

Shear bond strength of orthodontic brackets bonded to different ceramic surfaces

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SUMMARY This study was undertaken to measure the shear bond strength (SBS) of stainless steel brackets bonded to different ceramic surfaces, to compare the SBS of the different ceramics with each other and with conventional ceramo-metal porcelains, and to determine the mode of failure for each group following debonding.

A total of 60 ceramic crowns were constructed on extracted teeth and divided into three equal groups as follows: In-Ceram ceramic crowns, IPS-Impress ceramic crowns, and conventional ceramo-metal porcelain. Standard edgewise metal premolar brackets were bonded to the prepared porcelain surfaces. After bonding, all samples were tested in shear mode on an Instron universal testing machine. Statistical analysis was undertaken using analysis of variance, LSD, and chi-squared tests.

The results showed that the SBS for the ceramo-metal and the In-Ceram groups were comparable, with mean values of 80.54 ± 13.44 N and 78.87 ± 13.47 N, respectively. The IPS-Impress group showed the weakest SBS which averaged 67.40 ± 8.99 N. This was significantly lower than that of the conventional ceramo-metal porcelain ($P < 0.001$) and the In-Ceram surface ($P < 0.01$). The mode of failure in the ceramo-metal group was between the porcelain surface and adhesive and in the other two ceramic groups, between the brackets and adhesive ($P < 0.001$). The SBS of orthodontic brackets to the three tested ceramic surfaces were adequate for orthodontic use.

Introduction

Ceramic restorations are now widely used for restoring damaged or missing teeth in adult patients. Dental porcelain may be classified as feldspathic, aluminous, and glass (Zachrisson *et al.*, 1996). The feldspathic porcelain (conventional ceramo-metal porcelain) is made of the mineral, feldspar, with some additions for colour and translucency and contains silica (SiO_2) and alumina (Al_2O_3) with small amounts of potassium oxide (K_2O) and sodium oxide (Na_2O). The aluminous porcelain (In-Ceram, Vitadur Alpha, VITA Zahnfabrik H. Rauter GmbH & Co., Bad Sackingen, Germany) is composed of glass powder and fused alumina crystals which constitute up to 50 per cent by weight, whereas the glass-ceramics (IPS-Impress 2, Ivoclar Schaan, Lichtenstein, Germany) is a lithium disilicate glass-ceramic coated with sintered glass-ceramics and the chemical basis for the material is the SiO_2 –LiO system. These glass-ceramics contain fluorapatite.

The increased demand for orthodontic treatment in adult patients has resulted in the problem of bonding brackets to porcelain. As conventional bonding does not guarantee sufficient adhesion to porcelain to withstand orthodontic forces, a number of approaches have been attempted to alter the surface characteristics of porcelain to provide sufficient bond strength. The approaches suggested can be classified into three major groups, namely, mechanical, chemical, or combination. Mechanical alteration of porcelain surfaces to increase bond strength has been achieved by sandblasting

(Zachrisson *et al.*, 1996; Cochran *et al.*, 1997; Kocadereli *et al.*, 2001) or by using coarse diamond stone (Gillis and Redlich, 1998). However, it has been shown that although roughening of porcelain surfaces significantly increases bond strength, it also results in a higher incidence of porcelain fracture associated with debonding (Kao *et al.*, 1988).

Chemical alteration of the porcelain surface can be achieved by either etching or by changing the porcelain bonding affinity to adhesive materials. Etching the porcelain surface with hydrofluoric acid (HFA) to increase bond strength has been advocated (Zachrisson *et al.*, 1996; Cochran *et al.*, 1997; Bourke and Rock, 1999; Kocadereli *et al.*, 2001). However, it has been suggested that although HFA improves the bond strength for different feldspathic porcelain, it does not for the high aluminous porcelain (Calamia, 1983; Sorensen *et al.*, 1991; Liobell *et al.*, 1992). The high aluminium oxide content in aluminous porcelain increases the porcelain surface strength, making it more resistant to chemicals and reducing the effect of HFA. Clinically, there are drawbacks with the use of HFA. It is very acidic and must be used with great care, as it is extremely corrosive, and is capable of causing severe trauma to soft tissues and tooth substance (Hayakawa *et al.*, 1992). Careful isolation of the working area for several minutes is required.

Silane coupling agent has been reported to enhance bond strength to porcelain surfaces (Newman *et al.*, 1984; Wood *et al.*, 1986; Kao *et al.*, 1988; Winchester, 1991; Bourke and

Rock, 1999; Kocadereli *et al.*, 2001). The silane reacts with the silica within the porcelain and the organic groups of the bonding resin thus forming a bridge between the two materials (Newman, 1983; Kern and Thompson, 1994).

Zachrisson and Büyükyılmaz (1993) recommended the following technique for bonding to porcelain to obtain maximum bond strength: deglazing the porcelain surface by sandblasting with 50 µm aluminium oxide for 2–4 seconds and etching the surface with 9.6 per cent HFA gel for 2 minutes followed by application of two to three coats of silane porcelain primer and the bonding agent.

The aims of this study were to (1) measure the shear bond strength (SBS) of stainless steel brackets bonded to In-Ceram and IPS-Impress ceramic surfaces, (2) compare the SBS of In-Ceram and IPS-Impress with each other and with conventional ceramo-metal porcelain (control group), and (3) determine the mode of failure following debonding.

Materials and methods

Upper and lower premolar teeth ($n=60$) were collected from patients having extractions as part of their orthodontic treatment plan. The teeth were randomly divided into three equal groups. Each tooth was mounted in cold-curing, fast-setting acrylic (Leocryl; Leone, Sesto Fiorentino, Italy). The teeth were aligned so that their labial surface was exposed and parallel to the axis of the force during SBS testing. The teeth were prepared for porcelain crown construction by a single operator (AMSA). Three types of ceramic crowns were fabricated by one technician and allocated to one of the three groups as follows: the In-Ceram ceramic crowns, the IPS-Impress ceramic crowns, and the conventional porcelain fused to metal crowns (control).

Standard edgewise metal premolar brackets (mesh backed, 0.022 inch. Roth prescription without a hook; Leone) were bonded to the porcelain surfaces which were prepared as recommended by Zachrisson and Büyükyılmaz (1993).

The porcelain surfaces were deglazed by aluminium oxide sandblasting with 50-µm abrasive powder with microetcher at 80 psi for 2 seconds through a nozzle at a distance of 10 mm and an angle of 45 degrees. After sandblasting, the porcelain surfaces were cleaned with water and dried with oil-free compressed air. They were then etched with 9.6 per cent HFA for 2 minutes followed by silane coupling agent. Transbond XT primer (3M/Unitek, Monrovia, California, USA) was applied to the etched surface in a thin film. Transbond XT adhesive paste was applied to the bracket base, and the bracket was positioned and pressed firmly on the crowned tooth. Excess adhesive was removed from around the bracket base, and the adhesive was light cured for 40 seconds. The composite resin (Transbond XT) was light cured using XL300 (3M/Unitek).

After bonding, all samples were stored in distilled water at room temperature for 24 hours and subsequently tested in shear mode on a universal testing machine (Instron 1195,

Instron Limited, High Wycombe, Buck, UK). For shear testing, the specimens were secured in the lower jaw of the machine so that the bracket base parallel to the direction of the shear force. The force required to remove the brackets was measured in Newtons (N) at a crosshead speed of 0.5 mm/seconds.

After bond failure, the bracket bases and porcelain surfaces were examined visually by one operator (ESAA). The amount of adhesive left on the porcelain surface was scored for each tooth using the modified adhesive remnant index (ARI; Årtun and Bergland, 1984; Bishara *et al.*, 1999) taking into consideration that the porcelain surface rather than the enamel surface was examined.

The ARI scale ranges from 1 to 5:

1. all of the adhesive remaining on the enamel, with the impression of the bracket base
2. more than 90 per cent of the adhesive remaining on enamel surface
3. less than 90 per cent but more than 10 per cent of the adhesive remaining on the enamel surface
4. less than 10 per cent of the adhesive remaining on the enamel surface
5. no adhesive remaining on the enamel surface.

Method error

Twenty randomly selected teeth were re-examined on two occasions separated by a period of 1 week, and the kappa test was applied to test intraexaminer reliability (Cohen, 1960). Kappa values ranged between 96 and 100 per cent for the ARI scores.

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. If a significant difference was present, LSD multiple comparison tests were used to identify which of the groups were different. The chi-squared test was used to determine significant differences in the ARI scores between the different groups. Significance for all statistical tests was predetermined at $P<0.05$.

Results

The SBS for the ceramo-metal and the In-Ceram groups were comparable and averaged 80.54 ± 13.44 N and 78.87 ± 13.47 N, respectively. The IPS-Impress group showed the weakest SBS, which averaged 67.40 ± 8.99 N.

The ARI scores for the three groups are shown in Table 1. All of the adhesive remained on the ceramic surface in 80 per cent of the IPS-Impress, in 65 per cent of the In-Ceram, and in 20 per cent of the conventional ceramo-metal groups. There were significant differences between the three groups in the

mode of failure ($P < 0.001$). The mode of failure in the ceramo-metal group was between the ceramic and adhesive and in the other two groups between the brackets and the adhesive.

Scanning electron microscopy (SEM) of the bracket bases of the three tested ceramic groups are shown in Figures 1 a–c. Most of the adhesive remained on the brackets in the ceramo-metal porcelain group, whereas it remained on the porcelain surface in both the In-Ceram and the IPS-Impress groups.

Table 2 shows mean differences in the SBS between the three groups. A significant difference existed in bond strength between the conventional ceramo-metal and the IPS-Impress ceramics ($P < 0.001$) and between the In-Ceram and IPS-Impress groups ($P < 0.01$).

Discussion

Commercially available porcelains are usually similar in chemical formula but have distinct differences in constituents, particle size, and crystalline structure. Therefore, different results are expected regarding bonding to porcelain.

When bonding orthodontic brackets to porcelain surfaces, it is necessary to change the inert characteristics of the surface to achieve a clinically acceptable bond strength. Glaze removal has been advocated in order to create mechanical retention (Wood *et al.*, 1986; Smith *et al.*, 1988; Zelos *et al.*, 1994). Sandblasting with microscopic particles of aluminium oxide to remove the glaze is better than using burs or stones since only a small amount of surface is removed and the procedure is more uniform (Zachrisson *et al.*, 1996). The use

of strong acids such as 9.6 per cent HFA to etch porcelain has been suggested to increase bond strength (Zachrisson *et al.*, 1996). However, HFA should be used with great care as it is capable of causing severe trauma to soft tissues and tooth substance (Hayakawa *et al.*, 1992). Superior bond strengths to porcelain have been reported following the use of a silane coupling agent (Whitlock *et al.*, 1994). Silane bonding acts as a chemical link between the inorganic ceramic surface and the organic resin adhesive agent. In this study, brackets were bonded to ceramic surfaces as recommended by Zachrisson and Büyükyılmaz (1993).

The results of this study showed that the SBS for the three ceramic groups were above 58 N, which is considered as the minimum bond strength to be adequate for orthodontic bonding (Tavas and Watts, 1984). In the present study, the conventional ceramo-metal and the In-Ceram had comparable SBS, which was higher than that of IPS-Impress. This may be related to structural differences between the three groups.

Årtun and Bergland (1984) suggested a scale for determining adhesive remaining on the enamel surface after debond. The ARI has a scale ranging from 0 to 3; 0 indicates no adhesive left on the tooth, 1 less than half of the adhesive left on the tooth, 2 more than half of the adhesive left on the tooth, and 3 all adhesive left on the tooth with a distinct impression of the bracket mesh. In this study, evaluation of the adhesive remaining on the ceramic surface was performed using a modified ARI (Bishara *et al.*, 1999). The modification provides an accurate assessment as it divides the scale into five scores. In this study, ARI scores indicated that there was higher frequency of bond failure at the bracket–adhesive interface in the In-Ceram and IPS-Impress groups. SEM of cross-sections of brackets bonded to the three ceramic surfaces confirmed this finding. The chemical bond of the silane agent and the mechanical bond by sandblasting the porcelain surface before bonding caused failure to occur within the adhesive and at the bracket–adhesive interface (Joseph and Rossouw, 1990; Sorensen *et al.*, 1991; Suliman *et al.*, 1993). This type of failure in the adhesive–bracket interface shows that the chemical and mechanical bonding was equal to or exceeded the mechanical retention provided

Table 1 Adhesive remnant index scores for the groups tested.

Group	ARI scores				
	1	2	3	4	5
Ceramo-metal porcelain	4	2	4	8	2
IPS-Impress porcelain	16	2	2	—	—
In-Ceram porcelain	13	3	3	—	1

$\chi^2 = 26.04$, $P = 0.001$.

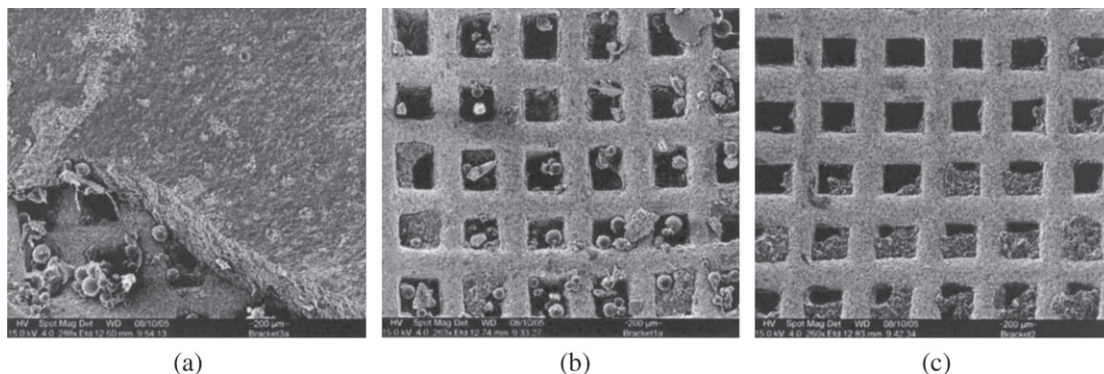


Figure 1 Scanning electron microscopy of debonded bracket from (a) ceramo-metal, (b) IPS-Impress, and (c) In-Ceram porcelain surfaces.

Table 2 Mean differences in shear bond strength between the tested groups using the LSD test.

Group	Ceramo-metal	IPS-Impress	In-Ceram
Ceramo-metal porcelain		13.15***	1.67
IPS-Impress porcelain	13.15***		11.48**
In-Ceram porcelain	1.67	11.48**	

** $P < 0.01$, *** $P < 0.00$.

by the bracket base, and the bond strength to the ceramic surface was greater than the cohesive strength of the adhesive. Bond failure in the ceramo-metal porcelain group was predominantly between the porcelain and the adhesive.

One limitation of this investigation may be that surface properties of porcelain in the oral environment could be altered by variations in temperatures, humidity, acidity, and plaque (Zachrisson *et al.*, 1996); thus, the results of this *in vitro* study may not apply to the clinical situation. Further studies should be performed using porcelain previously exposed to the oral environment or prior exposure of the specimens to thermocycling. In addition, this investigation only evaluated the shear forces during orthodontic treatment; torquing forces and tensile forces should also be studied.

Conclusions

1. The SBS of orthodontic brackets bonded to three different ceramic surfaces were adequate for orthodontic attachments.
2. The SBS of In-Ceram was comparable with that of ceramo-metal porcelain and both had a higher SBS than IPS-Impress.
3. The mode of failure of the In-Ceram and IPS-Impress ceramics was between the bracket and adhesive, whereas in the ceramo-metal group, it was between the porcelain and adhesive.

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