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Original Article

Bonding to a porcelain surface: Factors affecting the shear bond strength

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Abstract

Objectives: Bonding to porcelain veneers, crowns or restorations is a major challenge for an orthodontist. A study was undertaken wherein, the shear bond strengths of metal and ceramic brackets on porcelain were compared and the effects of debonding on the debonded surfaces were evaluated. **Materials and Methods:** A total of 50 acrylic duplicate samples were fabricated from a therapeutically extracted maxillary first premolar, duly prepared for metal crown with porcelain facing. The samples were divided into two equal groups for bonding of metal and ceramic brackets. The shear bond strength of the samples was measured with a universal testing machine. **Results:** The metal brackets showed shear bond strengths with a mean of 12.21 ± 1.4 MPa, whereas the ceramic brackets displayed shear bond strengths with a mean of 17.45 ± 2.36 MPa. Visual and scanning electron microscope examination revealed multiple failure patterns with more of porcelain fractures in the ceramic brackets group. **Conclusion:** Bonding of metal and ceramic brackets to porcelain can be achieved with bond strengths comparable to that when bonded to enamel surface. Porcelain fractures are more commonly associated with debonding of ceramic brackets.

Key words: Ceramic brackets, metal brackets, scanning electron microscope, universal testing machine

INTRODUCTION

The need to bond orthodontic brackets to a surface other than enamel has become more common as the number of adult patients seeking orthodontic treatment is steadily increasing. Orthodontists are more likely to bump into the problem of placing orthodontic attachments on teeth restored with porcelain crowns, bridges, veneers or laminates, amalgam and composite restorations. Recent progress in materials and techniques has shown that direct bonding to dental restorations is also possible.

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Conventional acid etch technique is ineffective in the preparation of porcelain surfaces for mechanical retention. Research has now made it possible to achieve direct bonding to porcelain surface using 9.6% hydrofluoric acid[1,2] for etching and silanes[3-5] for chemical bonding. It is imperative to achieve optimum bond strength as brackets attached to such restorations experience various torsional forces through orthodontic treatment and mastication. At the same time, it is crucial not to achieve an extremely high bond strength, which may damage the porcelain surface at the time of debonding.

The orthodontic attachments primarily comprise of brackets, which may be made up of metal, ceramic, polycarbonate and composite. The mechanical interlocking for metal brackets is provided by a meshwork brazed at their back, whereas a ceramic bracket has a surface that is lopsided. Even though, bonding of orthodontic attachments to enamel has

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been tested time and again; very less research has been conducted on bonding to porcelain surface.[6-9] Hence, a study was carried out to test and compare the shear bond strengths of metal and ceramic brackets bonded to metal crowns with porcelain facing and evaluate the porcelain surface and bracket base after debonding through visual and scanning electron microscopic (SEM) examination.

MATERIALS AND METHODS

A therapeutically extracted human maxillary premolar tooth was procured and crown reduction done for metal crowns with porcelain facings. Rubber base impressions (Express XT, 3M ESPE, USA) of the prepared tooth was made including the base. Clear self-cure acrylic was poured into each impression and 50 acrylic duplicates of the prepared tooth were procured. 50 wax patterns of the teeth were prepared for the metal coping, which had flat lingual facet to facilitate the samples to be observed under SEM. The wax patterns were then invested in casting ring following which metal casting was done (Dispersalloy, Dentsply International, USA). The buccal surface of the metal coping was sandblasted using 50 micron aluminium oxide. Subsequently, porcelain (Ceramco 3, Dentsply International, USA) was fired onto the buccal surface of the metal coping. The porcelain surface was trimmed so that the final thickness at the area of bonding of a bracket was maintained at 1.5 mm to maintain uniformity. Finally, the porcelain surface was glazed using the overglaze (Ceramco 3, Dentsply International, USA) and the metal surface was polished.

The sample was divided into metal bracket group (25) (0.022 Roth prescription Elite Opti MIM, Ortho Organizer, USA) and ceramic bracket group (25) (0.022 Roth prescription Illusion Plus, Ortho Organizer, USA). 9.6% Hydrofluoric acid gel (Porcelain etch gel, Pulpdent, USA) was used for conditioning of porcelain surface. Silane coupling agent (Relyx, 3M ESPE, USA), adhesive primer (Transbond XT, 3M Unitek, USA) and light cure adhesive (Transbond XT, 3M Unitek, USA) were utilized for bonding. The adhesive was cured using tungsten halogen curing light with an intensity of 400 mW/cm^2. Brackets were bonded at a height of 4 mm from cusp tip. The samples, with a lapse of 5 min subsequent to bonding, were stored in a dark container for 24 h at 37°C, as per the recommendation of International Organization for Standardization (ISO).[10]

The samples were subjected to shear bond strength testing on a universal testing machine (Lloyd's Instruments, West Sussex,UK) capable of delivering a controlled and measured force to the bonded brackets through a movable crosshead having a speed of 1 mm/min. The bond strength was recorded in Newtons and was converted to Megapascals (1 MPa = 1 N/mm^2), as suggested by ISO (1991).

Six samples comprising of three samples from each group were selected on random basis and were viewed under SEM. The glazed and etched porcelain specimens and the bracket base were examined.

RESULTS

The shear bond strengths of metal and ceramic brackets bonded to porcelain crowns were measured. The data was put to statistical analysis. The metal brackets showed shear bond strengths ranging from 8.94 MPa to 13.89 MPa with a mean of 12.21 ± 1.4 MPa. The ceramic brackets displayed shear bond strengths ranging from 12.3 MPa to 20.9 MPa and a mean of 17.45 ± 2.36 MPa [Table 1].

The coefficient of correlation between the two groups was very weak (r = 0.2310). A Student t-test was performed to check the correlation coefficient at both 1% and 5% level of significance, which was also weak (t = 0.469). An unpaired t-test showed statistically significant difference between the shear bond strengths of metal and ceramic brackets; t calculated (t_{cal}) > t tabulated (t_{tab}) [Table 2].

Failure pattern

After debonding, multiple failure patterns were observed, which were assigned adhesive remnant index scores (ARI).[11] There were more cohesive failures (13)

Table 1: Mean shear bond strength of metal and ceramic brackets

Group	Mean (MPa)	Standard deviation (MPa)	Range (MPa)
Metal brackets	12.21	1.4	5.03
Ceramic brackets	17.45	2.36	8.6

MPa = Mega pascal

Table 2: Comparison of shear bond strengths of metal and ceramic brackets (unpaired *t* test)

Group	Mean±SD (MPa)	t_{cal}	$t_{tab\ (2,\ 0.05)}$	$t_{tab\ (2,\ 0.01)}$
Metal brackets	12.21	−9.5377*	1.714	2.500
Ceramic brackets	17.45			

*Statistically significant; t_{cal} = t calculated; t_{tab} = t tabulated; SD = Standard deviation within adhesive and less failures (3) at the bracket/adhesive interface in the metal brackets group. Ceramic brackets group had more (17) of cohesive failures within porcelain, whereas no adhesive failure at the porcelain/adhesive interface [Table 3].

The SEM revealed a smooth surface of the glazed porcelain [Figure 1] and micro-porosities on the porcelain surface etched with 9.6% hydrofluoric acid [Figure 2].

Table 3: Comparison of failure pattern in metal and ceramic brackets with the ARI scores

Metal brackets (25)		Ceramic brackets (25)	
Cohesive failures	**Adhesive failures**	**Cohesive failures**	**Adhesive failures**
52% within the adhesive (ARI scores 1 and 2)	12% porcelain/adhesive interface (ARI score 0)	20% within adhesive (ARI scores 1 and 2)	0% porcelain/adhesive interface (ARI score 0)
32% within porcelain	4% bracket/adhesive interface (ARI score 3)	68% within porcelain	12% bracket/adhesive (ARI scores 2 and 3)

ARI = Adhesive remnant index

The SEM views of cohesive failure within the adhesive and porcelain [Figures 3 and 4] were also observed along with SEM photomicrographs of the base of metal bracket. They illustrated an adhesive failure at the porcelain-adhesive interface [Figure 5]. Furthermore, the base of ceramic bracket illustrated cohesive failure within the adhesive at ×10 magnification [Figure 6].

DISCUSSION

Bonding of orthodontic attachments onto the porcelain surface has been researched extensively. The literature[6-9] has highlighted numerous factors other than surface preparation, affecting the bond strength of orthodontic attachments to porcelain, but very few researchers including Cochran *et al*.[3] have pointed

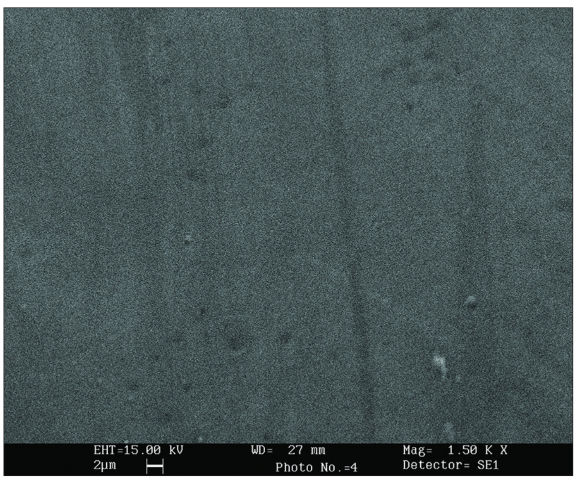

Figure 1: Scanning electron microscope view of glazed porcelain

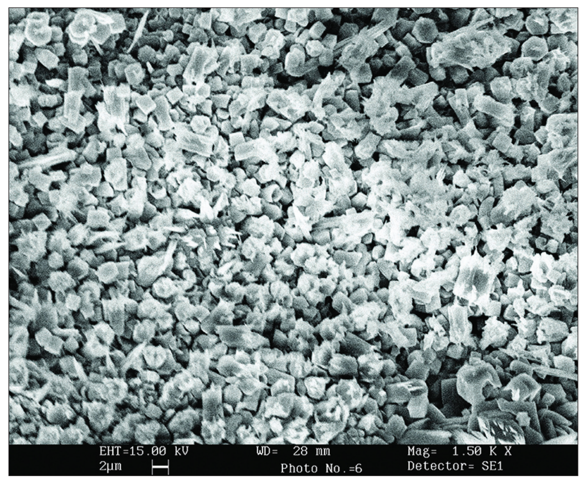

Figure 2: Scanning electron microscope view of etched porcelain

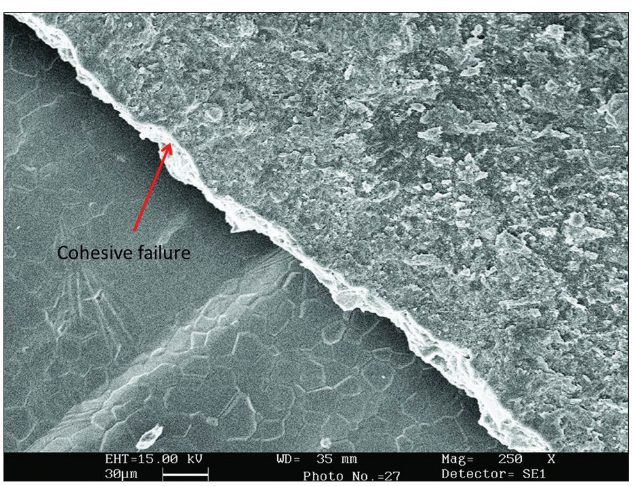

Figure 3: Cohesive failures within adhesive

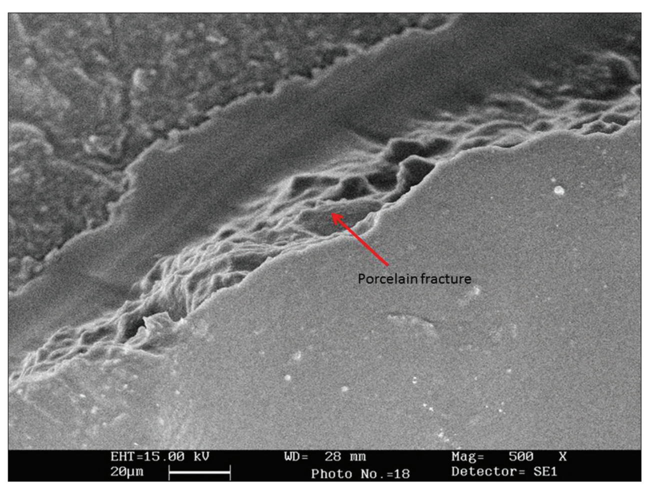

Figure 4: Cohesive failures within porcelain

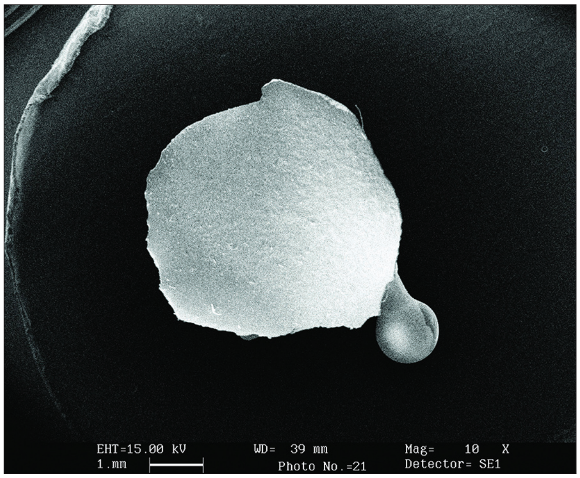

Figure 5: Metal bracket representing adhesive failure at porcelain-adhesive interface

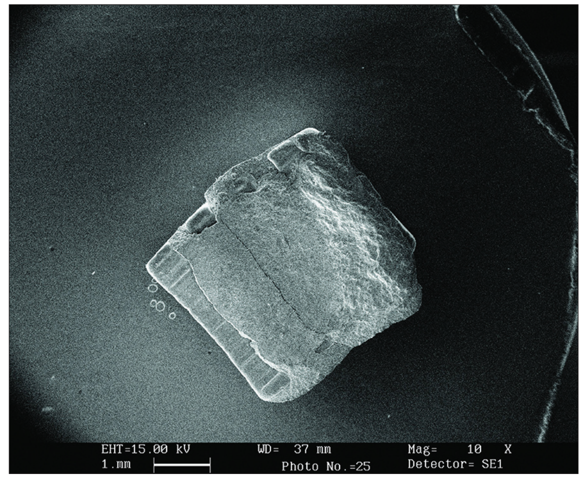

Figure 6: Ceramic bracket representing cohesive failure within adhesive

out the difference in the effects of bonding metal and ceramic brackets on the porcelain surface.

A sample size of 50 was selected so as to have statistically valid results. Feldspathic porcelain was utilized for crown preparation, which had characteristic external contour perfectly fitting the base of metal and ceramic brackets. This was essential to maintain a constant thickness of adhesive, which could be an important determinant of bond strength.[12]

Porcelain surface roughening procedures such as abrasion, sand paper, discs, stones and burs were avoided as they were found to be unsatisfactory. Furthermore, they would have resulted in cracks on the porcelain surface, which would have propagated further to cause cohesive failure.[6,7] Hydrofluoric acid was selected for etching at the most appropriate concentration of 9.6% applied for 2 min, a regime followed by most of the researchers world over including Zachrisson *et al*.,[6] Türk *et al*.[13] and Türkkahraman and Küçükeşmen[14]. The depth of porcelain etching with 9.6% hydrofluoric acid was estimated to be in the range of 5-7 microns by Yen *et al*.[15] which is adequate for sufficient retention. Silane was used as a primer as it is capable of displacing the adsorbed water from the porcelain surface, thus increasing the wetting and penetration of resin into micro-porosities of porcelain surface. In addition, silane functions to provide a chemical link between oxide groups in porcelain and polymer molecules of the resin.[16]

The shear bond strength of metal brackets had a mean of 12.21 MPa ± 1.4 MPa, which was close to the findings of Major *et al*.[16] and slightly higher than that of a study done by Karan *et al*.[9] where the mean was found to be 10.5 ± 6.0 MPa.

The failure pattern of debonded metal brackets was studied through visual inspection and SEM. Nearly 32% cohesive failures were found within porcelain and 52% cohesive failures within adhesive (ARI Scores 1 and 2). 12% adhesive failure were seen at the porcelain/adhesive interface (ARI Score 0) and 4% adhesive failure at the bracket/adhesive interface (ARI Score 3). Cohesive failure in the ceramic material could indicate that the bond between the adhesive resin and the ceramic was stronger than the ceramic itself. Thurmond *et al*.[17] reported that, when bond strength values between the ceramic and the composite resin exceeded 13 MPa, there would be cohesive fractures in the ceramic material. Similarly, Karan *et al*.[9] in their research reported 22% porcelain fractures and 36% cohesive failures within adhesive (ARI Scores 1 and 2).

The shear bond strength on debonding of ceramic brackets from porcelain surface ranged from 12.3 MPa to 20.9 MPa with a mean of 17.45 ± 2.36 MPa. There were cohesive failures within porcelain in 68% and within the adhesive in 20% of the samples (ARI Scores 2 and 3), 12% adhesive failures at porcelain/bracket interface and no failure at porcelain/adhesive interface. It was clearly seen that ceramic brackets had more frequent porcelain surface fractures as reported earlier by Zelos *et al*.[8] Türkkahraman and Küçükeşmen[14] reported in their study that the shear bond strength of ceramic brackets had a mean of 11.38 ± 1.65 MPa, fairly less than our results, which might be because of the thermocycling of samples that reduces bond strengths.

There was a significant difference in the shear bond strengths of metal and ceramic brackets in the study, similar to the findings of Cochran *et al*.[3] It may be because of the difference in the bracket base design of the two brackets. Winchester[18] had observed higher shear bond strength values in the shear/peel testing than in tensile/peel testing for different ceramic brackets indicating that brackets with a dovetail design base better resist shear/peel than tensile/peel forces. Unidirectional shear debonding forces caused maximum porcelain fractures when compared with tensile or peeling forces as suggested by Zelos *et al*.[8] Furthermore, silane coupling agent helped in achieving bond strength far beyond the clinically acceptable limits whenever ceramic brackets were used.[3]

CONCLUSION

Bonding of metal and ceramic brackets to porcelain can be achieved with bond strengths comparable to that when bonded to enamel surface. Ceramic brackets displayed greater mean shear bond strengths when compared with metal brackets.

The results of SEM show more cohesive failures within the adhesive in metal brackets group, whereas more cohesive failures within porcelain in ceramic brackets group. Porcelain fractures were more commonly associated with debonding of ceramic brackets. Therefore, unidirectional shear forces are not recommended for debonding of ceramic brackets when bonded to porcelain surface.

Further research is recommended for the evaluation of the effects of long-term water storage and thermocycling of the samples. It is also recommended to compare bond strength of metal and ceramic brackets bonded to porcelain in a shear and tensile mode.

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