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Original Article

Shear Bond Strength of Orthodontic Brackets to Resin-Infiltrated Enamel

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Abstract

Objectives This study aims to evaluate shear bond strength (SBS) of orthodontic brackets to enamel after resin infiltration pretreatment using different adhesive systems.

Materials and Methods Sixty extracted maxillary first premolars were divided into five groups ($n = 12$). Group I: sound enamel + Transbond XT; group II: resin-infiltrated enamel (ICON) + Transbond XT; group III: ICON + Scotchbond Universal Plus; group IV: ICON + Assure PLUS; group V: ICON + Transbond Plus Self Etching. The SBS was measured using universal testing machine and analyzed using analysis of variance (ANOVA). The adhesive remnant index (ARI) score after debonding was determined under stereomicroscope with a 10× magnification.

Statistical Analysis A one-way ANOVA and post hoc Tukey's test were used to compare the data. Further, the ARI scores were evaluated using a chi-squared test. The level of significance was set at $p = 0.05$.

Results SBS of group I, II, III, IV, and V were 11.70 ± 3.17, 11.23 ± 3.06, 9.52 ± 1.73, 8.97 ± 1.12, and 9.14 ± 0.70 MPa, respectively. SBS of group IV and V was significantly lower than group I and II ($p < 0.05$). There was no significant difference in the ARI scores among the five groups ($p > 0.05$).

Conclusion The SBS of enamel resin infiltration pretreatment depends on the adhesive system. The SBS of all groups was within adequate SBS range in clinical use. The most common ARI score was 2, which indicated lower risk of enamel fractures when debonding.

Keywords
- demineralized enamel
- orthodontic adhesives
- resin infiltration
- shear bond strength

Introduction

The attachment of orthodontic brackets can lead to increased plaque retention, making it more likely for demineralization and early caries to develop around the brackets, especially when the patient's oral hygiene is inadequate. It is worth noting that white spot lesions may already exist at the beginning of orthodontic treatment.[1] during the rebonding process, white spot lesions may be observed on the buccal surface of teeth. This could raise concerns for the orthodontist regarding the effectiveness of the bonding procedure on these surfaces.[2]

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In orthodontic treatment, brackets need to have a strong attachment to withstand orthodontic forces and enable to controlled tooth movement. However, at the final stage of treatment, brackets must be removed easily without causing damage to the enamel surface. Therefore, the brackets' bonding failure is an orthodontic treatment limitation that negatively impacts both patients and orthodontists.[3]

Shear bond strength's (SBS) limits of orthodontic bracket are not clearly defined in the literature.[4] The most frequently cited SBS for orthodontic brackets within the minimum range of 5.9 to 7.8 MPa that was adequate to resist masticatory force, was suggested by Reynolds.[5] However, it is important to ensure that adhesion forces are not too strong (around 40–50 MPa) to prevent any enamel loss during the debonding process.[4]

Demineralized enamel has a negative effect on the SBS of orthodontic brackets. Several studies[2,6–9] showed that SBS was significantly reduced when brackets were applied to demineralized enamel compared with that to sound enamel.

The traditional method to treat white spot lesions was the use of fluorides to remineralize incipient lesions. However, it is still controversial whether this treatment improves the porous enamel's milky color or only rehardens the surface layer with no impact on the tooth's appearance. White spot treatment methods have developed over time to ensure covering up lesions and making them less visible. Furthermore, the most recent treatment technique was applying the affected area with low viscosity infiltrant resins.[10–12] Resin infiltration is a minimally invasive procedure that penetrates into the initial carious lesion and creates a micromechanically interlocking polymer framework, which acts as a barrier to prevent further demineralization and arrest the lesion progression.[11,12] Several studies assessed the aesthetic improvement of the white spot lesion using different techniques. A statistically significant improvement in camouflage effect and considerable color change were seen in the lesions treated with resin infiltration.[13]

For orthodontic application following treatment with resin infiltration, several studies demonstrated that SBS of resin infiltration pretreatment is significantly comparable to intact enamel.[8–10] On the contrary, Gulec and Goymen[14] and Attin et al[2] demonstrated that SBS values of resin infiltration pretreatment were significantly lower when compared with the intact enamel group. The aim of this study was to evaluate the SBS of resin-infiltrated enamel to orthodontic brackets using different adhesive systems: in vitro study. The null hypothesis was that the SBS of resin-infiltrated enamel to orthodontic brackets using different adhesive systems is not different for each adhesive system.

Materials and Methods

Sample Preparation

Correcting extracted teeth was approved by the Ethics Review Subcommittee Board for Human Research Involving Sciences, Thammasat University, No. 3 (Faculty of Health Sciences and Science and Technology, approval date: April 2, 2022).

The G*Power 3.1 software was utilized to calculate the sample size, with 0.05 serving as the significance level and 0.95 as the power. Sixty extracted maxillary first premolars were collected. Teeth with caries, cracks, erosion, fluorosis, hypomineralization, and dental restorations were excluded. Note that 0.1% thymol solution was used to store extracted teeth for no longer than 2 months.[15] All extracted teeth were randomly allocated into five groups ($n = 12$) and removed the root at 2 to 3 mm under cementoenamel junction using a carborundum disc.

Except for group I (control), groups II to V were coated with nail varnish, with a 5×5-mm uncoated area on the buccal surface to limit demineralizing of the entire enamel surface. Then, the creation of artificial white spot lesions was conducted in groups II to V according to Pintanon et al and Klaisiri et al.[11,16]

Resin Infiltration Procedure

Each sample of group II to V was performed a resin infiltration procedure (ICON, DMG Chemisch-Pharmazeutische Fabrik GmbH, Hamburg, Germany) as the manufacturer recommended on the lesion surface of the enamel as the following:

(1) Applying Icon-Etch for 120 seconds followed by a 30-second water rinsing and air-drying.
(2) Applying Icon-Dry for 30 seconds and air-drying.
(3) Applying Icon-Infiltrant for 180 seconds removing excess material with a cotton roll, and light curing for 40 seconds.
(4) Reapplying Icon-Infiltrant for 60 seconds and then light curing for 40 seconds.

Bonding Procedure

GEMINI MBT 0.022 Twin premolar brackets (3M Unitek, Monrovia, California, United States) were bonded by the same expert operator at the middle area of the buccal surface according to the following systems:

Group I: the brackets were bonded to intact enamel. 37% phosphoric acid gel (FineEtch, Spident Co., Ltd., Namdong-Gu, Incheon, Korea) was applied for 15 seconds, water rinsed for 20 seconds, and air dried for 10 seconds followed by applying a thin layer of the Transbond XT primer (3M Unitek). The brackets were bonded with Transbond XT adhesive resin (3M Unitek) and light cured using a Mini LED SuperCharged light curing unit (Satelec, Acteon, Merignac Cedex, France).
Group II: the brackets were bonded to resin-infiltrated enamel. Then, they were treated in the same order and the same adhesive as the samples in group I.
Group III: the brackets were bonded to resin-infiltrated enamel. Note that 37% phosphoric acid gel was applied for 15 seconds, water rinsed for 20 seconds, and air dried for 10 seconds followed by application of Scotchbond Universal Plus (3M Deutschland GmbH, Neuss, Germany) to the etched surface, 20 seconds rubbing, and 10 seconds light curing. Then, the brackets were bonded with Transbond XT adhesive resin and light cured.

Group IV: the brackets were bonded to resin-infiltrated enamel. Note that 37% phosphoric acid gel was applied for 15 seconds, water rinsed for 20 seconds, and air dried for 10 seconds followed by application of Assure PLUS (Reliance Orthodontic Products, Itasca, Illinois, United States) to the prepared tooth, gently air-drying, and 10 seconds light curing. Then, the brackets were bonded with Transbond XT adhesive resin and light cured.

Group V: the brackets were bonded to resin-infiltrated enamel. Transbond Plus Self Etching Primer (3M Unitek) was used with rubbing for 5 seconds, dried into a thin layer, and light cured for 10 seconds. Then, the brackets were bonded with Transbond XT adhesive resin and light cured.

Thermocycling Procedure

The thermocycling procedure will be performed to allow an artificial aging effect on the dental materials. All samples were embedded in a self-cured acrylic resin in a polyvinyl chloride ring and immersed in artificial saliva for 24 hours at 37°C. Using a thermocycling machine (Medical and Environment Equipment Research Laboratory, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand), the samples were run through 2,000 cycles[17] of 30 seconds in each bath of 5°C cold water and 55°C hot water with a transfer time of 10 seconds.

Shear Bonding Procedure

Under a universal testing machine model AGS-X (Shimadzu Co., Ltd., Kyoto, Japan), the samples were placed in a mounting jig. The force was vertically applied over the tooth-bracket base interface by a knife-edge chisel with a 500-N load cell and a 1-mm per minute crosshead speed. The data was recorded and calculated the SBS for debonding brackets (MPa) using the following equation:

$$\mathrm{SBS} = \frac{F}{A}$$

where F is the maximal load before the debonding of the bracket (N), and A is bonding area (mm^2).

Adhesive Remnant Evaluation

A stereomicroscope with a 10× magnification (Euromex Microscopen BV, Arnhem, Netherlands) was used to determine the adhesive remnant on the debonded area and calculated by using image analysis (ImageJ software, Maryland, United States). The adhesive remnant index (ARI) scores were classified into four categories as shown in ►**Table 1** and ►**Fig. 1**.[18]

Statistical Analysis

The IBM SPSS Statistics for Windows version 25.0 (IBM Corporation, Armonk, New York, United States) was used for analysis. The normality of distribution and the homogeneity of variance were confirmed by the Shapiro–Wilk test and Levene's test, respectively. A one-way analysis of variance (ANOVA) and post hoc Tukey's test were used to compare the differences if the data was normal distribution and homogenous variance.

A one-way ANOVA and post hoc Dunnett's T3 test were used if the data was normal distribution but nonhomogenous variance. A Kruskal–Wallis test and Dunnett's T3 test were used if the data was nonnormal distribution. Further, the ARI scores were evaluated using a chi-squared test. The level of significance was set at $p = 0.05$.

Results

Shear Bond Strength

The highest and lowest SBS were obtained from group I (11.70 ± 3.17 MPa) and IV (8.97 ± 1.12 MPa). The SBS of group II, III, and V were 11.23 ± 3.06, 9.52 ± 1.73, and 9.14 ± 0.70 MPa, respectively, as shown in ►**Table 2**.

Adhesive Remnant Index

There was no significant difference in ARI scores among the five groups ($p > 0.05$). The frequency of the distribution of ARI score obtained from each sample is presented in ►**Table 3**. The most common score observed from all sample was 2.

Discussion

The aim of this study was to evaluate the SBS of orthodontic brackets to enamel after resin infiltration pretreatment using different adhesive systems. The hypothesis was rejected because the results showed statistically significant differences in mean SBS among the group of adhesive systems.

The strength of bonding between enamel and brackets is important to allow transferring force from the archwire to the teeth without dislodgement during the orthodontic process. Moreover, the bond strength needs to be sufficient to withstand the masticatory forces present in the oral environment and able to be removed without damaging the enamel at the end of the orthodontic treatment.[19,20] In the current time, the International Organization for Standardization has not established any minimum standards for the SBS of orthodontic adhesives. However, it was suggested

Table 1 The definition of ARI scores

ARI score	Definition
0	No adhesive remained on the tooth surface
1	Less than 50% of the adhesive remained on the tooth surface
2	More than or equal 50% of the adhesive remained on the tooth surface
3	All of adhesive remained on the tooth surface

Abbreviation: ARI, adhesive remnant index.

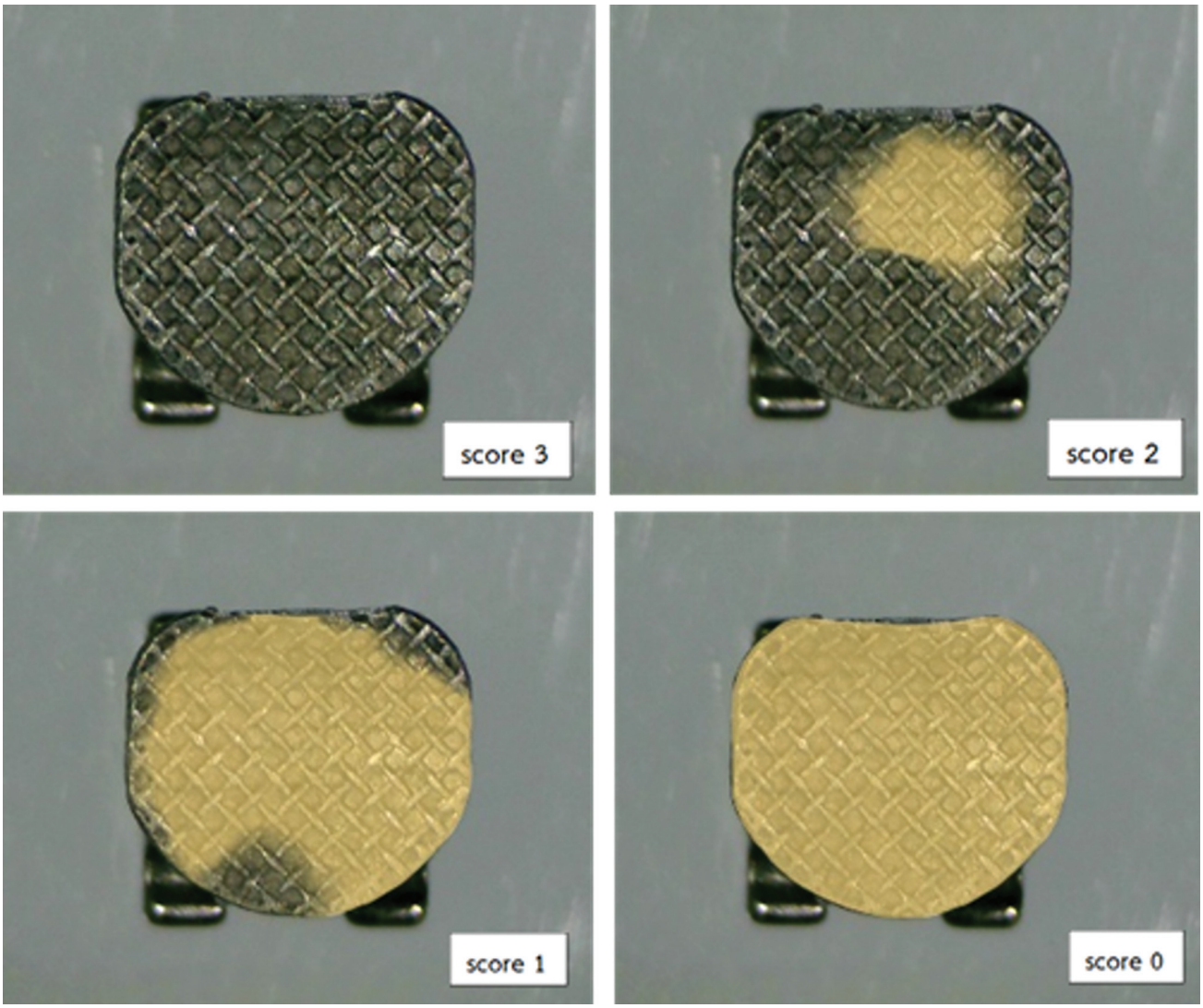

Fig. 1 The schematic of adhesive remnant index (ARI) score.

by Reynolds that the minimum SBS to adequate resistance in clinical use was 5.9 to 7.8 MPa.[5] Additionally, to prevent enamel loss resulting from debonding, adhesion forces should not be greater than 40 to 50 MPa.[6]

In this study, the SBS values among the five groups were within the acceptable range as mentioned earlier. There are no statistically significant differences of mean SBS between group I (sound enamel + Transbond XT) and group II (resin-infiltrated enamel [ICON] + Transbond XT). Corresponded to previously studies, resin infiltration pretreatment did not decrease the SBS when using the Transbond XT system and the results showed SBS of resin-infiltrated enamel was similar to that of intact enamel.[7,8,21] As a result, the resin infiltrant more deeply penetrated into the body of the lesion, in contrast to the primer or paste.[1] The triethylene glycol dimethacrylate content of ICON monomer formulations has been increased. It has a high

Table 2 Means, standard deviations (SD), and ranges (minimum, maximum) of shear bond strength for each adhesive system

Groups	Shear bond strength (MPa)			
	Mean	SD	Minimum	Maximum
I[a]	11.70	3.17	6.91	15.68
II[b]	11.23	3.06	7.41	18.71
III[c]	9.52	1.73	6.38	13.63
IV[a,b]	8.97	1.12	6.90	10.93
V[a,b]	9.14	0.70	8.01	10.17

Note: $F = 3.94$; $p = 0.007$. Mean values in each row with the same letter are significantly different at $p \leq 0.05$.

Table 3 Raw data of adhesive remnant index of all sample groups

Groups	ARI scores			
	Score 0	Score 1	Score 2	Score 3
I[a]	0	3	5	4
II[b]	0	2	7	3
III[c]	0	1	9	2
IV[d]	0	0	5	7
V[e]	0	0	11	1

Abbreviation: ARI, adhesive remnant index.
Note: Chi-square =14.82; $p = 0.063$. Scores in each row with the same letter are significantly different at $p \leq 0.05$.

penetrating potential and results in the formation of a thick oxygen-inhibited layer, which presumably causes the resin infiltrant to chemically bond with the monomers of the primer.[1,22]

The SBS of group IV (ICON + Assure PLUS) was significantly lower than group I (sound enamel + Transbond XT) and group II (ICON + Transbond XT) ($p < 0.05$). On the contrary, the study by Simunovic Anicic et al[23] reported that pretreatment with ICON and bonded with Assure PLUS was significantly higher than both of no pretreatment and pretreatment with ICON before being bonded with Transbond XT.

The SBS of group V (ICON + Transbond Plus Self Etching) was significantly lower than group I (sound enamel + Transbond XT) and group II (ICON + Transbond XT) ($p < 0.05$), agreed with a study by Montasser and Taha.[24]

ARI scores have been used in several studies to determine the area of bond failure in enamel, adhesive, and bracket base by evaluating the amount of residual adhesive on enamel surfaces after debonding.[25] In this study, ARI scores use classification criteria established by Årtun and Bergland. This classification scale ranges from 0 to 3. A score of 0 means no adhesive remains on the enamel bonding surface. A score of 1 means less than half of the adhesive remaining on the enamel surface. A score of 2 means more than half of the adhesive remaining on the enamel surface. A score of 3 means all adhesive remains on the enamel surface.[26]

In this study, the most common ARI scores of the experimental groups (group II–V) are 2, which means the adhesive left on enamel after debonding is high. According to the mode of bond failure classified by Stratmann et al, the fracture interface of our sample is partially between within the adhesive and partly between adhesive and bracket base. As a result, the polishing process will take longer and there may be a lower danger of enamel fractures.[27,28] Corresponded to a study by Mews et al,[21] which applies resin infiltration and conventional adhesive to demineralization bovine, they reported that the frequency of enamel facture was lowest and the ARI score was 3 when surface pretreatment was done with resin infiltration. Additionally, they suggest that pretreatment resin penetration improves the enamel's strength and better stress distribution during shear bond testing. On the other hand, our result disagreed with a study by Simunovic Anicic et al[23] which observed the SBS values of brackets bonded to demineralized human third molar tooth pretreatment with resin infiltration on three different adhesive systems. They found the most frequent ARI scores were 0 and 1, which suggested a higher incidence of bond failure at the enamel-adhesive contact in all groups.

This study was an in vitro study; therefore, it is important to interpret its clinical results carefully. The current study has a small sample size which may not present the real value or identified the difference. Moreover, studies about the number of thermocycling cycles are controversial. Hence, the SBS following long-term thermocycling should be evaluated to mimic the long-term clinical use with a large sample size in future works.

Conclusion

The mean SBS between the adhesive system and enamel resin infiltration pretreatment depends on the adhesive system. The Transbond XT primer and Scotchbond Universal Plus had SBSs higher than Assure PLUS and Transbond Plus Self-Etching primer. However, the SBS of Assure PLUS and Transbond Plus Self-Etching primer showed adequate SBS to withstand clinical use.

The ARI scores among five groups were not significantly different ($p > 0.05$). The most common score was 2, which indicated lower risk of enamel fractures when debonding.

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Conflict of Interest
None declared.

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