The shear bond strength of composite brackets on porcelain teeth

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SUMMARY Recent advances in materials and techniques suggest that direct bonding of orthodontic attachments to surfaces other than enamel may now be possible. To test the effectiveness of bonding orthodontic attachments to porcelain teeth, composite brackets (Spirit MB) were bonded to 64 porcelain teeth by means of a self-cure non-mixed resin system (Unite). The 64 porcelain teeth were divided into groups of eight and after roughening with a green stone they were subjected to a combination of treatments. Some were etched, some primed with a silane coupling agent and some received both treatments before the brackets were bonded to them. Half of the teeth were then thermally-cycled 500 times between 4 and 60°C before all the brackets were removed in a shear test. The shear data was analysed by one way analysis of variance and the Student–Newman–Keul test.

The results showed that the highest bond strength existed in the group which had been both etched and primed but not thermocycled ($P < 0.05$). The factors that affected the bond strength, beginning with the most significant, were acid etching, primer application, and then thermocycling. A mechanical based composite bracket can offer good bond strength to porcelain teeth.

Introduction

The attachment of brackets to teeth plays a key role in the early stages of orthodontic treatment. Formerly, this was achieved by banding the teeth, but the introduction of the acid–etching of enamel and the direct bonding of brackets has led to dramatic changes in the practice of orthodontics (Zachrisson, 1985).

The orthodontist is often faced with the challenge of bonding attachments to various restorative materials, including porcelain crowns and veneers and to metallic crowns and bridges. Major *et al.* (1995) have made useful suggestions as to how this may be achieved under clinical conditions.

A glazed surface is not responsive to adhesive penetration and, if the surface is roughened to provide mechanical retention, it may not be acceptable after debonding (Smith *et al.*, 1988). In the late 1970s, organosilanes gained popularity in the fields of prosthodontics for porcelain

repair (Dent, 1979) and in orthodontics for the direct bonding of attachments to porcelain (Such, 1979). For a permanent chemical bond to form between porcelain and resin, the following must occur: (i) hydrolysis of the organosilane to form an organosilanol; (ii) initial formation of an oxane linkage; and (iii) a condensation reaction to form a permanent oxane bond (Lu *et al.*, 1992).

In recent years, many studies have demonstrated that the use of silane coupling agents, or porcelain priming agents, will increase the strength in the bond to dental porcelain (Wood *et al.*, 1986; Andersen and Stieg, 1988; Diaz-Arnold *et al.*, 1989). Several investigations have indicated that greater bond strengths, especially in bonding to enamel, could be achieved using organosilane primers in conjunction with traditional bis-GMA adhesives, but not all primers were equally effective (Kao *et al.*, 1988; Stokes *et al.*, 1988; Lu *et al.*, 1992). Recent research has shown that an appropriate

adhesive–primer system and porcelain pre-treatment, including acid etching or mechanical roughening, can have an effect on the nature of bond failure and the incidence of porcelain fracture (Cochran *et al.*, 1988; Eustaquio *et al.*, 1988; Kao *et al.*, 1988).

Current interest has been directed toward the bond strength between cosmetic brackets and porcelain teeth. The composite bracket (one of the cosmetic brackets) is made of polycarbonate and is used mainly for aesthetic reasons (Miura *et al.*, 1971). Such composite brackets may be useful in minimal force situations and for treatment of short duration, particularly in adults (Zachrisson, 1985).

Many studies have investigated the bond strength of stainless steel or ceramic brackets bonded to enamel (Sheykholeslam and Brandt, 1977; Gwinnett, 1988; Ödegaard and Segner, 1988; Eliades *et al.,* 1991). Others have evaluated different combinations of adhesives and porcelain primers used in bonding stainless steel or ceramic brackets to porcelain. In a previous study, it was demonstrated that the shear bonding of a composite bracket bonded on porcelain teeth with light- or self-cured resin differed in strength. The self-cured resin group with etching and primer application had a higher bonding strength than the light-cured group (Kao and Huang, 1997). From the results of that study, it was clear that there was a lack of information on the bond strength of composite bracket to porcelain surfaces treated with a variety of bonding procedures. The purpose of this study was to investigate the shear strength of composite brackets bonded to porcelain using different bonding procedures.

Materials and methods

Bracket bonding to porcelain teeth

Sixty-four porcelain-fused-to-metal teeth (Shou Fu, Tokyo, Japan) were constructed according to the manufacturer's recommendations and stored in distilled water at 100 per cent humidity 37°C until bonding.

The materials used in the procedure are shown in Table 1. The porcelain-laminated labial surface of the teeth was modified with a green

Table 1   Materials used in the study.

Agent	Composition	Manufacturer
Unite adhesive	Self cure resin	3M Unitek Co.
Composite bracket	Polycarbonate	Ormco Co.
Scotchprime	Silane agent	3M Unitek Co.
Etching agent	9.6% HF solution	3M Unitek Co.
Ceramic tooth	Porcelain	Shou Fu Co.

HF: hydrofluoric acid.

stone to roughen the surface glaze. According to the different bonding procedures, the 64 samples were divided into eight groups (Table 2) as follows:

Group 1, the porcelain surface was etched with 9.6 per cent hydrofluoric acid (HF, 3M, St Paul, MN, USA) for 2 minutes, washed with water, and then dried. At this point, the water line had to be clean and oil-free, and also free of contamination on the surface. Scotchprime (Unitek, 3M) was applied in two layers with a pledget and gently air-dried. The lower central incisor composite brackets with mechanical base (Spirit, Ormco Corp., Glendora, CA, USA) were then bonded to the porcelain with no-mix self-cure adhesive (Unite, Unitek, 3M) according to the manu-facturer's recommendations. The lower central incisor brackets were chosen because the bracket base was relatively flat and was best suited to bonding to the flat porcelain surface. The excess resin was then removed with a sickle scaler and, after 10 minutes, the samples were returned to the distilled water bath for 24 hours and then

Table 2   The various conditions for porcelain surface treatment.

Condition	Roughening	Etching	Priming	Thermocycling
Group 1	+	+	+	+
Group 2	+	+	+	–
Group 3	+	+	–	–
Group 4	+	–	–	–
Group 5	+	–	+	+
Group 6	+	–	–	+
Group 7	+	+	–	+
Group 8	+	–	+	–

+: with treatment.
–: without treatment.

thermocycled. Each specimen underwent 500 complete cycles with a temperature range of 4–60°C and a dwell time of 30 seconds in each bath (Peterson *et al.*, 1966). The specimens were then stored in distilled water at 37°C for 7 days before mechanical testing.

Group 2, etched and primed but not thermally-cycled.

Group 3, etched but not primed or thermally-cycled.

Group 4, no surface treatment and thermally-cycled.

Group 5, primed and thermally-cycled but not etched.

Group 6, thermally-cycled but not etched or primed.

Group 7, etched and thermally-cycled but not primed.

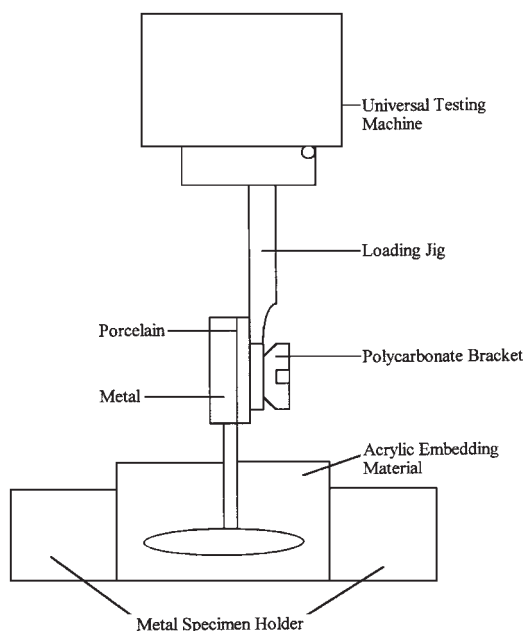Group 8, primed but not etched or thermally-cycled.

Shear force testing

The shear bond strength was tested with a universal testing machine (Shimadzu AG-1000E, Tokyo, Japan). Each bonded unit was placed in a jig that allowed a shear force to be applied to the bond interface, including failing shear stress (Figure 1). A crosshead speed of 1 mm/min was used (Kidd, 1976). The load at failure was recorded and the stress at failure was calculated. The surface area of each bond was 0.09 cm^2.

Statistical analysis

The statistical analysis of the bond strength data included a one-way analysis of variance (ANOVA) and the Student–Newman–Keuls multiple comparison test at the 5 per cent level of significance.

Results

The mean shear bond strengths and standard deviations in bond strengths for the eight groups are shown in Table 3. The bond strength was shown to be significantly different by one-way ANOVA ($F = 1632.03$, $P = 0.000$). The highest shear bonding strength was in group 2 (182.0 /cm^2).

Figure 1 Schematic drawing of the test device.

Table 3 Shear bond strength different groups.

Group	Bond strength Mean (kg/cm^2)	SD	Student–Newman–Keuls test
2	182	6.3	A
1	176.6	4.6	B
7	129.3	6.5	C
3	107.5	4.5	D
8	47.2	3.2	E
5	46.4	5.6	E
4	15.2	2.6	F
6	10.9	4	F

The statistical analysis of the shear bond strength used a one-way ANOVA.
The results showed a statistical difference in groups ($P < 0.05$, $n = 8$).
Groups not statistically significant were given the same letter.

After analysing the groups with a Student–Newman–Keuls test, those that were not statistically significant were given similar letters (Table 3). Significant positive effects of silane and HF acid application and significant negative effects of thermocycling on shear bond strength were found.

Bonding strength with a one-step difference in the bonding procedure (Table 3)

Etching. The following groups were compared, 1 and 5, 2 and 8, 3 and 4, 6 and 7. The shear bond strength was higher in groups 1, 2, 3, and 7 with etch treatment on the porcelain surface compared with the other groups.

Priming. Groups 1 and 7, 2 and 3, 4 and 8, and 5 and 6 were included. The shear bond strength was higher in groups 1, 2, 5, and 8 with primer application on the porcelain surface compared with the other groups.

Thermocycling. Groups 1 and 2, 3 and 7, 4 and 6, and 5 and 8 were included. The difference in shear bond strength was statistically significant between groups 1 and 2, and 3 and 7, but not between groups 4 and 6, or 5 and 8.

Bonding strength with a two-step difference in the bonding procedure (Table 3)

Etching and priming. Comparisons were made between groups 1 and 6, 3 and 8, 2 and 4, and 5 and 7. The shear bond strength was higher in the groups treated with etching and priming than in those without etching and priming (groups 1 and 6, 2 and 4). The groups with etching without priming had a higher shear bond strength than without etching and with priming (groups 3 and 8, 5 and 7). That is, etching assumed more of an important role than priming in the comparison of bond strength.

Etching and thermocycling. Comparisons were made between groups 1 and 8, 2 and 5, 3 and 6, and 4 and 7. The shear bond strength was higher in the groups treated with etching and thermocycling than without etching and thermocycling (groups 1 and 8, 4 and 7). The group with etching without thermocycling had a higher shear bond strength than without etching but with thermocycling (groups 2 and 5, 3 and 6). That is, etching had more influence on the bond strength than thermocycling.

Priming and thermocycling. Groups 1 and 3, 2 and 7, 5 and 4, and 6 and 8 were included. The shear bond strength was higher in the groups treated with priming and thermocycling than in those without priming and thermocycling (groups 1 and 3, 5 and 4). The groups with priming without thermocycling had higher shear bonding strength than those without priming but with thermocycling (groups 2 and 7, 6 and 8). That is, priming had a greater effect on the bonding strength than thermocycling.

Bonding strength with a three-step difference in the bonding procedure (Table 3)

Comparisons were made between the following groups: 1 and 4, 2 and 6, 3 and 5, and 7 and 8. The groups with etching, priming and thermocycling had higher bond strengths than those without (groups 1 and 4). The groups with etching but without priming and thermocycling had a higher bond strength when compared with groups that had priming and thermocycling but no etching (groups 3 and 5). The groups with etching and priming but no thermocycling had a greater bond strength than those without etching and priming but with thermocycling (groups 2 and 6). The groups with etching and thermocycling but no priming had better bond strength than those without etching and thermocycling but with priming (groups 7 and 8).

Discussion

In this study, acid etching played an important role in bond strength. The group treated with acid etching showed a higher bond strength than the group without acid etching. Hydrofluoric acid was used since it has been shown to increase the surface area of porcelain by differentially dissolving the crystalline and glassy phase (Stamgel *et al.*, 1987; Al Edris *et al.*, 1990). As in the study of Major *et al.* (1995), a clinically acceptable bond strength with minimal porcelain damage on debonding could be achieved without significant alteration to the porcelain surface by mechanical means. In this study, HF was used primarily to acidify the alkaline layer of water at the surface and to also achieve some etching effects.

In etching the enamel, a reduction in phosphoric acid concentration from 37 to 20 per cent results in a statistically significant decrease in shear bond strength (Carstensen, 1995). The determination of the ideal HF acid concentration for optimum bond strength on porcelain surface requires further investigation. Regarding the amount of etching time needed for enamel, it is suggested that any etching regimen between 15 and 60 seconds should be valid (Kittipibul and Godfrey, 1995). The most commonly used porcelain etch solution is 9.6 per cent HF acid in gel form applied for 2–4 minutes (Zachrisson and Buyukyilmaz, 1993).

Etching creates micro-porosities on the porcelain surface that achieve a mechanical interlock with the composite resin. There have been some suggestions for the etchant concentration and the time of etching on porcelain. For instance, application of a 1.23 per cent acidulated phosphate fluoride (APF) gel for 10 minutes may provide a bond strength equivalent to 9.6 per cent HF acid applied for 4 minutes (Zachrisson and Buyukyilmaz, 1993). It is suggested that when maximum bond strength to porcelain is desired, etching should be undertaken with HF or APF gel (Zachrisson and Buyukyilmaz, 1993). Therefore, this study using HF for etching provided a stronger shear bond strength than those groups without acid etching.

The primer used in this investigation was a silane coupling agent. Organosilanes increase the bond strength by performing two functions. First, they provide a chemical link between dental porcelain and composite resin, and second, the organic portion of the molecule increases the wettability of the porcelain surface, thereby providing a more intimate micromechanical bond (Major *et al.*, 1995). The results of this study show that the decisive factors affecting bond strength, in the order of significance, were etching, priming, and then thermocycling. However, primed porcelain surfaces still need to be combined with etching to increase bond strength. The results show that the group treated with primer and etching agent illustrated a higher bond strength.

The sites of failure among the ceramic and the mesh-base brackets were mostly at the enamel/ resin interface when bonded with chemical-cured resin, and at the resin/bracket interface when bonded with light-cured resin (Joseph and Rossouw, 1990). With the composite bracket, the most common bond failure site has been found to be at the enamel/resin interface. Enamel bonding studies have shown that bond failure site of ceramic and mesh-based brackets is usually located at the bracket/resin interface (Buzzitta *et al.*, 1982; Gwinnet, 1988). In the present investigation, the bond failure site most often occurred at the resin/porcelain interface. This result was similar to the failure site of composite brackets bonded to enamel (Buzzitta *et al.*, 1982).

For the ceramic bracket, mechanical bonds (metal foil mesh and groove-based ceramic bracket bases) fail mostly at the adhesive–bracket interface (Viazis *et al.*, 1990); that is, the bond strength is higher between the adhesive and the enamel. In the present study, the composite bracket had a mechanical base, and the failure site of the adhesive was at the resin/porcelain interface. This difference might be caused by the various experimental materials and methods. A porcelain surface after etching can produce a mechanical surface. The mechanical based bracket and etched porcelain offer the same type of mechanical bonding surface. The reason failure sites were seen mostly at the resin/porcelain surface may be that the porcelain surface structure was less suitable for adhesive than the composite bracket base structure.

The minimal shear bond strength that is required to withstand normal orthodontic force is 6–8 MPa (58.8–78.4 kg/cm^2; Reynolds, 1975). In the present study of the shear force of composite brackets bonded to a porcelain surface, groups 1, 2, 3, and 7 showed bond strengths which were all greater than those required for minimal orthodontic forces, whereas the bond strengths in groups 4, 5, 6, and 8 were below those needed for minimal orthodontic forces. The higher the mean shear bond strength, the greater the incidence of damaged porcelain. By following the normal procedures for bracket bonding to porcelain surface as suggested by Major *et al.* (1995), it is believed that the bond strength will be sufficient for clinical use.

Conclusion

Under the conditions of this study, the following conclusions can be drawn:

1. The bond strength of the composite bracket bonded to a porcelain surface is sufficient for clinical use.
2. For bonding to a porcelain surface, roughening the porcelain, etching agent, and primer application can increase the bond strength.
3. The most significant factors that affected the bond strength were acid etching, primer application and thermal stress, respectively.
4. The group treated with etching and priming but not with thermocycling showed the highest bond strength.

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