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ORIGINAL RESEARCH

Comparison of Shear Bond Strength of Metal Brackets Bonded to Porcelain Surface using Different Surface Conditioning Methods: An *in vitro* Study

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ABSTRACT

Aim: To evaluate and compare the shear bond strength of metal brackets bonded to ceramic surfaces using different conditioning methods and to assess the site of bond failure after debonding.

Materials and methods: A total of 70 ceramic surfaces were produced with uniform shape, size and composition. The samples were divided into 7 groups (each of 10 samples).

Group 1 was the control group (untreated surface); in group 2 the surface were roughened with a diamond bur; in group 3 the surface were etched with hydrofluoric acid; in group 4 the surfaces were sandblasted; in group 5 the surfaces roughened with bur and silane applied; in group 6 the surfaces were etched with hydrofluoric acid and silane applied and in group 7 the surfaces were sandblasted and silane applied.

To all the above groups, metal orthodontic brackets were bonded with light cure adhesive. The brackets were later stored in artificial saliva and incubated at 37°C (24 hours). The samples were then subjected to shear bond strength test using an Instron universal testing machine. The debonded porcelain surfaces were then studied under stereomicroscope to assess site of bond failure.

Results: Sandblasting the ceramic surface and silane application showed the highest bond strength. Stereomicroscope examination after debonding showed that the bond failure is at bracket-adhesive interface in four groups namely hydrofluoric acid, sandblasting, hydrofluoric acid with silane and sandblasting with silane.

Conclusion: Sandblasting with silane combination produced the highest shear bond strength, so it is a clinically suitable method for bonding orthodontic metal brackets onto ceramic surface.

Clinical relevance: Bonding orthodontic brackets to ceramic crowns of patients has been a tough task. In this study, different conditioning methods were used to treat the ceramic surfaces before bonding. The results showed that sandblasting the ceramic surface prior to application of silane produced the highest shear bond strength which is clinically suitable to reduce bond failures.

Keywords: Dental porcelain, Orthodontic bracket, Shear strength, Metal ceramic alloys, Dental debonding.

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INTRODUCTION

Many patients seeking orthodontic treatment have teeth restored with porcelain crowns or laminates. Therefore, bonding orthodontic attachments to porcelain is becoming a common procedure.[1] Ceramic and metal-ceramic restorations are widely used for restoring damaged or missing teeth to enhance the esthetics of the natural dentition. Particularly in adults, there is an increased likelihood that orthodontic brackets have to be fitted to patients who have porcelain surfaces on some crowns or veneers.

Many ceramics are marketed for use as dental crown and bridge materials. The types range from traditional hand-condensed jacket crown porcelains with or without alumina reinforcement to porcelains for metal-bonding, pressure-formed ceramics, castable glasses and new all-ceramic single crowns.[2] Because classifications may vary between reports, the characterization of dental ceramics as feldspathic porcelains, aluminous porcelains and glass ceramics would appear useful for practical orthodontic purposes.

The orthodontist might not be aware of the type of dental ceramic, whether it is feldspathic porcelain, aluminous porcelain or glass ceramic. It is common to find feldspathic porcelain in ceramic-fused-to-metal restorations.

There have been many advances in the direct bonding of orthodontic attachments to natural teeth, since the pioneering studies of Buonocore in 1955. Recent progress in materials and techniques has shown that direct bonding of orthodontic attachments to surfaces other than enamel is also possible, such as on porcelain surfaces.[3] However, the bond strength of composite resins to ceramic restorations has often been reported to be insufficient.

When bonding to a porcelain surface, maximum bond strength is desired to minimize bond failure during the treatment period. To enhance bracket's bond strength to porcelain, pretreatment of the porcelain preparation is required.

Numerous conditioning methods have been suggested for pretreating ceramic surfaces. Organosilane coupling agents are suggested to enhance bonding of brackets to ceramic. Hydrofluoric acid and acidulated phosphate fluoride are reported to facilitate micromechanical retention, but hydrofluoric acid has been found to be a harmful and irritating compound for soft tissues. Nevertheless, the efficiency of these agents to improve the bracket bonding on ceramics has been well investigated. Although earlier studies have relied on mechanical roughening of the ceramic surfaces, the bond strength of composite resins bonded to such ceramic restorations was unsatisfactory.

Furthermore, mechanical roughening with fine and coarse diamond burs and sandblasting are reported to provoke crack initiation and propagation within the ceramic. Because the restorations generally remain in the mouth after debonding the brackets, damage to the ceramic due to extreme roughening of the surfaces during retreatment or debonding must be avoided. To improve bond strengths of composite resins to ceramics, combinations of different mechanical and chemical conditioning methods are recommended.

Studies have shown that chemical conditioning methods such as silanation increase the adhesion of the composite resin bond to the ceramic.[4] The silica of the dental ceramic is chemically united with the acrylic group of the composite resin through silanation. However, the results obtained in the past studies are contradictory, showing that using silane with hydrofluoric acid does not increase the bond strength.[5]

Few of the drawbacks of the previous studies are that some of them have used denture teeth, which are burned at considerably higher temperatures and have properties that differ significantly from the feldspathic porcelains commonly used for porcelain crowns. Furthermore, most of the earlier studies have not included storage in artificial saliva before the testing.

Hence, the purpose of the present study is to find a clinically useful method of bonding orthodontic metal brackets onto porcelain surfaces. The objectives of the present study are to evaluate and compare the shear bond strength of metal brackets bonded to ceramic surfaces using conditioning methods namely roughening with diamond bur; sandblasting; hydrofluoric acid etching; roughening with diamond bur and application of silane coupling agent; sandblasting and application of silane coupling agent hydrofluoric acid etching and application of silane coupling agent. Another objective is to determine the site of bond failure after debonding the metal brackets from the ceramic surfaces.

MATERIALS AND METHODS

The ceramometal samples were divided into seven groups each comprising of 10 samples (Table 1). The metal orthodontic brackets were bonded onto their surface with a set protocol. (Fig. 1).

The brackets used in the study were maxillary right central incisor for standardization (Gemini Roth Brackets, 3M Company).

In group 1 (control group), the ceramometal samples were cleaned with dry air (oil-free). The Transbond XT Primer (3M Unitek, Monrovia, California) was applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds (Fig. 2).

Table 1: Sample size distribution with ceramometal samples using different surface conditioning methods

Sl no.	*Surface conditioning method*	*Sample size (number)*
1.	Untreated surface (control)	10
2.	Bur	10
3.	Hydrofluoric acid	10
4.	Sandblasting	10
5.	Bur + silane	10
6.	Hydrofluoric acid + silane	10
7.	Sandblasting + silane	10
Total	Overall	70

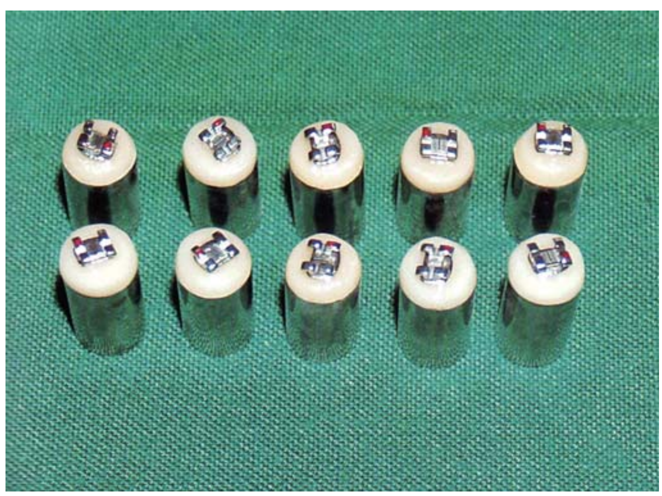

Fig. 1: Brackets bonded on ceramometal samples

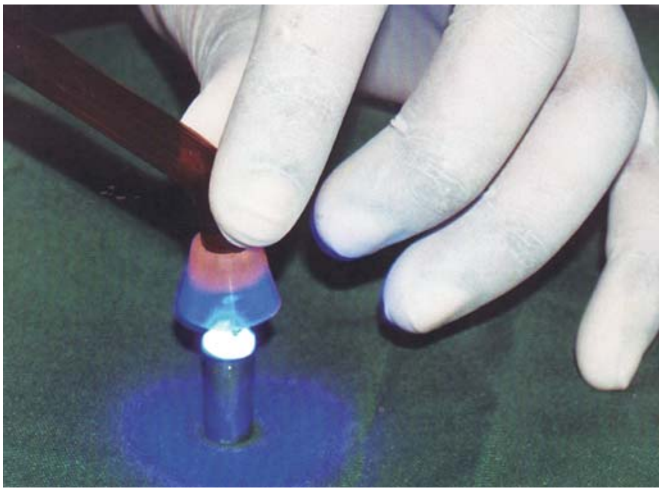

Fig. 2: Light curing brackets

In group 2, the ceramometal samples were cleaned with dry air (oil-free). The ceramic surface was then roughened using a diamond bur (attached to an airotor handpiece with water spray) for 10 seconds. The surface was then dried with oil free air. The Transbond XT Primer (3M Unitek, Monrovia, California) was then applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds.

In group 3, the ceramometal samples were cleaned with dry air (oil-free). A coat of hydrofluoric acid was applied using an applicator tip onto the ceramic surface and then washed after 1 minute using air-water spray. The surface was then dried using dry (oil-free) air. The Transbond XT Primer (3M Unitek, Monrovia, California) was then applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds.

In group 4, the ceramometal samples were cleaned with dry air (oil-free). The ceramic surface is microetched using an intraoral sandblaster (with Aluminum oxide – 50 µ) for 10 seconds. The surface was then air dried. The Transbond XT Primer (3M Unitek, Monrovia, California) was then applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds.

In group 5, the ceramometal samples were cleaned with dry air (oil-free). The ceramic surface was then roughened using a diamond bur (attached to an airotor handpiece with water spray) for 10 seconds. The surface was then dried with oil-free air. A thin coat of silane coupling agent (Ultradent) was applied onto the surface using an applicator tip and allowed to evaporate for 1 minute. After 1 minute if any silane is visible it was dried with dry, oil-free air.

The Transbond XT Primer (3M Unitek, Monrovia, California) was then applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds.

In group 6, the ceramometal samples were cleaned with dry air (oil-free). A coat of hydrofluoric acid was applied using an applicator tip onto the ceramic surface and then washed after 1 minute using air-water spray. The surface is then dried using dry (oil-free) air. A thin coat of silane coupling agent (Ultradent) is applied onto the surface using an applicator tip and allowed to evaporate for 1 minute. After 1 minute if any silane is visible it is dried with dry, oil-free air. The Transbond XT Primer (3M Unitek, Monrovia, California) was then applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds.

In group 7, the ceramometal samples were cleaned with dry air (oil-free). The ceramic surface is microetched using an intraoral sandblaster (with Aluminum oxide – 50 µ) for 10 seconds. The surface is then air dried. A thin coat of silane coupling agent (Ultradent) is applied onto the surface using an applicator tip and allowed to evaporate for 1 minute. After 1 minute if any silane is visible it is dried with dry, oil-free air. The primer (Transbond XT Primer) was then applied using an applicator tip. The Transbond XT adhesive (3M Unitek, Monrovia, California) was applied onto the bracket base and a force of 200 g was applied using a pressure gauge. The excess resin was removed with an explorer and the bracket was light cured using a 3M light curing unit for 20 seconds.

All the samples were placed into metal containers and labeled. The artificial salivary solution was poured into them until the samples were completely submerged in the solution. The samples were then transferred into an incubator and were stored in it for 24 hours at 37°C.

An universal testing machine (Instron 4467, 3M) with a load carrying 0 to 3000 kg was used in the study. A crosshead speed of 1mm/min was used to debond the brackets. The aluminum jig holding the ceramometal sample (with the bonded bracket) was positioned so that the bracket was perpendicular to the long axis of the ceramo-metal sample. A loop was made with 0.5 mm stainless steel wire and the ends were gripped in the upper jaw of the machine. The loop was positioned just under bracket and the specimen was then stressed in a vertical direction at a crosshead speed of 1mm/min, producing a shear force at the ceramic-bracket interface; Fig. 3).

In a similar manner the shear bond strength was recorded for all the 70 samples. A computerized or electronically connected display unit with the test machine recorded the results of each test.

The following variables were evaluated:

1. The amount of shear force required to debond the bracket.
2. The residual adhesive remaining after bracket removal with adhesive remnant index (ARI) index.

Debonding strengths were calculated and recorded in kg/sq centimeters and the following equation was used for conversion to Megapascals:

$$\frac{\text{Debonding force in kg} \times 9.18}{\text{Bracket base area}} = \_\_\_\_ \text{ MPa}$$

The teeth were examined under a stereomicroscope (Fig. 4).

Any adhesive remnants were graded as per Artun and Bergland,[6] which is as follows:

0 – all adhesive removed with bracket.

1 – adhesive remnants covering less than 50% of former bracket site.

2 – adhesive remnants covering more than 50% of former bracket site.

3 – all adhesive left behind on former bracket site with clear imprint of bracket base.

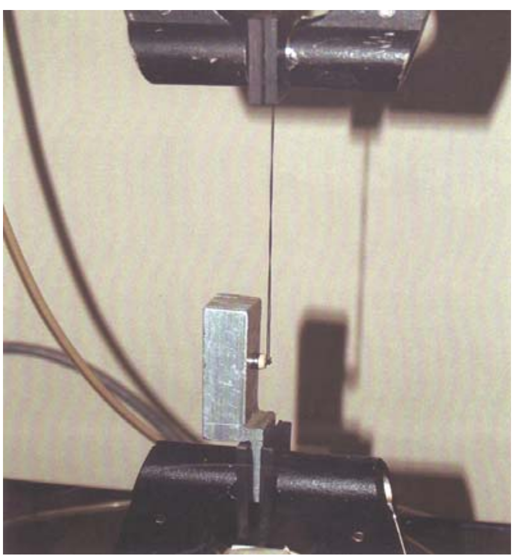

Fig. 3: Testing in universal testing machine

Fig. 4: Stereomicroscope view of ceramic surface (after debonding)

ARI scores were used to assess the site of bond failures on the ceramic—adhesive interface and adhesive-bracket interface.

Statistical Analysis

The results of the various groups were subjected to statistical analysis. The SPSS software version 13.0 was used for the statistical analysis. Descriptive statistics including the mean and standard deviations were calculated for each of the three groups. Analysis of variance was used to determine whether significant differences existed between the various groups.

RESULTS

Sandblasting with silane produced the highest shear bond strength among all the groups and showed a mean value of 15.18 MPa (Table 2). The weakest shear bond strength was seen in the control group with a mean of 1.57 MPa. The statistical results showed that there was a significant difference between all the groups (Table 3).

The stereomicroscope examination of the ceramic surfaces after debonding the brackets showed that the bond failure is at bracket-adhesive interface in four groups namely hydrofluoric acid, sandblasting, hydrofluoric acid with silane and sandblasting with silane suggesting that these methods can produce clinically acceptable bond strengths (Table 4).

Among all the groups sandblasting with silane combination produced the highest shear bond strength, so it a clinically suitable method for bonding orthodontic metal brackets onto porcelain surface.

Table 2: Mean shear bond strength values of all groups after debonding using Instron machine (in MPa)

Group	*N*	*Mean (in MPa)*	*Std. deviation*	*Std. error*	*Minimum*	*Maximum*
Group 1	10	1.5707	0.4129	0.1306	0.83	1.93
Group 2	10	8.396	0.7043	0.2227	7.34	9.34
Group 3	10	8.707	0.3531	0.1117	8.26	9.34
Group 4	10	7.45	0.6345	0.2006	6.28	8.4
Group 5	10	7.764	0.739	0.2337	6.2	8.77
Group 6	10	12.83	0.5645	0.1785	11.76	13.69
Group 7	10	15.179	0.3844	0.1216	14.62	15.8
Total	70	8.8424	4.0689	0.4863	0.83	15.8

Table 3: Statistical analysis: Analysis of variance

	SBS (MPa)				
	Sum of squares	*df*	*Mean square*	*F*	*Sig.*
Between groups	1122.504	6	187.084	593.569	0.000
Within groups	19.857	63	0.315		
Total	1142.361	69			

Table 4: ARI of the debonded ceramic surfaces

ARI value	*Group 1*	*Group 2*	*Group 3*	*Group 4*	*Group 5*	*Group 6*	*Group 7*
0—No adhesive left on the ceramic surface	10	7	2	1	8	2	0
1—less than half of the adhesive left on the ceramic surface	0	3	7	9	2	6	6
2—more than half of the adhesive left on the ceramic surface	0	0	1	0	0	2	4
3—entire adhesive left on the ceramic surface	0	0	0	0	0	0	0

DISCUSSION

Great progress has been made from the early days of EH Angle and Calvin case to the present day orthodontics. There have been many advances in direct bonding of orthodontic attachments to natural teeth, since the pioneering studies of Buonocore in 1955. As a result of increased education and communication, the field of orthodontics has recently expanded to include a greater number of adult treatment; a problem that frequently arises is the placement of appliances on teeth restored with porcelain. Although bands can be placed on single porcelain crowns, it is not acceptable due to esthetic concerns.

When esthetics is a concern, the orthodontists will have to depend on direct bonding techniques. Conventional acid etch technique, however, is not effective in the preparation of porcelain surfaces for mechanical retention of orthodontic attachments.

The use of silanes in bonding to porcelain followed the use of silane materials with some success in laboratory and clinical studies to increase the adhesion to porcelain.

Ceramic crowns may be metal-ceramic or all ceramic crowns. What is important for the orthodontist is the external surface of the crown. They have a glazed or highly polished surface.

Acid etching with phosphoric acid in the fashion used for enamel bonding is ineffective for bonding orthodontic appliances to dental ceramic surfaces, since these ceramics are not attacked by this acid.

Several alternatives surface preparation techniques have been found to achieve satisfactory results: Mechanical roughening with diamond burs, sandblasting, chemical roughening with hydrofluoric acid, a combination of sandblasting and chemical roughening with hydrofluoric acid and chemical coupling with use of silanes.

All the previous studies have not provided a clinically suitable method for bonding orthodontic attachments onto ceramic surfaces. Hence, the aim of the present study was to find a clinically suitable method to condition the porcelain surface prior to bonding orthodontic brackets.

In this study, ceramic surfaces were subjected to various surface conditioning methods namely: Bur, hydrofluoric acid, sandblasting, bur with silane, hydrofluoric acid with silane, sandblasting with silane. Later orthodontic metal brackets were bonded onto these surfaces. The samples were stored in artificial saliva at 37°C for 24 hours. They were then tested for shear bond strength using an Instron machine. The debonded surfaces of the ceramic were then observed under a stereomicroscope to assess the site of bond failure.

The present study shows that sandblasting with silane combination to condition the ceramic surface gives the highest shear bond strength among all the groups which is similar to the results obtained by Abdelnavy YL.[7] The second highest shear bond strength was seen in the group conditioned with hydrofluoric acid and silane combination. This result is concurrent with the results of a study conducted by Schmage P et al.[5]

Zachrisson Y, Zachrisson B and Buyukyilmaz T[2] had conducted a study, in which he concluded that silane application after sandblasting the ceramic surface significantly increases the bond strength of metal brackets bonded to ceramic surface, which is concurrent to the results obtained in our study.

Gillis I and Redlich M[1] had studied the effect of different porcelain conditioning techniques on shear bond strength of metal brackets and their results showed that hydrofluoric acid preparation produced greater bond strengths than diamond bur roughening and sandblasting and their results are concurrent with the results obtained in our study.

A study by Kocaderali I and Canay S[8] showed that porcelain surface treated with hydrofluoric acid followed by silane application resulted in a statistically significant bond strength which is concurrent with results from our study.

Sandblasting the ceramic surfaces produced a mean SBS of 7.45 MPa which is not enough to resist the stresses in the oral cavity especially on ceramic surfaces, the effect of which was shown by Karan et al[9] who found that the lowest shear bond strength values were found in the sandblasted-only samples.

Bishara S et al[10] showed that acceptable bond strengths can be produced by use of hydrofluoric acid with silane coupling agent, which is similar to the results in our study.

Atsu et al[11] showed that in comparison to sandblasting, silica coating with aluminum trioxide particles followed by silanization resulted in higher bond strengths of rebonded brackets.

This study aimed at evaluating a suitable method of bonding orthodontic brackets onto porcelain surface that could help the clinician choose a method that is clinically acceptable. Although sandblasting with silane combination has the potential to replace other methods for orthodontic bonding to porcelain, the forces generated during debonding may cause irreversible damage to porcelain surfaces. Hydrofluoric acid has proven to be a suitable alternative, except that hydrofluoric acid has been found to be a harmful and irritating compound for soft tissues.

The limitations of this study are that the experimental specimens were not subjected to thermocycling. Thermocycling causes differences in thermal expansion coefficients, microleakage which could have affected the bond strength of the metal brackets bonded to porcelain surface. The clinically acceptable bond strengths are in the range of 6 to 8 MPa. In this study, since thermocycling was not done, the results showed shear bond strengths in the range of 6 to 16 MPa.

This study also does not consider the restoration of the porcelain surface to its previous glaze and finish after the debonding was done. Further studies are needed to be done which can simulate the intraoral environment and fulfil the problems of irrepairable damage to the porcelain surface while debonding.

CONCLUSION

The results of this study indicated that among all the groups, sandblasting with silane combination produced the highest shear bond strength, so it a clinically suitable method for bonding orthodontic metal brackets onto ceramic surface. The stereomicroscope examination of the ceramic surfaces after debonding the brackets shows that the bond failure is at bracket-adhesive interface in four groups namely hydrofluoric acid, sandblasting, hydrofluoric acid with silane and sandblasting with silane suggesting that these methods can produce clinically acceptable bond strengths. However, the use of hydrofluoric acid extra care is to be taken because of the harmful effects on the soft tissues, even though it produced good shear bond strength that is clinically acceptable for bonding metal brackets onto ceramic surfaces. Further studies are required to simulate the intraoral environment and fulfil the problems of irrepairable damage to the porcelain surface while debonding.

Clinical Relevance

Bonding orthodontic brackets to ceramic surfaces of patients has been a tough task because of the nature of the glazed ceramic surface. Recent advancements in bonding techniques along with silane application have to some extent solved the problem. In this study, different conditioning methods were used to surface treat the ceramic before bonding the metal brackets onto them. All the samples were subjected to Instron testing machine for shear bond strength. The results showed that sandblasting the ceramic surface prior to application of silane produced the highest shear bond strength which is clinically suitable in order to reduce bond failures.

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