

Original Article

Shear bond strength of orthodontic buccal tubes to porcelain

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ABSTRACT

Background: Bonding of molar tubes is becoming more popular in orthodontics. Occasionally, these bonding are done on posterior porcelain crowns or bridges. The purpose of this study was to evaluate the shear bond strength of buccal tubes on feldspathic porcelain crowns with two different methods.

Materials and Methods: Forty porcelain right molar crowns were fabricated for this study. The crowns were randomly divided into two groups. In group 1, the crowns were etched with 9.6% hydrofluoric acid, silane coupling agent applied, coated with bonding primer and bonded with Transbond XT (3M Unitek, Monrovia, Calif). In group 2, the crowns were etched with phosphoric acid 37%, silane coupling agent applied, coated with bonding primer and bonded with Transbond XT. All the crowns were stored for 24 hours at 37°C and thermo-cycled before the shear bond test. The analysis of variance (ANOVA) was used to determine whether significant difference were present between the groups.

Results: The results of the analysis of variance ($F = 0.23$) indicated the shear bond strength of group 1 (3.57 ± 0.87 MPa) was not significantly different ($P > 0.05$) from group 2 (3.46 ± 0.65 Mpa). Fisher's exact test for the adhesive remnant index (ARI) revealed significant difference between both groups ($P < 0.05$). Eighty percent of group 1 buccal tubes failed at buccal tube/resin interface and eighty percent of group 2 mostly failed at porcelain/resin interface.

Conclusion: Etching with phosphoric acid with the use of silane coupling agent would be safer and should make it easier for clinicians to clean the adhesive on the porcelain surface after debonding.

Key Words: Acid etching, porcelain, shear bond strength

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INTRODUCTION

Buccal tubes are slowly replacing molar bands in orthodontic treatment. The reason for this increase in the popularity of molar bonding is because it is more convenient for both the clinician and patient. Amongst the advantages include, elimination of additional appointment time for placement of separators, easier maintenance of gingival health and elimination of

post-orthodontic space in between the molars. Banks and Macfarlane^[1] in a clinical study showed bonded tubes were more likely to fail compared to bands. This problem of retention of the buccal tube is compounded if there is a porcelain crown or bridge on the molars. Porcelain is an inert material which makes bonding of orthodontic attachment difficult. Several methods like sandblasting,^[2] using diamond burs to roughen the surface, etching with hydrofluoric acid,^[2] using silane coupling agent,^[3] etching with laser^[4] and curing with halogen and plasma arc light curing^[5] have been advocated to increase the bond strength of orthodontic brackets to the porcelain surface. Mechanical alteration of the surface of porcelain can cause irreversible damage and compromise the integrity of the crown or bridge. Anecdotal evidence suggests brackets bonded with silane coupling

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agents and phosphoric acid or hydrofluoric agent has sufficient bond strength for orthodontic treatment.^[6-10]

However, none of the investigators used buccal tubes or molar porcelain crowns to test the bond strength. There were variations in the testing procedures because some investigators did not do thermocycling^[6,7,9] or used porcelain denture tooth.^[6] Thermocycling of at least 500 cycles is required due to the different thermal expansion coefficient of ceramic, resin and metal.^[8] There are different types of porcelain which is routinely used in dentistry. Denture porcelain teeth are made at higher temperature and have different properties from the commonly used porcelain for crowns and bridges.^[11]

In our previous study,^[12] we investigated the shear bond strengths of buccal tubes and determined the sites of failure. Four orthodontic buccal tubes were selected: A, American Orthodontics; B, 3M Unitek - small base; C, 3M Unitek - large base; D, Hangzhou Dentop. Twenty buccal tubes from each group were bonded to the buccal surfaces of lower right first molars with the same light-cured composite resin. The buccal tubes were debonded with a universal testing machine and the data analyzed. The amount of adhesive remaining on the teeth after debonding was classified with the modified adhesive remnant index (ARI).^[12] The purpose of this study was to compare the shear bond strength of orthodontic buccal tube to feldspathic dental porcelain fused to metal crown after surface treatment with hydrofluoric acid (HFL) and phosphoric acid (PA) using silane coupling agent. We also would like to evaluate the amount of adhesive remaining on the ceramic surface.

MATERIALS AND METHODS

Forty porcelain (IPS Classic, Ivoclar Vivadent Inc, New York, USA) bonded to metal crowns were fabricated for the lower right first molar. All the crowns were identical and produced by a single experienced technician. Exclusion criteria were: Crown that did not fit in the prepared tooth, defect on the porcelain crown like cracks, air bubble or deficiency, anatomy of the crown is not similar especially the labial surface.

Lower right single buccal tubes (American Orthodontic Corporation, Sheboygan, Wis) were used for this study. The mean surface area for this buccal tube was 26.50 mm². This was calculated with a graph paper and the average was taken from

10 buccal tubes. The specimens were divided into two groups of twenty. The crowns were mounted in a custom made base of acrylic resin to facilitate the debonding exercise. The buccal surface of each crown was polished with pumice (fluoride free) powder for 20 seconds and then rinsed with abundant water spray and dried with air spray.

Group 1 (HFL) group: The crowns were etched with 9.6% hydrofluoric acid (Pulpodent, Basingstoke, UK) for 2 minutes. The etchant was completely washed and dried for 20 seconds. A thin layer of silane coupling agent (Ormco, Glendora, CA) was applied. Another layer of bonding agent (Transbond XT primer, 3M Unitek, Monrovia, CA) was applied. Finally (Transbond XT-3M Unitek, Monrovia, CA) resin was placed on the bonding surface of the buccal tube and positioned on the crown.

Group 2 (PA) group: The crowns were etched with 37% phosphoric acid liquid (3M ESPE, Minnesota, USA). In the presence of the acid, the silane coupling agent (Ormco, Glendora, CA) was applied with a cotton pellet. A second layer of the silane was applied with a different cotton pellet. After one minute, the crowns were thoroughly rinsed and dried for 20 seconds. Next a thin layer of bonding agent (Transbond XT primer, 3M Unitek, Monrovia, CA) was applied. Finally (Transbond XT-3M Unitek, Monrovia, CA) resin was placed on the bonding surface of the buccal tube and positioned on the crown.

The buccal tubes were placed by a single experienced orthodontist in its ideal position on the crown. The cement was cured at 400 MW/cm² for 20 seconds mesial and 20 seconds distal at a distance of 10 mm with a visible light cure source (Optilu × 400, Demetron Research Corp, Danbury, Conn). All the samples were stored in distilled water at 37°C for 24 hours before the thermocycling exercise.

All the specimens were thermocycled 1000 times between 5° and 55° with a dwelling time of 30 seconds.

The embedded crown and its cemented buccal tubes were positioned in a Shimadzu universal testing machine (Shimadzu Corporation, Kyoto, Japan). The buccal tubes were shear tested to failure using a load cell of 1 kg and a crosshead speed of 1 mm/min [Figure 1]. The force producing failure was recorded in Newtons and converted into Megapascal (MPa) by dividing the measured force values by the mean surface area of the buccal tubes.

For each specimen, the porcelain and buccal tube surfaces were analyzed using an image analyzer (Leica Image Analyzer) with $\times 10$ magnification to determine the site of bond failure. After bond failure, the amount of adhesive remaining on porcelain surface was coded using the criteria proposed using the modified adhesive remnant index (ARI).^[13,14]

The ARI scale ranges from 1 to 5:

1. All of the adhesive remaining on the enamel, with the impression of the buccal tube base
2. More than 90% of the adhesive remaining on the tooth surface
3. Less than 90%, but more than 10% of the adhesive remaining on the tooth surface
4. Less than 10% of the adhesive remaining on the tooth surface
5. No adhesive remaining on the tooth surface

Method error

Ten randomly selected teeth were re-examined on two occasions separated by a period of 2 weeks and the kappa test was applied to test intra-examiner reliability for the ARI score. Kappa values were between 98 to 100% for the ARI scores.

Statistical analysis

Descriptive statistics including mean, standard deviation, maximum and minimum values were calculated for the both groups tested. The data was tested for normality with Shapiro-Wilk test. The *P* value of 0.21 (Group 1) and 0.41 (Group 2) indicated that the data were normally distributed. Therefore, the analysis of variance (ANOVA) was used to determine whether significant difference were present between both the groups. The residual adhesive was compared using the Fisher's exact test. A significant level of 0.05 was used for both tests.

RESULTS

The shear bond strength, necessary to dislodge the buccal tubes was higher in Group 1 compared to Group 2 [Table 1]. The ANOVA test was run on the data and it showed no significant difference in bond strength among the groups ($P > 0.05$).

The ARI scores for the two groups are shown in Table 2.

The ARI scores were regrouped to 2 categories to highlight the position of the remaining adhesive in relation to the crown surface. In Group 1 (HFL) group, more than 80% of the sample had most of the



Figure1: Buccal tube and porcelain crown positioned for the debonding exercise

Table 1: Descriptive statistics for shear bond strength and analysis of variance between both groups

Group	N	Minimum	Maximum	Mean	Std. deviation
Group 1 (HFL)					
Force over area (Mpa)	20	2.41	5.17	3.57	0.87
Group 2 (PA)					
Force over area (Mpa)	20	2.50	4.84	3.46	0.65

Analysis of variance F ratio: 0.23; $P=0.63$; PA: Phosphoric acid; HFL: Hydrofluoric acid; Mpa: Megapascal

composite on the porcelain (category 1) compared to Group 2 (PA) in which 80% had most of the composite on the base of the buccal tube (category 2). All the debonds were adhesive in nature and there were no porcelain fracture. This difference was statistically significant ($P < 0.05$) with the Fisher's exact test.

DISCUSSION

Currently the commonly used dental ceramic in posterior crowns are feldspathic porcelain.^[2] This restoration contains silica (SiO_2), alumina (Al_2O_3), potassium oxide (K_2O) and sodium oxide (Na_2O).^[15] However, other types of porcelain like aluminous porcelain, glass ceramics, zirconium based porcelain are also becoming more popular.^[16] These newer types of porcelain are believed to be more resistant to etching.^[17] Therefore, it might not be possible to extrapolate the result of this study with the use of different types of porcelain.

The purpose of this study is to identify the shear bond strength of buccal tubes to feldspathic porcelain.

Table 2: Adhesive remnant index for both groups

Group	All on porcelain (1)	>90% on porcelain (2)	<90% on porcelain (3)	<10% on porcelain (4)	none on porcelain (5)	Total
Group 1 (HFL)						
Count	6	8	2	2	2	20
% within the group	30	40	10	10	10	100
Group 2 (PA)						
Count	1	1	2	5	11	20
% within the group	5	5	10	25	55	100

Fisher's exact test P value=0.000; Category 1 (most composite on porcelain): ARI score 1, 2 and 3; Category 2 (most composite on base of the buccal tube): ARI score 4 and 5; PA: Phosphoric acid; HFL: Hydrofluoric acid;

It has been established that silane coupling agent (porcelain primer) can be used to enhance the bond strength to porcelain.^[18,19] Although, the mean shear bond strength was slightly higher in Group 1 (HFL group) compared to Group 2 (PA group) as shown in Table 1, the mean difference of 0.11 MPa was not statistically significant ($P = 0.63$). The clinical problem with using hydrofluoric acid is that, it is very corrosive. The hydrofluoric acid can damage the oral soft tissues and dental tissues if it is not handled with care.^[20] Therefore, using phosphoric acid 37% as an alternative can be advocated in bonding to the porcelain. The steps that were recommended by the manufacturer,^[21] i.e., applying the silane coupling agent (porcelain primer) together with the phosphoric acid solution must be adhered to. This procedure will coat the porcelain surface with a mono-molecular layer of acrylic which would be able to bond with the orthodontic resin. The silane coupling agent increases the wet ability of the porcelain and provides a clear bonding surface.^[22] Acid solution of the silane enhanced the formation of siloxane bonds and facilitated the adhesion of composite resin and porcelain. The main contribution to the obtained value in group II was not by the mechanical interlocking of the composite to the porcelain but by the formation of siloxane bonds.

The shear bond strength in this study (3.57-3.46 MPa) is less than other similar studies^[4-6] using hydrofluoric and phosphoric acid (4.40-12.20 Mpa). The reason could be because they used pre-molar or incisor brackets which had a smaller base area (10-13 mm²). When the force in Newtons is divided by the total bonding surface area to get the force in MPa, the buccal tube used (surface area 26.5 mm²) would give a reduced amount of force per unit area. It has been established by other researchers^[21,22] that increasing the bonding surface beyond 7 mm² does not

improve the retentive capabilities. Moreover some studies^[7,8,23] have used porcelain tabs with flattened surface area or did not do any thermocycling.^[3,10] This does not simulate the clinical environment. The results of our previous study^[12] showed shear bond strengths of the buccal tubes fell below the value considered to be clinically acceptable. There were no differences between the shear bond strengths of the buccal tubes with photo-etched and micro-etched bases. The buccal tubes with the largest base failed prematurely, possibly because the unsupported bonding pad flexed during debonding.^[12]

The bond strength for routine orthodontic treatment has been quoted to range from 2.8 Mpa to 10 Mpa by various investigators.^[24-27] Although, the mean bond strength of both groups in this study falls in that range, we realize the bond strength *in vivo* might be lower.^[28] The porcelain surfaces in the oral cavity will be altered by variations in temperature, saliva, acidity and absorptions of mucoproteins and mucopolysaccharides.^[2] We also did not take into account the tensile and torsional forces that will affect the buccal tubes. However, this research has identified that the shear bond forces to dislodge the buccal tubes are towards the lower range of the force level and clinically it would be useful in cases where excessive force is not applied to the buccal tube.

When we analyzed the porcelain and buccal tube surface after the debonding exercise, there were no cohesive failures. All were adhesive failures either between the resin and porcelain surface, between the buccal tube bonding surface and resin or a combination of both. We used a modified ARI score as suggested by Bishara^[14] which gives a 5 scale and shows where most of the failure occurs. From the ARI score [Table 2], most of the failure occurred in between resin and the buccal tube in Group 1. This is in contrast with Group 2 where most of the failure occurred between the resin and the porcelain.

This difference is significant with Fisher's exact test ($P < 0.05$). The failure in Group 1 indicated that the chemical and mechanical bonding with HFL acid exceeded the mechanical retention of the buccal tubes. In Group 2, the chemical bond between the resin and porcelain were weaker than the mechanical bond between resin and the buccal tube. Tylka and Stewart^[29] reported that etching with hydrofluoric acid causes preferential dissolution of the crystal phase of the porcelain. This enhances the micro retention for bonding. Etching with phosphoric acid in SEM revealed smooth linear interface between the resin and porcelain without any interdigitation.^[7] Graber^[30] did mention that the addition of silane did not improve the retention when used together with hydrofluoric acid. This was probably because the bond strength with hydrofluoric acid was already maximum and addition of silane did not increase it any more. In our study, we wanted to avoid using hydrofluoric acid because of its known toxicity and used a weaker acid with a silane group. The use of silane to enhance bonding to porcelain has been proven by other researchers like Wood, *et al.*^[31] and Aida, *et al.*^[32] The silane provides a chemical link between the porcelain and composite resin. It chemically unites the silicon in the porcelain to the bonding material used by increasing the wet ability of the porcelain surface. From the clinical perspective, phosphoric acid and the silane which was used in Group II would require minimal clean-up and less damage to the porcelain surface when debonding.

CONCLUSION

Within the limitation of this study, it can be concluded that:

1. There was no significant difference in the shear bond strength with both groups of etching acids. The bond strength would be sufficient for clinical use if it was not subjected to excessive force during treatment.
2. Etching with phosphoric acid would be safer and should make it easier for clinicians to clean the adhesive on the porcelain surface after debonding.

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