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Shear bond strength of new and rebonded orthodontic brackets to the enamel surfaces

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Abstract:

OBJECTIVES: The objective of this study was to compare the shear bond strength (SBS) of new and rebounded orthodontic brackets bonded to the buccal sound and cleaned enamel surfaces using two orthodontic adhesives: resin‑modified glass‑ionomer (RMGI) and resin‑composite.

MATERIALS AND METHODS: Forty premolars were randomly allocated into four groups, 10 teeth/group. New and rebonded brackets were bonded to sound and cleaned enamel surface, and then were subjected to thermocycling. The bond strength was determined using a universal testing machine at a crosshead speed of 1 mm/min. Remaining adhesives on enamel after bracket debonding was scored independently by two investigators who were not aware of the four different groups, using adhesive remnant index (ARI).

RESULTS: There was a statistical significant difference in SBS of the four groups ($P = 0.005$). SBS values were significantly higher with cleaned enamel surfaces after adhesive removal compared to sound enamel. SBS was significantly higher for rebonded brackets, when compared with the new brackets. No significant difference was found between the two adhesives types. The level of agreement between the two raters was higher toward the classification of higher categories of ARI (scores 5 and 6) with agreement percentage 91.7% and 100%, respectively. There was more adhesive remained among resin‑composite groups.

CONCLUSIONS: The bond strength of debonded sandblasted stainless‑steel brackets was higher than new brackets. Resin‑composite and RMGI orthodontic adhesives used in this study exhibited sufficient SBS values for bonding brackets to sound and cleaned enamel and comparable to each other.

Keywords:

Bonding, orthodontic adhesive, orthodontic bracket, sandblasting, shear bond strength

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Introduction

Many orthodontic adhesives have been developed with different properties such as good bonding and easy removal without damaging enamel.[1] Resin‑composite materials are the most commonly used adhesives because of their well‑established clinical and laboratory performance.[1,2] Whereas resin‑modified glass ionomer (RMGI) combines some advantages of resin‑composite and some properties of glass‑ionomer such as less sensitivity to moisture and fluoride release that make its use preferable.[3]

High bond strength of the brackets is essential to stand orthodontic forces and allow for control of tooth movement; however, it should detach easily at the end of treatment without destruction to the enamel surface.[4,5] Failure in bonding of the brackets is a hindering aspect in orthodontic treatment that adversely affect patient and orthodontist.[5,6] Accidental debonding or improper orthodontic bracket positioning may require the need for rebonding, which

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consists of removing the adhesive remnant from the enamel surface and cleaning the bracket base, so the bracket could be used again.[7] Different techniques have been used to clean brackets including heat application followed by electrolytic polishing or by using chemical solvents to dissolve the remaining bonding agent in combination with high frequency vibrations and electrochemical polishing.[8,9] Sandblasting has been shown to be a superior option in bracket cleaning for its simple technique that can be performed chair-side, which reduces the working time and costs.[10] Sandblasting technique uses a high-speed stream of aluminum oxide particles driven by compressed air to remove undesired oxides, contaminants, increase surface roughness as well as increase surface area.[11] The recommended aluminum oxide particle is the use of 50 µm.[12] Compare to new brackets, it has been reported that values of SBS of rebounded brackets were higher or similar after sandblasting.[12,13]

There are many factors that cause the orthodontic bracket bond to fail including the nature of the oral cavity that has a changing PH, continuous masticatory forces and extreme temperatures,[5,6,14] problem in the bonding technique, low retentiveness of the bracket base or in small-sized brackets used in esthetic cases.[5,14] The location of failure within the bracket-adhesive-enamel can occur within the bracket, between the bracket and the adhesive, within the adhesive, and between the tooth surface and the adhesive.[6,14] An adhesive remnant index (ARI) has been developed to evaluate enamel condition after debonding of the bracket base by measuring the amount of adhesive that remains on the tooth surface.[15]

The effect of different experimental settings on bond strength of orthodontic brackets is still unclear particularly after bonding became a standard clinical practice initiating the exploration of different adhesive protocols that can improve clinical outcomes of the rebonded brackets. Therefore, the purpose of this *in-vitro* study was to evaluate the SBS of new orthodontic compared to the rebonded brackets bonded to buccal enamel surface using two orthodontic adhesives: resin-composite (Transbond XT) and resin-modified glass-ionomer (RMGI, Fuji Ortho LC). In addition, the study aimed to quantify the remaining adhesive on enamel after bracket debonding using ARI. The null hypothesis of this study was there is no difference in SBS of the new orthodontic and rebonded brackets bonded to buccal enamel surface using two orthodontic adhesives.

Materials and Methods

Sample preparation

The Research and Ethical Committee of Human Studies at College of Dentistry Research Center, King Saud University, approved the investigation proposal. Forty premolar teeth that were extracted due to orthodontic treatment were stored in 0.1% thymol solution and used in this study. The inclusion criteria included that all teeth should have intact crown, and free from attrition, hypoplastic areas, cracks, gross irregularities, decay, and fractures. Enamel surface of each tooth was scaled and polished with rubber polishing cup and pumice in low-speed handpiece for 10 s, then, they stored in deionized water at room temperature (25°C) until used. The apical part of each root was mounted in self-curing acrylic resin (Vertex™ Orthoplast, Vertex-Dental B.V. Asia Pte Ltd, Singapore) to facilitate perpendicular sectioning of each tooth into two sections, and the buccal section was decorenated 4 mm below the cementoenamel junction (CEJ) using a diamond saw under water spray (IsoMet-2000 Precision Saw, Buehler, Lake Bluff, IL, USA). Then the buccal surfaces were placed in standardized mold and embedded in self-curing acrylic resin, where each surface was kept parallel to the floor. Teeth were divided into four groups, 10 specimens/group according to the adhesive material and brackets status. The power sample size was 0.81 and level of significant σ =0.05 with estimated standard deviation = 0.9, the sample size should be at least 9 in each group. Orthodontic premolar brackets with gingival offset (Ortho Classic - Roth. 022, Ortho Classic Inc., McMinnville, OR, USA) were positioned with firm and even pressure and bonded to the middle of the surface of enamel following the recommendations of the manufacturer using two types of orthodontic adhesives: resin-composite (3M-Unitek Transbond™ XT Light Cure Adhesive, Monrovia, CA, USA) was used for groups 1 and 2, whereas RMGI (GC Fuji Ortho™ LC Capsule, GC Corporation, Tokyo, Japan) was used for groups 3 and 4. Excess adhesive was removed with a regular size brush #2 (Dental Micro Applicator Brush, Shanghai Smedent Medical Instrument Co., Ltd., Shanghai, China) without disturbing the bracket and one brush was used for each specimen and then light cured using Ortholux™ Luminous Curing Light (3M Unitek Orthodontic Products, Monrovia, CA, USA) (App. 1600 mW/cm^2) (LED). One investigator performed all procedures and steps in a consistent manner. Then, the bonded specimens were stored in deionized water in laboratory oven (Memmert Universal Oven, Memmert Edestahl, Rost Frei, Schwabach, West Germany) at 37°C for 48 h before debonding of groups 1 and 3. The brackets were debonded using debonding plier, ETM, Bracket Removing Plier #803-0104 (Ormco Corporation, Orange, CA, USA). The remaining adhesive was removed from the buccal surface similar to another study,[16] using tungsten carbide burs in a slow-speed handpiece (Komet, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany). Then, the enamel surfaces were polished with rubber polishing cup and pumice in a slow-speed hand piece for 5 s by one investigator. Sandblasting was performed for the de-bonded brackets using sandblaster (Microcab + Danville Materials, San Ramon, CA, USA) by one investigator. The teeth in groups 1 and 3 were prepared for second enamel conditioning similar to groups 2 and 4. One investigator performed all procedures and steps in a consistent manner. All specimens in groups 1–4 were subjected to thermocycling between 5°C and 55°C with a dwell time of 30 s and a transfer time of 15 s for 3,000 cycles (Thermocycler THE-1100, SD Mechatronik GMBH, Feldkirchen-Westerham, Germany).

Bond strength assessment (Quantitative)

The SBS measurement was completed for all specimens in groups 1–4 using a universal testing machine (Instron®, Illinois Tool Works Inc., Norwood, MA, USA) at a crosshead speed of 1 mm/min. The maximum required load to debond each bracket was recorded and bond strength was expressed in megapascal (MPa).

Adhesive remnant assessment (Qualitative)

After debonding procedures, the assessment and scoring of residual adhesives on each specimen was evaluated using a stereomicroscope (Nikon Corporation Instruments Company, Tokyo, Japan) at 10× magnification using a modified ARI.[17] The ARI had a range between 1 and 6, with 1 indicating that all of the adhesive remained on the tooth surface along with the impression of the bracket base; 2 indicating that more than 90% of adhesive remained; 3 indicating that more than 10% but less than 90% of the adhesive remained; 4 indicating that less than 10% of adhesive remained on the enamel surface; 5 indicating that no adhesive remained on the enamel; and 6 indicating part of the enamel fractured. Two investigators who were not aware of the groups scored the ARI scores independently.

Statistical analysis

Data were analyzed to report the descriptive statistics for the SBS in MPa for the four groups as well as the frequency and percentages of teeth for each ARI score. The results were analyzed using one-way analysis of variance (ANOVA) and Tukey multi-comparison tests to compare SBS between the four groups. All statistical analyses were set at a significance level of $P < 0.05$. The statistical analysis was carried out with SPSS Version 16.0 (SPSS Inc. Released 2007. SPSS for Windows, Chicago, SPSS Inc., Ill, USA).

Results

Shear bond strength

Descriptive statistics of SBS values expressed in MPa for the two adhesives and the four groups are presented in Table 1. There was statistical significant difference in SBS values of all groups ($P = 0.005$). Further, statistically analysis showed significant difference of the SBS values of groups 3 and 4 but no significant difference in the SBS values of groups 1 and 2. However, no significant difference was found between the two adhesives types: Transbond XT and Fuji Ortho LC ($P = 0.449$). There was statistically significant difference in SBS in relation to enamel surface (sound or after adhesive removal) ($P = 0.030$). SBS values were significantly higher with enamel surfaces after adhesive removal compared to sound enamel. There was statistically significant difference in SBS in relation to the condition of bracket (new or sandblasted) ($P = 0.030$). SBS was statistically significantly higher with rebonded brackets when compared with new brackets. Comparison of mean ranks of the study variables in relation to SBS values and the statistical significance is presented in Table 2.

Adhesive remnant index scores and failure modes

The inter-examiner reliability for ARI evaluation was 60% (kappa = 0.642; $P < 0.0001$), which is statistically significant agreement. The first rater had categorized 40 samples to the scores of 3, 4, 5, and 6 in the proportion of 7.5%, 40%, 30%, and 22.5%, respectively, whereas the second rater had categorized 40 samples to the scores of 3, 4, 5, and 6 in the proportion of 5%, 30%, 42.5%, and 22.5%, respectively. The level of agreement between the two raters was higher toward the classification of higher categories of ARI (scores 5 and 6) with agreement percentage 91.7% and 100%, respectively. However, this agreement decreased toward the classification of lower categories of ARI (scores 4 and 3). No specimens assigned to the ARI scores of 1 and 2. Agreement between the raters in relation to their scoring using ARI is presented in Table 3. Descriptive statistics of ARI for all groups is presented in Table 4. There was more adhesive remained among resin-composite groups. Enamel fracture occurred among RMGI groups and when using new brackets bonded to sound enamel.

Table 1: Descriptive statistics of SBS values expressed in MPa for the two adhesives and the four groups

Groups	Adhesive Material	Brackets Status	Mean	Std. Deviation	Std. Error of Mean	Median
1	Resin-composite	Rebonded	25.801	11.200	3.542	26.885
2	Resin-composite	New	28.830	14.600	4.621	27.932
3	RMGI	Rebonded	42.128	13.200	4.186	36.578
4	RMGI	New	19.530	9.770	3.088	19.254

Table 2: Comparison of mean ranks of the study variables in relation to SBS values and the statistical significance

Study Variables	No. of Specimens	Mean (SD)	Mean Ranks	*P*
Groups				
1	10	25.80 (11.2)	18.0	0.005*
2	10	28.83 (14.6)	20.2	
3	10	42.12 (13.2)	31.0	
4	10	19.53 (9.77)	12.8	
Enamel surface				
Sound	20	24.18 (13.0)	16.5	0.030*
After adhesive removal	20	33.96 (14.6)	24.5	
Adhesive				
Resin-composite	20	27.32 (12.77)	19.1	0.449
RMGI	20	30.82 (16.20)	21.9	
Bracket				
New bracket	20	24.18 (13.0)	16.5	0.030*
Sandblasted bracket	20	33.96 (14.6)	24.0	

*Statistically significant: $P<0.05$

Table 3: Agreement between the two raters in relation to their scoring using ARI - Frequency (Percent)

ARI score	Description	Frequency (Percent)	
		Rater 1	Rater 2
1	All of the adhesive remained on the tooth surface along with the impression of the bracket base	-	-
2	More than 90% of adhesive remained 2	-	-
3	More than 10% but less than 90% of the adhesive remained 3	3 (7.5)	2 (5)
4	Less than 10% of adhesive remained on the enamel surface 4	16 (40)	12 (30)
5	Indicating that no adhesive remained on the enamel 5	12 (30)	17 (42.5)
6	Indicating that part of the enamel was removed with the adhesive 6	9 (22.5)	9 (22.5)
Total		40 (100)	40 (100)

Table 4: Descriptive statistics of the adhesive remnant index (ARI) for all groups

Groups	Adhesive Material	Brackets Status	Mean	Std. Deviation	Std. Error
1	Resin-composite	Rebonded	4.550	0.662	0.204
2	Resin-composite	New	4.650	1.117	0.353
3	RMGI	Rebonded	4.750	0.791	0.250
4	RMGI	New	5.050	0.969	0.306

Discussion

The null hypothesis was partially rejected, as bond strength of rebonded stainless steel brackets was higher than new brackets for the RMGI. The results of this study evaluate SBS of new and the rebonded brackets, the two orthodontic adhesives, and effect of the sandblasting. The bond strength of bracket-adhesive-enamel system is extremely important to have a successful clinical performance.[18] Orthodontic bracket recycling provide a bracket that has ideal qualities comparable to new brackets, and able to withstand all the forces.[19] Several methods of recycling orthodontic brackets could be done by specialized companies have been introduced, which is time consuming and expensive.[20] Other methods of recycling orthodontic brackets could be done in the dental office such as sandblasting that provide higher SBS compared to new brackets due to the roughened surface.[16] A study suggested not to sandblast new brackets because the bond strengths of the new brackets are adequate for clinical use (6–8 MPa).[21] A study showed that to have a satisfying treatment outcome bond strength of 5.9–7.8 MPa is required *in vitro*.[22] Another study showed that up to 17 MPa are recommended values of bond strength whereas higher values are considered too high for orthodontic use and could result in enamel fracture during deboning.[23] However, other studies reported that increase number of enamel fracture associated with bond strength exceeding 13.5 MPa.[24,25] In the present study, the SBS of the new and rebonded brackets ranged between 19.530 MPa and 42.128 MPa, which is higher than what is reported in the aforementioned studies. Some studies showed no significant difference in the bond strength values of resin-composite and RMGI adhesives.[26] However, other research revealed the SBS of Transbond XT resin-composite adhesive to be 24.6 MPa.[2] Whereas SBS of Fuji Ortho LC RMGI adhesive was 10.2 MPa.[27] The present study showed that the two types of adhesive have sufficient SBS values for orthodontic clinical use and they were comparable to each other.

In the present study, we investigated new and debonded sandblasted stainless steel brackets and these two adhesive systems commonly used in orthodontic practices.[2,28] Also, the sandblasting was used as it is simple, easy to handle technique that can be performed in the clinic for cleaning brackets.[10] In addition, we used the SBS test that has acceptable accuracy and reproducibility using a crosshead speed of 1 mm/min. However, crosshead speeds of 0.1–10 mm/min have been used for SBS testing; but these values do not correspond to values in the clinical oral environment because the speed of mastication is in the range of 81–100 mm/s or 4,860–6,000 mm/min with a frequency of 1.03–1.2 Hz.[29] The direction of application of the debonding force in this study was standardized as previous study reported that SBS measurements were significantly influenced by the direction of the debonding force.[30] In the present study, SBS was significantly higher in group 3 (rebounded brackets with RMGI) and significantly low in group 4 (new brackets with RMGI). Whereas there was no significant difference in the SBS of group 1 (rebounded brackets with resin-composite) and group 2 (new brackets with resin-composite). This might be explained by the hybrid nature of RMGI, which can form chemical bond with enamel, and metal,[31] whereas in resin-composite adhesive bonding is only mechanical.[21] In the present study, SBS was significantly higher with enamel surfaces after adhesive removal compared to sound enamel. In addition, SBS was significantly higher with rebonded brackets, when compared with the new brackets. This result coincides with another study.[32] However, these results differ from other studies.[10,11] This might be due to sandblasted brackets, which have increased mechanical retention and surface area for bonding in comparison to new brackets and sound enamel. In the present study, no significant difference in the SBS between the two adhesive types even with the differences in their compositions and properties, which in theory will affect the SBS. Our results in agreement with other studies conducted by different investigators.[28,33] However, many studies reported that Fuji Ortho LC RMGI has weaker bond strength than resin-composite but it is still acceptable for clinical uses.[25,28,34,35]

In the present study, the torque forces generated during debonding the brackets using debonding plier in groups 1 and 3 might affect the results. Nevertheless, the thoughts on this part are controversial.[36,37] As forces applied to the outer wings of the bracket transmitted the smallest amount of stress to the enamel, whereas forces applied to the base of the bracket and to the adhesive zone generated stress that is concentrated in the enamel resulting in separation at the adhesive-enamel interface.[36] Therefore, in this study application of the pliers was by the same investigator and in a consistent manner. In addition, the force generated by the debonding plier during debonding may not be similar. Furthermore, some debonding pliers such as cutter plier may cause significant structural deformations at the base and/or at the slot of the bracket whereas other debonding plier such as LODI showed that all brackets debonded remained structurally intact.[38,39] In the present study, no attempt was made to evaluate the structural deformations at the base and/or at the slot of the bracket. However, recorded SBS was high and acceptable.

In the present study, ARI assessment revealed most of the specimens of all the groups had a score 4 or 5 (less than 10% or no adhesive remained on the enamel surfaces), respectively and only few specimens had ARI scores of 3 (more than 10% but less than 90%) and 9 specimens had score of 6 (part of the enamel was removed with the adhesive). Another study evaluated the surface enamel after bracket debonding and residual resin removal reported that score 3 was the most frequent (41%) and the second most common failure was score 0 (40.6%) that implies weak adhesion between the enamel and the adhesive.[40]

The effect of different experimental settings in the laboratory studies on bond strength of orthodontic brackets is still inexplicit, which initiated the aim and methodology of this study to improve clinical outcomes of the rebonded brackets that may guide clinicians in their clinical practice. Extrapolation of the results of this laboratory study to the clinical setting would indicate that the bond strength of debonded sandblasted stainless-steel brackets was higher than new brackets and resin composite and RMGI orthodontic adhesives exhibited sufficient SBS values for bonding brackets to sound and cleaned enamel and comparable to each other. This laboratory study might be different from previous studies as the setting of different parameters such as the mode of the debonding force, crosshead speed, the type of surface preparation, different adhesive protocols, and bracket type could influence the findings. The clinical significance of this study is reflected on the benefit that debonded sandblasted brackets can be beneficial if used and results in higher bond than new brackets.

This study have some limitations including *in vitro* setting as the nature of forces of orthodontic brackets are subjected to complex of shear, tensile, and torsion,[41] which is not produced *in vitro*. *In vitro* studies are unable to simulate the oral environment and other factors that could have an influence on the SBS such as tooth brushing technique, bad oral habits, age and sex of the patient, kind of food and drinks consumed, and type of saliva. However, *in vitro* studies provide us with valuable information about the amount of controlled force lead to bond failure and that protocol possibly gives the clinically desired bond strength and also to guide clinicians about the condition of enamel after debonding. Therefore, results of *in vitro* to the clinical situation must be through with caution. In addition, the Instron universal testing mechanic gives a constant load that is not the case in oral cavity.[42] Furthermore, aging of the specimens was done with thermocycling only and it would be beneficial if long-term storage is also tested in future study.

Conclusions

Within the limitations of this *in-vitro* study, the following can be concluded:

1. Resin-composite and RMGI orthodontic adhesives used in this study exhibited sufficient SBS values for bonding brackets to sound and cleaned enamel and comparable to each other
2. SBS values were significantly higher with enamel surfaces after adhesive removal compared to sound enamel
3. The bond strength of debonded sandblasted stainless-steel brackets was higher than new brackets

4. There was more adhesive remained among resin-composite groups. Enamel fracture occurred among RMGI groups and when using new brackets bonded to sound enamel.

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Conflicts of interest

There are no conflicts of interest.

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