Evaluation of the shear bond strength of metal bracket bonded to porcelain restorations (In vitro study)

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ABSTRACT

Background: Direct bonding of orthodontic attachments to porcelain is a great challenge. The purpose of this in vitro study to evaluate the effect of different methods of porcelain surface treatments on the bond strength of metal bracket bonded directly using ONE-STEP orthodontic adhesive and study the mode of bond failure.

Materials and methods: Sixty maxillary right central incisor porcelain denture teeth were randomly divided into six groups(Gp),ten specimens for each; Gp.I(P): phosphoric acid 37% (control), Gp.II(PS): phosphoric acid 37% & silane coupling agent, Gp.III(HS): hydrofluoric acid 9% & silane coupling agent, Gp.IV(SP): sandblasting with 50 µm Al2O3 particles & phosphoric acid 37%, Gp.V(SPS): sandblasting with 50 µm Al2O3 particles, phosphoric acid 37% & silane coupling agent, Gp.VI(SHS): sandblasting with 50 µm Al2O3 particles, hydrofluoric acid 9% & silane coupling agent. Metal brackets were bonded to treated porcelain surfaces (Pc.) using One -Step alpha-dent® orthodontic adhesive. After thermocycling the shear bond strength (SBS) & mode of bond failure were determined.

Results: One Way ANOVA-test showed a statistically highly significant difference (p = 0.000) in SBS of the non-sandblasting groups and also showed a statistically highly significant difference (p = 0.000) of the sandblasting groups. SHS Gp. had the highest values in mean shear bond strength (6.459 ± 13 Mpa) of all groups followed by HS Gp.(3.961 ± 0.9 Mpa) then SPS Gp.(2.096 ± 0.5 Mpa) then SP Gp.(1.16 ± 0.8 Mpa).On the other hand both P & PS groups had zero Mpa values of SBS.

Conclusions: The most reliable procedure for bonding orthodontic brackets to porcelain surfaces is through the surface treatment combinations of three methods: sandblasting, 9% hydrofluoric acid treatment and silane coupling agent application. On the other hand all other methods produced insufficient SBS for orthodontic treatment. Adhesive-porcelain interface failure was the predominant mode of bond failure in all groups except the last group, cohesive failure was the predominant & none of the samples displayed fractures within the porcelain itself during debonding.

Key words: Orthodontic bonding to porcelain; Shear bond strength. (J Bagh Coll Dentistry 2010;22(2):123-128).

INTRODUCTION

With the increased number of adults seeking orthodontic treatment, clinicians often bond orthodontic brackets to teeth that have different types of restorations, including amalgam, gold, composite, and porcelain. The inert porcelain surface characteristic presented problems to both the operative dentist as well as the orthodontist. Whether to repair a porcelain crown or to bond a bracket to such a restoration, therefore, a number of approaches have been attempted to alter the surface characteristics of porcelain or ceramic to provide sufficient bond strength to the orthodontic brackets.

These approaches can be grouped into three broad categories, namely mechanical, chemical, or combination. The purpose of mechanical alteration of the porcelain surface is to remove the glaze and roughen the surface to provide sufficient mechanical retention for the adhesive for successful placement of the orthodontic bracket. This alteration has been achieved by microetching (air abrasion or sandblasting), using a coarse diamond stone, or sandpaper disks.

Although the changes introduced by this approach have sufficiently increased the bond strength for orthodontic purposes, they also cause irreversible damage to the porcelain glaze. [1-6]

Chemical alteration of the porcelain surface can be introduced by either etching the surface to increase the mechanical retention of the adhesive or by changing the porcelain surface affinity to the adhesive materials; hydrofluoric acid has been used successfully to etch the porcelain surface (glassy ceramics) and significantly increases the bond strength of orthodontic attachments. Phosphoric acid, and acidulated phosphate fluoride have also been used to etch porcelain surfaces because they do not cause as much damage as hydrofluoric acid, but they were also found not to be as effective in providing adequate and consistent bond strength for orthodontic purposes. [3-9]

Another approach used to enhance bond strength to porcelain surfaces is by changing the nature of the surface, using a coupling agent such as silane. The action of the silane coupler can be observed as performing two functions; the hydrolysable group of the coupler reacts with the inorganic dental porcelain whereas its organofunctional group reacts with the resin and enhances adhesion. [6, 9-15]

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MATERIALS AND METHODS

Samples selection

Sixty Porcelain denture teeth of maxillary right central incisors of identical size & shape of the same company were used in this study (STRONG, USA). All samples were hydrated in deionized distilled water at 37˚C in incubator, for 1-week before bonding procedure to simulate the oral condition. [(16)]

Bracket used

Sixty Upper central Incisor standard Edgewise metal Brackets, 0° Torque, 0°Angulation with surface area for the bracket base is (13.2 mm²), DENTAURUM, Germany.

Bonding procedure

The labial surface of all porcelain teeth were polished using a non- fluoridated pumice and water slurry in a rubber cup attached to a low speed hand piece for 30 seconds, then each tooth was washed with water spray for 10 seconds, and dried with oil-free air for 10 seconds. [(17)]

The porcelain teeth were randomly divided into six groups (10) specimens for each; Gp.I (control) the porcelain surfaces were etched with 37% phosphoric acid for 30 seconds, washed with water spray for 20 seconds, and then dried with oil-free air for 20 seconds[(17)]. Gp.II: the porcelain surfaces were etched with 37% phosphoric acid for 60 seconds, washed with water spray for 20 seconds, dried with oil-free air for 20 seconds[(9)] and then coated with silane coupling agent (Ultradent, Germany)for 60 seconds according to the manufacturer instruction. Gp.III: the porcelain surfaces were etched with 9 % hydrofluoric acid(Ultradent, Germany) for 60 seconds, washed with water spray for 20 seconds, dried with oil-free air for 20 seconds, and then coated with silane coupling agent (Ultradent, Germany) for 60 seconds according to manufacturer. Gp. IV: the porcelain surfaces were sandblasted(AIR PROPHY UNIT) by 50µm Aluminum Oxide powder for 5 seconds at 10 mm distance with 2.5 bars [(18)] , etched with 37% phosphoric acid for 30 seconds, washed with water spray for 20 seconds, and then dried with oil-free air for 20 seconds[(17)] Gp.V: the porcelain surfaces were sandblasted (AIR PROPHY UNIT) by 50µm Aluminum Oxide powder for 5 seconds at 10mm distance with 2.5 bars, etched with 37% phosphoric acid for 60seconds, washed with water spray for 20 seconds, dried with oil-free air for 20 seconds[(9)], and then coated with silane coupling agent (Ultradent, Germany) for 60 seconds according to the manufacturer instruction .Gp.VI: the porcelain surfaces were sandblasted(AIR PROPHY UNIT) by 50µm Aluminum Oxide powder for 5 seconds, at 10mm distance with 2.5 bars, etched with 9 % hydrofluoric acid (Ultradent, Germany) for 60 seconds, washed with water spray for 20 seconds, and dried with oil-free air for 20 seconds, then coated with silane coupling agent (Ultradent, Germany) for 60 seconds according to the manufacturer instruction.

A thin layer of liquid activator was applied on both the conditioned labial porcelain surface in each group and on the bracket base then an equal amount of the adhesive paste (One-step alpha-dent® orthodontic adhesive) was applied on the activated bracket base according to the manufacturer instructions. During bonding procedure, each bracket in all groups was subjected to a constant load of 300 grams by pressure tension gauge (ETM Corporation, USA) which placed at 90 ° for 10 seconds to ensure that each bracket was seated under equal force.[(19)] Any excess bonding material was carefully removed from around the bracket base with a sharp hand scaler without disturbing the seated bracket. After the completion of the bonding procedure, the specimens were allowed to bench cure for 30 minutes, then immersed in deionized distilled water and stored in the incubator at 37º C for 24 hours. [(20)] Then samples were aged after bonding procedure by thermocycling (500 cycles in hot and cold baths at 5˚-55˚C ± 4 ˚C for 30 seconds dual interval) as a means of artificial aging to simulate the oral environment prior to testing, as described by Organization for International Standardization .[(3)]

Debonding procedure

The sixty porcelain denture teeth were embedded in the center of cubic cold cure acrylic blocks in such away that their labial surface were exposed for surface treatment and bonding procedure. Shear test was accomplished using Tinius Olsen universal testing machine with loading cell 50 kilogram & a crosshead speed of 0.5 mm/min .[(21)] Each sample was seated in the mounting metal vice and placed on the base of the testing machine (which was parallel with the horizontal plane). The chisel end rod was fitted inside the upper arm of the testing machine with its chisel end downward parallel to the bonded porcelain labial surface to apply a force in an gingivo-incisal direction of the bracket that produce a shear force at the bracket base/ porcelain surface interface, until debonding occurs. When the bracket was debonded from the porcelain labial surface by the force applied from the testing machine, the ultimate magnitude of the reading is taken; this force is measured in kilograms and converted into Newtons, then divided by bracket surface area to obtain SBS in Mpa.

The debonded bracket and porcelain surface of each tooth were inspected using a 10X magnifying lens to determine the predominant site of bond failure according to Wang et al. (1997) index [22], as follow:

Score (1): Between the bracket base and adhesive.

Score (2): Cohesive failure within the adhesive itself.

Score (3): Between adhesive and porcelain surface.

Score (4): porcelain detachment.

Statistical Analysis

Descriptive statistics: including mean, standard deviation, minimum, maximum were calculated for each of the six groups.

One way analysis of variance (ANOVA) was used to test any significant difference in the shear bond strength among the non-sandblasting groups & among the sandblasting groups. If significant differences were present, least significant difference (LSD) test was used to investigate where the significant difference did occur for both groups. Student T-test was used to test any significantly differences between the non-sandblasting groups & the comparative sandblasting groups.

RESULTS

Shear bond strength comparisons

The results of One way analysis of variance among the non-sandblasting groups & among the sandblasting groups, indicated that there were a highly significant difference among both of them, then (LSD) test was taken for both non-sandblasting (table 2) & sandblasting groups (table 3). Gp.VI (SHS) had the highest values in mean shear bond strength (6.459 ± 1.3 Mpa) of all groups followed by Gp. III (HS) (3.961 ± 0.9 Mpa) then Gp. V(SPS) (2.096 ± 0.5 Mpa) then Gp.IV (SP) (1.16 ± 0.8 Mpa).On the other hand both Gp. I (P) and Gp. II(PS) had (zero Mpa) values of mean shear bond strength (table 1, Figure 1). T-test showed that there is a highly significant difference ($p < 0.001$) between the non-sandblasting and comparative sandblasting groups (table 4)

Table 1: Descriptive statistics of Shear Bond Strength (Mpa) of all groups.

Group		Min.	Max.	Mean	Std. Dev.
Non-Sand blasting Group	I	0	0	0	0
	II	0	0	0	0
	III	2.84	5.55	3.96	0.9
Sand blasting Group	IV	0.14	2.55	1.16	0.8
	V	1.25	2.85	2.10	0.5
	VI	4.50	8.26	6.46	1.3

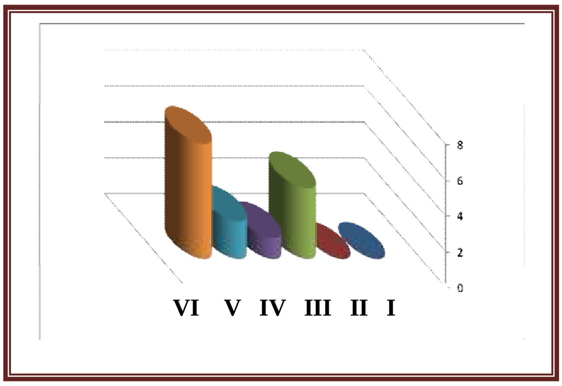

Figure 1: Mean Shear Bond Strength (Mpa) of all groups

Table 2: LSD-test to compare SBS between each two groups for non-sandblasting groups.

Groups	p-value	Level of significant
I vs. II	1.000	NS
I vs. III	0.000	HS
II vs. III	0.000	HS

Table 3: LSD-test to compare SBS between each two groups for sandblasting groups

Groups	p-value	Level of significant
IV vs. V	0.01	S
IV vs. VI	0.000	HS
V vs. VI	0.000	HS

Table 4: Student T- tests between comparative groups.

GROUP	T-test	df	P -Value	Sig.
I vs. IV	-4.447	18	0.000	HS
II vs. V	-13.014	18	0.000	HS
III vs.VI	-4.797	18	0.000	HS

DISCUSSION

As detailed earlier in literature review, when bonding orthodontic brackets to porcelain surfaces it is necessary to change the inert characteristics of the surface to achieve clinically acceptable bond strength. This alteration is accomplished by either increasing the roughness of the porcelain surface by chemical or mechanical means or through the use of silane coupling agent.

One of the variations that present in the complex oral environment is the humidity which has a great influence on bond strength, for simulation of the oral environment all the samples of this study were hydrated in distilled water for one week before bonding due to the fact that the chemical nature of dental porcelain at the surface has been shown to be modified in the presence of water for one week period. Presumably, this is due to oversaturation of porcelain with water leading to hygroscopic expansion, specifically alkaline earth oxides contained within the porcelain (e.g.; AL2O3), consequently an alkaline layer of water formed at the porcelain surface which can interfere with the bonding mechanism. [16, 23, 24]

Temperature fluctuations in the mouth is another variations which dramatically affect the bond strength, therefore after the completion of bonding procedure the samples were subjected to thorough thermocycling regimen (500 cycles in hot and cold baths at 5˚-55˚C ± 4 ˚C) prior to testing as means of artificial aging or bond weakening to approximate the clinical reality, as described by Organization for International Standardization. The influence of temperature fluctuations can be visualized by the effects of thermal expansion coefficient mismatch between porcelain, resin and metal and hygroscopic expansion of composite which greatly challenge the bonds to dental porcelains resulting in stresses that cause fatigue. [3,25]

Force recommendation for orthodontic treatment as suggested by Whitlock et al [26] is between the average of (6-8) Mpa of shear bond strength which will be clinically adequate for orthodontic attachments to endure a course of orthodontic treatment and sufficiently weak to preserve porcelain restoration following bracket removal.

One of the aims of this study is the evaluation of the effectiveness of different surface-conditioning methods on shear bond strength of metal orthodontic brackets bonded to feldspathic porcelain. For non-sandblasting groups:

The samples of the GpI(P) were demonstrated bond failures during thermocycling (zero Mpa) of mean shear bond strength. Bourke & Rock [9] and Ajlouni et al. [19] recorded similar results.

The premature loss of the brackets were occurred due to the fact that the phosphoric acid does not etch the porcelain surface ; it simply cleans the surface and hydrolyzes the silica of the porcelain in the same time preserving the intact smooth surface of porcelain without any mechanical pitting needed to improve the bond strength to porcelain, in addition to the weakening effect of thermocycling on bond strength caused by thermal stresses at porcelain-resin interface leading to fatigue, indicating that conventional bonding systems do not guarantee adequate adhesion to porcelain surface; therefore, special surface treatment is needed to increase the bond to porcelain.

The samples of GpII(PS) were demonstrated bond failure during thermocycling (zero Mpa) of mean shear bond strength ,also there is no statistically significant difference between this group and control group. This finding is in agreement with the results of Barbosa et al [2] who reported the premature loss of brackets bonded to glazed ceramic surfaces coated with silane after one week distilled water immersion. They explained that this premature loss was due to the high solubility of silane in water.

Furthermore many studies show that the great effect of thermocycling on silane action causing a weakened porcelain-silane bond system caused by thermal stresses. [27, 28] The premature loss of brackets confirms that bonding to glazed surfaces coated with silane does not provide adequate bond strength and that silane coating should be combined with surface roughening. [6,29,30].

On the other hand Lifshitz & Cardenas [31] who found that the use of phosphoric acid followed by silane coupling agent, result in clinically adequate bond strength when using either a composite resin or a resin- reinforced glass-ionomer cement.

Gp III (HS) show the highest mean of shear bond strength (3.9 ± 0.9 Mpa) among the non-sandblasting groups and statistically there is highly significant difference between this group and groups I & II.

On the other hand it show a 2nd highest value of mean among the all six groups, however, this result can not be considered clinically acceptable since it is lower than the ideally accepted range (6-8 Mpa) of mean shear bond strength.

Similar results were recorded by Kocadereli et al [6] who found that porcelain preparation with hydrofluoric acid etching followed by silane application resulted in highest mean of shear bond strength, but the significant increase in bond strength was clinically acceptable which was due to the effect of the hydrofluoric acid by facilitating micromechanical retention and silane provided a chemical link between porcelain and composite resin. In contrast, Schmage et al [32] who did not find any significant increase in bond strength when silane was used in conjunction with hydrofluoric acid.

However, the contradictory results may be explained by the differences in storage conditions, bonding agents and ceramic types.

For sandblasting groups: Gp.IV (SP) showed the lowest mean of shear bond strength values (1.16 ± 0.8 Mpa) among the sandblasting groups and 2nd lower values among the six groups, therefore this result can not be considered clinically useful.

Kocadereli et al [6] advocated that the mechanical roughening that produced by sandblasting the porcelain surface alone without using silane primer, produce low bond strength since the silane play an important role through providing a chemical link between the dental porcelain and composite resin.

Disagreement exists concerning the effectiveness of air-abrasion with AL2O3 particles by Sarac et al [(18)] who found that air-abrasion with AL2O3 particles was more effective than chemical etching with hydrofluoric acid, this can be attributed to AL2O3 particle size, concentration, type of acid and application period.

Although there is a statistically significant difference between Gp.V and Gp.IV but the silane application after sandblasting show a little increase in the mean of shear bond strength (2.1 ± 0.5 Mpa) than Gp.IV (1.16 ± 0.8 Mpa) and low mean concerning the all six groups rendering it clinically unacceptable .

Zachrisson [(33)] reported that silane application to sandblasted porcelain did not provide clinically acceptable bond strengths and suggested abandoning this technique. Whereas, Kocadereli et al [(6)] and Schmage et al [(32)] suggested the application of silane after sandblasting as an efficient method to improve the bond strength to porcelain surfaces. This can be attributed to the differences in AL2O3 particle size that used application period and the type of silane primer in each study.

Gp.VI (SHS) showed the highest mean value (6.5 ± 1.3 Mpa) of shear bond strength among the sandblasting groups as well as among all the six groups in addition to that statistically there is highly significance difference between this group and group IV &V. Since the mean value of this group is within the optimal range (6-8 Mpa) rendering it clinically acceptable.

Ajlouni et al [(19)] advocated that the most reliable procedure for bonding orthodontic brackets to porcelain surfaces is through sandblasting with the use of hydrofluoric acid and silane coupling agent. Whereas Turkkahraman and Kucukesmen [(34)] who found that sandblasting before hydrofluoric acid and silane application did not significantly increase the bond strengths advocating no contribution of sandblasting was found when the porcelain surface was treated with hydrofluoric acid and silane primer, showing that the most significant factor in bond strength of orthodontic brackets to porcelain surfaces is etching with hydrofluoric acid.

The result of this group can be attributed to effect of micro etching with AL2O3 particles by producing a uniform peeling of porcelain with deeper penetration and more undercuts in addition to the effect of hydrofluoric acid etching on porcelain which is just similar to that produced by phosphoric acid on enamel by producing a uniform depth in penetration as determined by scanning electron microscopy.[(35)] Consequently the combination of air- abrasion and hydrofluoric acid will produced a more penetration and more undercuts corroborating to shear bond strength values as the bond strength gradually increase because of gradual increase in roughening of porcelain.

In present study it obviously clear that the mechanical roughening by sandblasting before application of hydrofluoric acid and silane coupling agent significantly increase the bond strength when compared with Hydrofluoric Acid and Silane Coupling Agent Group (6.5 ± 1.3 Mpa & 3.9 ± 0.9 Mpa, respectively) of mean values of shear bond strength indicating that the combination of mechanical and chemical roughening with silane application is recommended to achieved clinically adequate bond strength for orthodontic attachments to endure a course of orthodontic treatment.

Concerning the adhesive remnant index scores which give the indication about the type of bond failure for each group.

The occurrence of ARI score 3 were (Group I = 100 % ; Group II = 100 % ; Group III =100 % ; Group IV= 100 % ; Group V=100% & Group VI= 20%) and ARI score 2 only in 80% of Group VI.

The ARI score 3 indicate failure at adhesive-porcelain interface, since the bond failure occurs usually at the area of least resistance which means that the bond strength between the adhesive–bracket interface and the cohesive bond strength of the adhesive itself were stronger than the bond strength between the adhesive and porcelain. Smith et al [(36)] found that adhesive-porcelain interface failure, score 3 is desirable, because the problem of residual adhesive is not encountered.

The ARI score 2 indicate cohesive failure within the adhesive itself, with some of the adhesive remained on the porcelain surface and some remained on the bracket base, this mean that the adhesive bond to the bracket base and to porcelain restoration were greater than the cohesive bond within the adhesive itself. Harari et al [(29)] and Sarac et al[(18)] reported that cohesive failure within the adhesive itself, score 2 is preferred to avoid porcelain fracture during debonding which clinically indicates the long-term integrity of the porcelain restorations.

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