (Enlight), ARI scores 2 and 3 were most common, indicating bond failure at the adhesive bracket interface, with most adhesive remaining on the tooth. This suggests that enamel cleanup would be more difficult. The higher ARI scores may be related to the use of 37% phosphoric acid, which enhances resin penetration. Schneble et al similarly reported that conventional acid-etch systems tend to leave more residual adhesive compared to self-etch systems.[39]

In Group 2, Transbond XT most frequently demonstrated ARI score 1, which reflects bond failure at the enamel-adhesive interface with less than 50% of adhesive remaining on the tooth.

Group 3, bonded with Xeno V+, showed ARI score 2 as the most frequent outcome, indicating bond failure at the adhesive-bracket interface, with more than 50% of the adhesive left on the enamel surface.

In Group 4, Transbond Plus most frequently showed ARI scores 0 and 1, indicating bond failure primarily at the enamel-bracket interface with very little or no adhesive remaining on the tooth. Clinically, this could be advantageous, as enamel cleanup becomes faster and less challenging.

Overall, there was a statistically significant difference in ARI scores among the four adhesive systems ($p<0.001$). The amount of adhesive remaining on teeth bonded with Enlight was significantly higher compared to Transbond XT, Transbond Plus, and Xeno V+.

This study has several limitations. As an *in-vitro* experiment, the samples were stored in normal saline, which does not accurately replicate the complex intraoral environment. Moreover, shear bond strength is influenced by multiple factors, including bonding technique, adhesive type, etching method, bracket design, enamel morphology, and fluorosis, many of which were not considered in this study. Additionally, while the universal testing machine applies controlled shear forces, orthodontic brackets in the oral cavity are subjected to a combination of stresses such as shear, peel, tensile, and torsional forces, which may affect their clinical performance.

CONCLUSION

The study concluded that there was a statistically significant difference in shear bond strength among the four orthodontic adhesives tested. Transbond XT, Enlight, and Xeno V+ demonstrated clinically acceptable bond strength, with Transbond XT showing the highest mean shear bond strength, followed by Enlight, Xeno V+, and Transbond Plus.

In terms of ARI, teeth bonded with Transbond XT and Transbond Plus showed minimal or no residual adhesive on the enamel surface (scores 0 and 1), suggesting bond failure at the enamel-adhesive interface and an easier, safer cleanup process. In contrast, Enlight and Xeno V+ exhibited higher residual adhesive scores (2 and 3), indicating bond failure at the adhesive-bracket interface and a more challenging enamel cleanup.

Overall, Transbond XT demonstrated superior performance, providing higher bond strength, reduced adhesive remnants, and a safer enamel cleanup process compared to Enlight, Xeno V+, and Transbond Plus.

Recommendations

Future studies with larger sample sizes and in vivo settings are recommended to better assess shear bond strength, including on incisors and canines. Prospective research should also evaluate enamel loss during adhesive removal after bracket debonding.

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