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Shear bond strength of orthodontic bracket bonded to buccal versus lingual surfaces

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Abstract
Objectives: *The objective of this investigation was to assess shear bond strength (SBS) of orthodontic brackets bonded to the buccal and lingual enamel using two orthodontic adhesives: resin-modified glass-ionomer and resin composite.*
Methods: *Twenty buccal and twenty lingual human premolar enamel surfaces, allocated into four groups 10/each were used in this study. Metal brackets were bonded to each surface using resin-modified glass-ionomer or resin composite orthodontic adhesive, and excess was removed with a brush. Specimens were stored for 24 hours, subjected to thermocycling and shear bond strength was measured 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 groups using modified adhesive remnant index (ARI).*
Results: *Kruskal Wallis test indicated significant difference of shear bond strength between the four groups (P=0.007). Pair-wise comparisons using Mann-Whitney test showed that the only significant difference was between resin composite of buccal and resin-modified glass-ionomer of lingual surfaces (P=0.003) as well as between resin composite of lingual and resin-modified glass-ionomer of lingual surfaces (P=0.001). Most of the specimens of all groups, achieved ARI scores 4 and 5 with a very low frequency of ARI scores 2 and 3.*
Conclusions: *This research shows that no significant differences in shear bond strength between buccal and lingual surfaces. Resin-modified glass-ionomer and resin composite adhesives exhibited sufficient shear bond strength for orthodontic use and no significant difference was found between the two adhesives.*
Key words: *Orthodontic Brackets, Shear Bond Strength, Orthodontic Adhesives, Enamel*

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I. Introduction

Many orthodontic adhesives have been developed with different properties.[1] Some of their ideal features are enough working time that is sufficient for the dentist but still convenient for the patient, fluoride release, good bonding to tooth structure, easy removal without damaging enamel surface and with minimal polishing needed.[1] Resin composites materials is the most commonly used adhesives because of their well-established clinical and laboratory performance.[1,2] On the other hand resin-modified glass-ionomer combines some advantages of resin composite and some properties of glass-ionomer which makes its use preferable.[3] Some of these advantages is the ability to form a chemical bond with the enamel and metal, less sensitivity to moisture and saliva contamination, fluoride release and the ability to serve as fluoride reservoir in the oral cavity.[3]

Only few investigations were initiated to evaluate the frequency of bond failure between the human teeth buccal and lingual sides.[4-7] The literature mainly focuses on buccal appliances, although lingual appliances could be considered as an alternative to buccal treatment and can offer multiple advantages over buccal treatment e.g. reduction of white spot lesions and providing the maximum esthetic need.[8,9] A study reported similar bond strength to the buccal or lingual surfaces when the brackets were adapted to either surfaces.[6] Another study reported considerably greater bond strength to detach brackets from the buccal surface compared to the lingual surface.[10]

High bond strength of the brackets is essential to stand orthodontic forces and to allow for control of tooth movement; however it should be simply detached at the end of treatment without destruction to the enamel surface.[11,12] Frequent accidental detachment of orthodontic bracket during the course of treatment; adversely affect the patient as well as the orthodontist regarding the treatment outcome, duration, cost, and convenience.[13]

Failure in bonding of the brackets is a hindering aspect in orthodontic treatment[11,13] because it is inconvenient to the patient and the orthodontist.[10,14]

Assessment and comparison of the frequency of bond failure in teeth treated with either lingual or buccal appliances is very important because it may influence treatment duration and costs.[10] As many bracket materials and orthodontic adhesives exist, portraying their characteristics using *in vitro* studies and bonding forces is crucial. Hence, the aims of this investigation were to assess SBS of orthodontic brackets bonded to the buccal and lingual enamel with two orthodontic adhesives: resin composite (Transbond XT) and resin-modified glass-ionomer (Fuji Ortho LC) as well as quantifying the remaining adhesives on enamel after bracket debonding using ARI. The null hypothesis of this investigation was there is no significant difference in SBS and ARI of orthodontic brackets bonded to the buccal and lingual enamel using the methods and materials used in this study.

II. Materials and Methods

Twenty premolar teeth that were extracted due to orthodontic treatment were stored in 0.1% thymol solution and used in this investigation. All teeth have intact crowns, no attrition, and free from hypoplastic area, cracks, gross irregularities, decay, and fractures. Buccal and lingual enamel surface of each tooth was scaled and polished with rubber polishing cup and pumice using low-speed handpiece for 10 seconds, then stored in deionized water at room temperature (25°C) for 48 hours. 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 (Buccal and lingual) and then each 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, each surface/section was placed in standardized mold and embedded in self-curing acrylic resin where the buccal and lingual surfaces of each tooth were kept parallel to the floor. Sections were allocated into four experimental groups 10/each, 20 buccal and 20 lingual surfaces. Distribution of specimens along with tooth surface and adhesive material for all groups is presented in Table 1.

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 enamel surface following the recommendations of the manufacturer using 2 kinds of orthodontic adhesives: resin composite (3M-Unitek Transbond XT Light Cure Adhesive, Monrovia, CA, USA) for groups 1 and 2 and resin-modified glass-ionomer (GC Fuji Ortho LC Capsule, GC Corporation, Tokyo, Japan) for groups 3 and 4. Each bracket was attached/bonded to the middle surface of each tooth. Excess adhesive was removed with a regular size brush #2 (Dental Micro Applicator Brush, Shanghai Smedent Medical Instrument Co., Ltd., Shanghai, China) and one brush was used for each specimen. One investigator performed all procedures and steps in a consistent manner. Then, the specimens were stored in deionized water in laboratory oven (Memmert Universal Oven, Memmert Edestahl, Rost Frei, Schwabach, West Germany) at 37^0C for 24 hours before thermocycling. All specimens were placed for thermocycling between 5^0C and 55^0C with a dwell time of 30 seconds and a transfer time of 5 seconds for 1500 cycles (Thermocycler THE-1100, SD Mechatronik GMBH, Feldkirchen-Westerham, Germany). The specimens were then stored in distilled water at room temperature until testing the SBS 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).

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 10X magnification using a modified ARI.[15] The ARI has a range between 1 and 5, 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.

Descriptive statistics of SBS values were calculated for each group. Comparison of different groups and identifying statistically significant differences were performed using Kruskal Wallis one-way analysis of variance and if there was a significant difference between the groups, pair-wise comparisons using Mann-Whitney test was carried out. Kruskal Wallis test and Mann Whitney test were also used to compare between different groups regarding ARI. Inter-examiner reliability for ARI scoring was done using Kappa test agreement. 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).

III. Results

Shear Bond Strength

The mean (±SD) of the SBS of resin composite adhesive for groups 1 and 2 was 0.277 ± 0.011 and 0.266 ± 0.020 respectively. While for resin-modified glass-ionomer adhesive groups 3 and 4, the SBS was 0.698 ± 1.060 and 1.0304 ± 1.167 respectively. Descriptive statistics of SBS values expressed in MPa for each group are presented in Table 2. Kruskal Wallis test showed significant difference of SBS between the four groups (P=0.007). Pair-wise comparisons using Mann-Whitney test showed that the only significant difference was between groups 1 and 4 (P=0.003) and between groups 2 and 4 (P=0.001). Combining SBS of buccal and lingual surfaces indicated no significant difference between the SBS of buccal and lingual surfaces (P= 0.213). In addition, no significant difference was found between the two adhesives: Transbond XT and Fuji Ortho LC (P=0.083).

Adhesive Remnant Index (ARI)

The inter-examiner reliability for ARI evaluation was about 80% agreement, which is considered an acceptable agreement (P=0.001), and correlation between examiners was 0.9 (P=0.001). In the assessment of ARI, the frequency of each index in each group was evaluated and the scores were reported according to the higher score between the raters. Most of the specimens of all groups (Table 3), have scores 4 and 5 (Less than 10% or no adhesive remained on the enamel surfaces) with a very low frequency of ARI scores 2 and 3 (More than 90% or more than 10% but less than 90%). The mean (±SD) of the ARI of resin composite adhesive for groups 1 and 2 was 3.950 ± 0.643 and 4.200 ± 1.111 respectively. While for resin-modified glass-ionomer adhesive groups 3 and 4, the mean ARI was 4.5 ± 0.710 and 4.250 ± 0.920 respectively (Table 4). Kruskal-wallis test and Pair-wise comparisons using Mann-Whitney test showed no significant difference between the groups regarding ARI scores. No score 1 (All adhesive remained on the tooth surface along with the impression of the bracket base) was found in any group.

IV. Discussion

The null hypothesis of this study was partially accepted, as there was in general no difference in SBS and ARI of metal brackets bonded to the buccal and lingual enamel using the methods and materials used in this investigation. There are many factors that can cause the orthodontic bracket bond to fail; it could be the nature of the oral cavity which has a changing PH, continuous masticatory forces, and extreme temperatures.[11,13,16] Also accidental debonding could occur because of a problem in the bonding technique, low retentiveness of the bracket base or in small sized brackets used in esthetic cases.[11,16] All these factors make it difficult to pinpoint the cause of debonding which could be multifactorial too.[13,16] The present study found no significant difference between the SBS of buccal and lingual surfaces. Another study reported similar bond strength to the buccal or lingual surfaces when buccal brackets were adapted to both surfaces.[6] In contrast, considerably greater bond strength to detach brackets from the buccal surface was reported compared to the lingual surface.[10] The difference in results could be related to the fact that the enamel of buccal surface is rougher than enamel of lingual surface due to presence of marked perikymata in form of horizontal ridges in the buccal surface but not in the lingual surface.[17] In addition, The lingual surface is smoother which could be associated with the self-cleansing activity from the tongue and salivary glands.[17] It is also possible that variation of the structure in enamel surface might influence acid etching and bonding techniques.[17] Consequently, the smoother enamel of the lingual surface may have smaller micro-holes after acid etching in contrast with the buccal surface, resulting in a less mechanical interlocking development between enamel and the resin which result in a slighter retentive force with lesser debonding strength and greater tooth damage compared with the buccal side.[10] It was reported that SBS of brackets to enamel need to withstand loads from 5.9 to 7.8 MPa to be effective clinically for orthodontic use.[16] Investigations have reported bond strengths ranging from 2.8 MPa to 10 MPa as being acceptable for clinical circumstances.[18,19] Bond strength of different orthodontic brackets to enamel has shown wide variation in the reported SBS.[20] Reported values of SBS in different studies are difficult to compare due to use of different parameters such as preparation and nature of the substrate, the design of the test and the adhesives used.[20] A study reported that the SBS of Transbond XT resin composite adhesive to be 24.6 MPa.[2] While SBS of Fuji Ortho LC resin-modified glass-ionomer cement adhesive ranged between 2.76 - 3.6.[21] Another study showed that up to 17 MPa is suggested value of bond strength (22). Moreover, several studies reported that increase number of enamel fracture associated with bond strength exceeding 13.5 MPa.[23,24]

In the present study stainless steel brackets were used since they are commonly used in orthodontic clinics.[14,25] Bonding brackets with resin composite adhesives may lead to enamel loss during the debonding and removal of residual resin.[12] This could be of clinical importance as the highest concentration of fluoride is present at the surface of enamel.[12] In the present study there was no significant difference in the SBS between the two adhesives used, despite the differences in their compositions and properties which in theory will affect the SBS. Our results coincide with studies conducted by other investigators.[25,26]

Esthetic demand in orthodontic treatment has become a popular treatment preference, which led to increase use of lingual orthodontics as an option of treatment.[8] and not many studies have been done to investigate the difference of SBS between the lingual and buccal surfaces.[4,7] In our study, there was no statistically significant difference between SBS of buccal and lingual surfaces. Nevertheless, significant difference was found between group 1, which is a buccal surface with resin composite adhesive and group 4, which is lingual surface with resin modified glass ionomer. It could be assumed that the morphological dissimilarities between the lingual and buccal surfaces have affected the bond strength of brackets. However, other studies reported no significant differences in bond strength between the two surfaces, therefore supporting the use of both surfaces of premolars for bracket bonding experiments.[5,6]

The location of failure within the bracket-cement-enamel can occur within the bracket, within the cement, between the cement and the bracket, and between the cement and the tooth surface.[13,16] In the present study, ARI assessment revealed no statistically significant differences among the groups. Most of the specimens of all groups had a score of 4 or 5 (less than 10% or no adhesive remained on the enamel surfaces) respectively and only few specimens had ARI scores of 2 and 3 (more than 90% or more than 10% but less than 90%) respectively. The higher remaining adhesive on enamel surface is found more when using Transbond XT, which is probably due to using the primer and 37% phosphoric acid etching. It has been shown that acid etching of enamel result in deep resin tags which may reach to a depth of 5-25µ (27) and the use of a primer which act as wetting agent to carry resin monomers into the collagen network, that has been exposed by acid etching, at the same time that it displaces moisture from the dentin surface by solvents; creating a resin-reinforced layer known as hybrid layer.[28] Whereas the use Fuji Ortho LC results in formation of chemical bond only when enamel conditioner was used as recommended by the manufacturer.

The results of this investigation should consider the limitations of the study, including its *in vitro* setting. As the nature of forces of orthodontic brackets are subjected to complex of shear, tensile and torsion.[29], 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 a bond failure and which protocol could possibly gives the clinically desired bond strength, and to guide clinicians about the condition of enamel after debonding. Therefore, results of *in vitro* to the clinical situation must be considered with caution. In addition, the Instron universal testing mechanic gives a constant load, which is not the case in oral cavity.[30] Furthermore, we used only two orthodontic adhesives, it would be beneficial to compare more orthodontic adhesives. Also, despite the fact that we thermocycled the specimens, it is difficult to mimic the clinical condition including saliva in the mouth to the laboratory setting, and also it would be beneficial if long-term storage is tested in future study and not only aging of the specimens by thermocycling. In general, this *in vitro* study allows standardization of experimental conditions, which was an advantage and the results, demonstrated a clear correlation between SBS of the two adhesives bonding metal brackets to the buccal and lingual surfaces. Moreover, *in vitro* studies provide us with valued data about the quantity of controlled measured force required for debonding and to guide clinicians about the condition of enamel after debonding.

V. Conclusions

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

1) There are no significant differences in shear bond strength between buccal and lingual surfaces, which may support the use of both surfaces of premolars for bracket bonding.
2) Resin-modified glass-ionomer and resin composite orthodontic adhesives exhibited sufficient shear bond strength for orthodontic use and no significant difference was found between the two adhesives.
3) A higher remaining adhesive on enamel surface is found when using resin composite adhesive compare to resin-modified glass-ionomer.

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Table 1: Distribution of adhesive materials and tooth surfaces between different groups

Groups	Surfaces	Adhesive Material
G1	Buccal	Transbond XT - Resin Composite
G2	Lingual	Transbond XT - Resin Composite
G3	Buccal	Fuji Ortho LC - Resin-Modified Glass-Ionomer
G4	Lingual	Fuji Ortho LC - Resin-Modified Glass-Ionomer

Table 2. Descriptive statistics of SBS values expressed in MPa for each group

SBS in MPa	Group 1 Buccal	Group 2 Lingual	Group 3 Buccal	Group 4 Lingual
Mean	0.277	0.266	0.698	1.030
Std. Deviation	0.011	0.020	1.060	1.167
Std. Error of Mean	0.003	0.006	0.335	0.369
Median	0.281	0.269	0.078	0.519

Table 3. Scores of the adhesive remnant index (ARI) found in different groups

Groups	**ARI Scores - Classification**				
	1	**2**	**3**	**4**	**5**
Group 1 Buccal	0	0	2	5	3
Group 2 Lingual	0	1	2	0	7
Group 3 Buccal	0	0	1	3	6
Group 4 Lingual	0	1	0	4	5
Total	**0**	**2**	**5**	**12**	**21**

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

Groups	Mean	Std. Deviation	Std. Error
Group 1 Buccal	3.950	0.643	0.203
Group 2 Lingual	4.200	1.111	0.352
Group 3 Buccal	4.500	0.708	0.224
Group 4 Lingual	4.250	0.921	0.291

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