Original Article

Shear Bond Strength of Ceramic Brackets with Different Base Designs to Feldspathic Porcelains

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ABSTRACT

Objective: To test the hypothesis that the there is no difference between the shear bond strengths of different base designs of ceramic brackets bonded to glazed feldspathic porcelains.

Materials and Methods: Forty glazed feldspathic porcelain specimens (15 mm in diameter and 1.5 mm in thickness) were prepared and divided into 4 groups ($n = 10$). Ten pieces of each group of different ceramic bracket base designs (beads, large round pits, and irregular base) and one group of stainless steel brackets (served as a control) were bonded to glazed feldspathic porcelains under a 200 gram load. Then all samples were subjected to shear bond strength evaluation with a universal testing machine at a crosshead speed of 0.2 mm/min. Data were analyzed through one-way ANOVA and Tukey's HSD test at a .05 significance level. The mode of failure after debonding was examined under a stereoscope.

Results: This study revealed that the beads base design had the greatest shear bond strength (24.7 ± 1.9 MPa) and was significantly different from the large round pits base (21.3 ± 2 MPa), irregular base (19.2 ± 2.0 MPa), and metal mesh base (15.2 ± 2.4 MPa). The beads base design had 100% porcelain-adhesive failure, the large round pits had 100% bracket-adhesive failure, and the irregular base design had 70% combination failure and 30% porcelain-adhesive failure.

Conclusions: The hypothesis is rejected. The various base designs of metal and ceramic brackets influence bond strength to glazed feldspathic porcelain, but all should be clinically acceptable. (*Angle Orthod.* 2009;79:571–576.)

KEY WORDS: Base design; Ceramic bracket; Debonding; Porcelain; Shear bond strength

INTRODUCTION

Ceramic orthodontics brackets were introduced in 1987 as a more esthetically pleasing alternative to the stainless steel bracket.[1] All currently available ceramic orthodontics brackets are composed of aluminium oxides,[2,3] which confer many advantages such as biocompatibility, good esthetics, resistance to temperature and chemical changes, and bond strength that is greater than or equal to that of stainless steel brackets.[4–11] Two types of ceramic brackets are available, and these are classified according to their distinct differences during fabrication, that is, as polycrystalline and monocrystalline (single-crystal) aluminas.[12–14]

The polycrystalline aluminas are made of sintered or fused aluminium oxide particles. These aluminium oxide particles are blended with a binder, and the mixture is formed into a shape from which a bracket can be machined. Temperatures above 1800°C are used to burn out the binder and fuse together the particles of the molded mixture. The particles then are heat-treated to remove surface imperfections and stresses created by the cutting operation. The monocrystalline aluminas also are manufactured from aluminium oxides. Aluminium oxides are heat-treated to temperatures in excess of 2100°C and then are cooled slowly to permit complete crystallization. This process minimizes the stress-inducing impurities and imperfections found in polycrystalline aluminas.[4]

Both polycrystalline and monocrystalline ceramic brackets have various base designs such as grooves, beads, or round pits for the purpose of mechanical interlocking between the brackets and the teeth. In addition, they provide chemical bonding with the silanes.

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Silanes (gamma-methacryloxyprophyl-trimethoxysilane) are coupling agents that have been developed for bonding glass fillers to polymers and increasing the wettability of the porcelain surface.[15,16] In most studies, silanes successfully increase adhesion of the resin composite to the porcelain surface.[16–24] However, conflicting results have been reported regarding the efficacy of silane coupling treatment in improving the bond strength between resin composite and porcelain.[25–28] Additionally, it is recommended that only fresh silanes be used because aged silanes can compromise bond strength.[29]

Hydrofluoric acid shows good bond strength and is widely recommended and used for porcelain surface modification.[30,31] However, hydrofluoric acid is considered a hazardous agent that can produce tissue rash and burns, resulting in deep tissue necrosis.[32] During intraoral use of hydrofluoric acid, special precautions must be taken. On the other hand, phosphoric acid at 37% concentration is not toxic or corrosive and achieves satisfactory bond strength.[33]

With the increased demand for adult orthodontics treatment, porcelain-fused-to-metal restorations are often present, and the orthodontist must bond orthodontic brackets to porcelain restorations. Clinically adequate bond strength for a metal orthodontic bracket to enamel ranges from 6 to 8 MPa.[21,34,35] Optimal bracket adhesion to a porcelain surface requires that orthodontic forces be applied without bond failure during treatment, and that porcelain integrity not be jeopardized during the debonding procedure. Unfortunately, little is known about the bond strengths of various ceramic bracket base designs when bonded to porcelain restorations.

The null hypothesis of this study was that there was no difference in the shear bond strengths of different base designs of ceramic brackets bonded to glazed feldspathic porcelains. Therefore, the objectives were (1) to evaluate the shear bond strengths of different ceramic bracket base designs to glazed feldspathic porcelains, and (2) to examine the mode of failure and debonding characteristics after bond failure.

MATERIALS AND METHODS

Forty samples of glazed feldspathic porcelain disks were produced according to the manufacturer's instructions. Feldspathic porcelain powder (Vita VMK 95, Shade A3, Vita Zahnfabrik, Bad Sackingen, Germany) was mixed with deionized water and was condensed into a round silicone mold (Provil, Haraeus Kulzer, Wehrheim, Germany), 15 mm in diameter and 1.5 mm in thickness. The mixture was left to dry for 2 minutes before it was heated to 600°C for 360 seconds in a vacuum furnace (Tru-Fire, Jelenko, Armonk, NY). The temperature then was increased at 38°C/min to 960°C and was held for 60 seconds.

Sintered feldspathic porcelain disks with a final diameter of 13.31 to 14.02 mm (6.53% to 11.27% shrinkage) were polished (Model Phoenix 4000, Buehler GmbH, Düsseldorf, Germany) under running water with the use of 600- and 1200-grit silicon carbide paper (3M ESPE, St Paul, Minn). The feldspathic porcelain disks then were autoglazed by heating to 960°C for 120 seconds in a furnace, according to the manufacturer's instructions.

Subsequently, the disks were embedded in autopolymerizing clear acrylic resin (Takilon, Rodont SRL, Milan, Italy), 20 mm in height and 30 mm in diameter. The specimens were randomly divided into four groups of 10 for bonding with three groups of ceramic brackets that had various base designs. One group of stainless steel brackets served as a quasi-control (Figure 1 and Table 1).

The porcelain surfaces were etched with 37% phosphoric acid solution (Etching Solution, Ormco/Sybron Dental Specialties, Glendora, Calif) for 60 seconds, and a thin coat of porcelain primer (Porcelain Primer, Ormco/Sybron) was applied twice with a microbrush for 10 and 60 seconds, respectively. The disks then were rinsed with a water spray for 15 seconds and were thoroughly air-dried. System 1+ liquid activator (Ormco/Sybron) was applied to both the porcelain surfaces and the bracket bases, and System 1+ paste (Ormco/Sybron) was applied to the activated bracket bases. The brackets then were positioned on the porcelain disks, and 200 grams of pressure was applied to the brackets. Excess adhesive was removed with a sharp scaler, and the adhesive was allowed to completely polymerize for 10 minutes. Finally, all specimens were stored in an incubator (Memmert, Model BE500, Memmert GmbH, Schwabach, Germany) at 37°C at 100% humidity for 24 hours before testing.

The shear bond strength of the brackets adhering to the porcelain disks was tested to failure parallel with the use of a customized single-blade jig to the disk face in an Instron Universal Testing Machine (Model 5583, Instron, Norwood, Mass) at 0.2 mm/min. The load at failure was recorded and converted to shear bond strength in MPa (force per surface area of the bracket base). The bracket bond area was determined by measuring the width and length of the bracket base with a digital caliper (Mitutoyo, Tokyo, Japan) and calculating to determine the area. The surfaces of the specimens were subsequently examined under a stereoscope (Model SMZ 1500m, Nikon Instech, Kanagawa, Japan) by one observer to determine the mode of failure. For determination of the mode of failure, each sample was recorded as one of the following failure types (as modified from Bordeaux et al[12]):

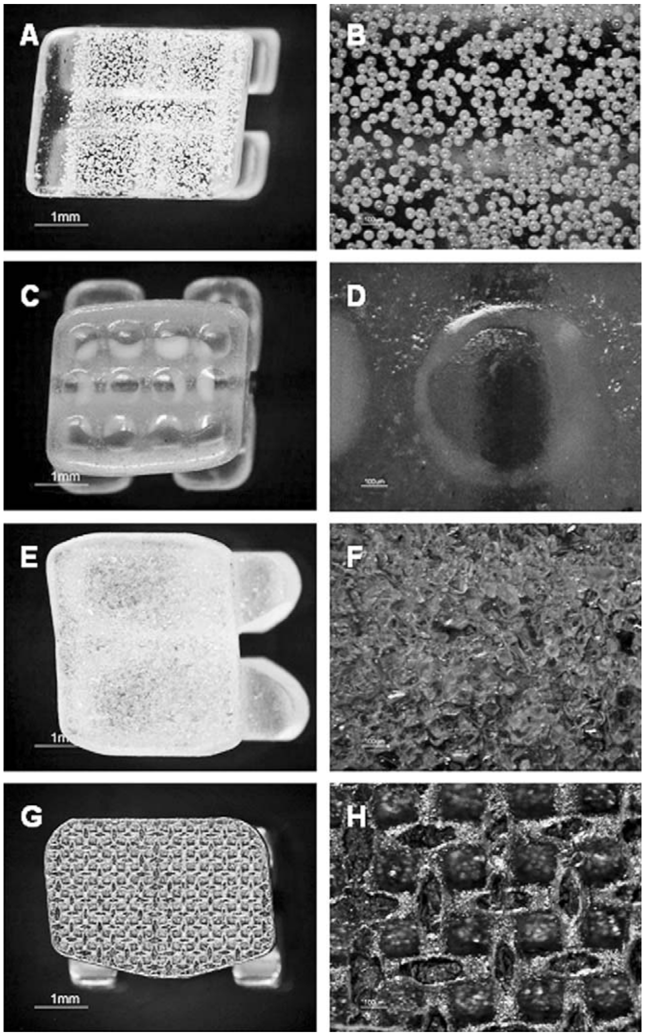

Figure 1. Base designs of ceramic brackets (×20 and ×100, respectively). (A and B) Beads base (Inspire ICE). (C and D) Large round pits base (Crystalline IV). (E and F) Irregular base (Clarity). (G and H) Mesh base (Optimesh XRT).

- Type 1: Failure at the adhesive–bracket base interface. Ninety percent or more of the bracket pad was exposed, and 10% or less of the bonded porcelain was free of adhesive.
- Type 2: Combination failure at the adhesive–bracket base interface and the porcelain-adhesive interface. Less than 90% but more than 10% of the bracket pad was exposed, or more than 10% but less than 90% of the bonded porcelain surface was free of adhesive.
- Type 3: Failure at the porcelain-adhesive interface. Ten percent or less of the bracket pad was exposed, and 90% or more of the bonded porcelain was free of adhesive.
- Type 4: Failure of the bracket itself. Fracture of the bracket during removal left a portion of the bracket still bonded to the porcelain.
- Type 5: Failure of the porcelain itself. A portion of the porcelain was removed along with the bracket base without loss of more than 10% of the adhesive from the bracket pad.

Data were statistically analyzed with the Statistical Package for the Social Sciences (SPSS), version 15 (SPSS Inc, Chicago, Ill). One-way analysis of variance (ANOVA) was used to find differences between groups. Tukey's Honestly Significant Differences (HSD) tests were used for post hoc comparisons ($\alpha = .05$).

Table 2. Mean Shear Bond Strength in MPa and Standard Deviation Among Different Base Designs of Ceramic Brackets

Ceramic Bracket (Manufacturer)	Base Design	Shear Bond Strength, MPa	Tukey Group[a]
Inspire ICE (Ormco/Sybron)	Bead	24.7 ± 1.9	A
Crystalline IV (Tomy)	Large round pit	21.3 ± 1.0	B
Clarity (3M Unitek)	Irregular	19.2 ± 2.0	B
Optimesh XRT (Ormco/Sybron)	Mesh	15.2 ± 2.4	C

[a] Groups marked with different upper case letters were significantly different ($P < .05$).

RESULTS

Mean shear bond strength values between ceramic brackets and feldspathic porcelains at fracture with their standard deviations (SDs) are presented in Table 2. Analysis of variance (ANOVA) and Tukey's HSD showed significant differences among groups ($P = .01$). The control group (stainless steel brackets) yielded the lowest mean shear bond strength and SD value (15.2 ± 2.4 MPa) ($P = .01$). Inspire ICE (beads base design) produced the greatest mean shear bond strength (24.7 ± 1.9 MPa) ($P = .01$). No significant

Table 1. Identification of Brackets Used in This Study

Name of Ceramic Bracket	Manufacturer	Type	Base Design	Area of Surface, mm²
Inspire ICE	Ormco/Sybron Dental Specialties, Glendora, Calif	Monocrystalline alumina	Bead	11.50
Crystalline IV	Tomy, Tokyo, Japan	Polycrystalline alumina	Large round pit	10.05
Clarity	3M Unitek, Monrovia, Calif	Polycrystalline alumina	Irregular	10.55
Optimesh XRT	Ormco/Sybron Dental Specialties, Glendora, Calif	Stainless steel	Mesh	11.71

Table 3. Mode of Failure After Shear Bond Strength Testing

Ceramic Bracket (Manufacturer)	Type of Failure					Total
	1	2	3	4	5	
Inspire ICE (Ormco/Sybron)	0	0	10	0	0	10
Crystalline IV (Tomy)	10	0	0	0	0	10
Clarity (3M Unitek)	0	7	3	0	0	10
Optimesh XRT (Ormco/Sybron)	0	10	0	0	0	10

Type 1: Failure at the adhesive–bracket base interface. Ninety percent or more of the bracket pad was exposed, and 10% or less of the bonded porcelain was free of adhesive.

Type 2: Combination failure at the adhesive–bracket base interface and the porcelain-adhesive interface. Less than 90% but more than 10% of the bracket pad was exposed, or more than 10% but less than 90% of the bonded porcelain surface was free of adhesive.

Type 3: Failure at the porcelain-adhesive interface. Ten percent or less of the bracket pad was exposed, and 90% or more of the bonded porcelain was free of adhesive.

Type 4: Failure of the bracket itself. Fracture of the bracket during removal left a portion of the bracket still bonded to the porcelain.

Type 5: Failure of the porcelain itself. A portion of the porcelain was removed along with the bracket base without loss of more than 10% of the adhesive from the bracket pad.

differences were noted between Crystalline IV (large round pits base design) and Clarity (irregular base design) ($P = .15$).

Table 3 and Figure 2 show the predominant site of bond failure after the debonded surface was examined with a stereoscope. None of the specimens evaluated in this study was found to display any cracks or fractures of the brackets or porcelain surfaces (type 4 and 5).

DISCUSSION

The null hypothesis was rejected because the present study showed that the shear bond strength of ceramic brackets bonded to feldspathic porcelain was greatly affected by base design. The beads base design (Inspire ICE) resulted in the greatest shear bond strength, followed by the large round pits design (Crystalline IV) and the irregular base design (Clarity). The mesh base of stainless steel brackets showed the least shear bond strength, which corresponds with the findings of previous studies.[4–11]

Base design characteristics were the reason for these results. Irregular bases incorporate small glass particles fused to the polycrystalline alumina to increase the surface area for adequate bonding, according to the manufacturer's intentions. However, these glass particles might not have adequately adhered to the alumina base, or mechanical retention of the adhesive resin may be inadequate to allow penetration to the rough base surface.[36] Likewise, large round pit base designs with about 12 pits of 1 mm diameter in a single bracket surrounded by a flat surface (Figure 1C and D) had no undercut for mechanical interlocking of adhesive resin. These results were shown with type 1 bond failure (adhesive-bracket failure). So the shear bond strength of irregular and large round pit base designs showed no significant difference ($P = .15$).

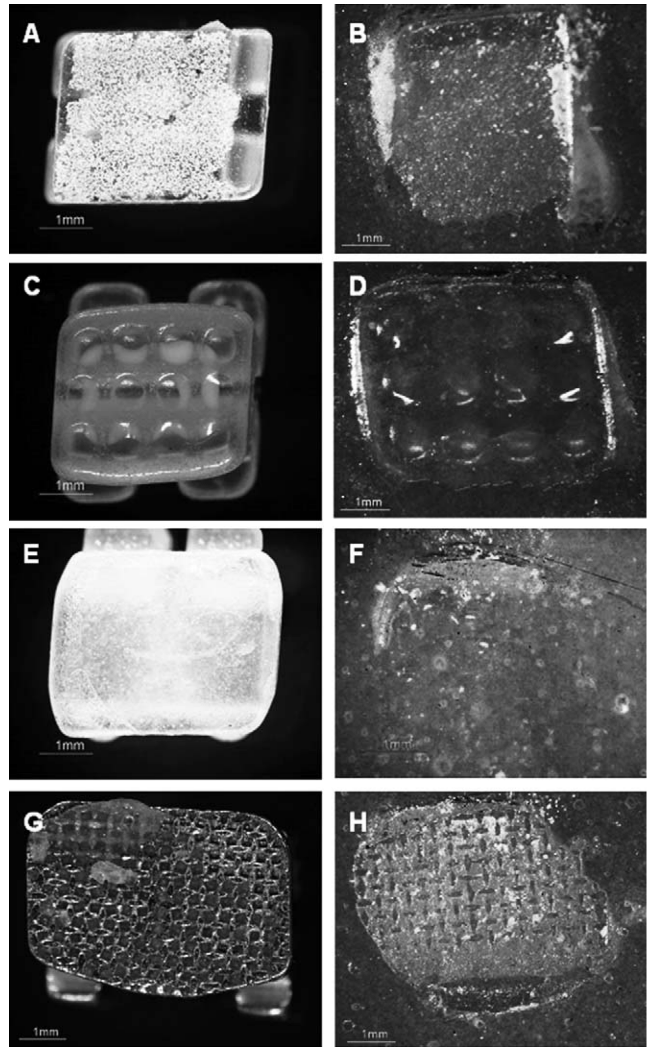

Figure 2. Failure characteristics (left side, at base of ceramic bracket and right side, at porcelain). (A and B) Type 3 failure of beads base design. (C and D) Type 1 failure of large round pits base design. (E and F) Type 2 failure of irregular base design. (G and H) Type 2 failure of mesh base design ($\times$20 magnification).

In contrast, the base surface of the bracket has as many as 50 μm round monocrystalline beads completely distributed onto the base surface as possible. These beads have undercuts for mechanical interlocking of adhesive resin that exhibited the statistically greatest shear bond strength among all groups ($P = .01$).

The interfacial area based on bracket base design, resin thickness, and inherent flaws or defects in brackets or porcelains could influence bond strength. However, in this study, an attempt was made to control for these factors. The anterior brackets were used for the best fit on flat porcelain surfaces and for minimizing the thicker adhesive layers, which may have produced increased imperfection and greater variability in the amount of polymerization obtained, and with which fracture may have occurred more readily.[21] In this study, no bracket or porcelain fractures were found, so the inherent flaws could not have affected bond strength.

Glazed porcelain surfaces are not amenable to resin penetration for orthodontics bonding.[20] Glazed surface removal has been advocated to create mechanical retention for adhesive resin through surface roughening.[37] However, the esthetic and structural qualities of the porcelain may be irretrievably lost with surface roughening. The glaze is effective in strengthening the porcelain and reducing crack propagation. If the glaze is removed by grinding, the flexural strength of the porcelain unit may be reduced. Several studies have recommended that the glaze not be removed by grinding for safety reasons.[18,19,38] This recommendation is justified by the results of the present study. Even though this study used ceramic brackets bonded to glazed porcelain surfaces, the shear bond strengths of all groups were greater than the minimum orthodontic bracket bond strength[21,34,35] and could be considered sufficient for clinical applications.

The high shear bond strength also should reflect the effects of phosphoric acids and silanes. Phosphoric acid, at 37% concentration, does not etch porcelain, and it does not produce physical or topographic changes in the porcelain surface. Instead, phosphoric acid has the effect of neutralizing the alkalinity of the adsorbed water layer, which is present on all porcelain restorations in the oral cavity. This enhances the chemical activity of the silanes subsequently applied.[39] This study confirms the necessity of using silanes, a finding that is consistent with the results of earlier studies.[16–24]

Stereoscopic examination revealed no damage to the porcelain surfaces in any group. A previous study[40] showed that if the bond strength between the porcelain and the adhesive resin is greater than 13 MPa, the porcelain is fractured. In this study, all groups obtained values greater than 13 MPa, which resulted in adhesive failures (types 1 to 3). Porcelain fractures were not observed. This observation is important because bonding and debonding should not cause damage to the porcelain surfaces that would affect the esthetics and strength of the restoration.

For a clinical recommendation, data from the present study advocate preserving the glaze, treating the porcelain with 37% phosphoric acid, applying a porcelain primer, and using either type of ceramic bracket with adhesive resin. All types of ceramic brackets should be clinically acceptable.

In the present study, high shear bond strength between the ceramic brackets and the feldspathic porcelain was found in all groups. However, an in vitro study cannot present the same environment as the oral cavity. The presence of water, proteins, and minerals and differences in pH levels and temperature changes can affect the bond strength of ceramic brackets on porcelains. The present study provided results on only one type of porcelain and adhesive bonding (Vita VMK95 and System 1+). Therefore, it should not be presumed that different types of porcelain will demonstrate the same pattern of bond strength. Further study is required.

CONCLUSIONS

- Bond strength values between beads base ceramic brackets and glazed feldspathic porcelains were the statistically highest values among all groups.
- The shear bond strengths of all groups exceeded the minimum orthodontic bracket bond strength.
- Debonding characteristics caused no damage to the porcelain surfaces.

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