Porcelain surface conditioning protocols and shear bond strength of orthodontic brackets

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Aim: The objective of the present study was to determine which of six bonding protocols yielded a clinically acceptable shear bond strength (SBS) of metal orthodontic brackets to CAD/CAM lithium disilicate porcelain restorations. A secondary aim was to determine which bonding protocol produced the least surface damage at debond.
Methods: Sixty lithium disilicate samples were fabricated to replicate the facial surface of a mandibular first molar using a CEREC CAD/CAM machine. The samples were split into six test groups, each of which received different mechanical/chemical pretreatment protocols to roughen the porcelain surface prior to bonding a molar orthodontic attachment. Shear bond strength testing was conducted using an Instron machine. The mean, maximum, minimal, and standard deviation SBS values for each sample group including an enamel control were calculated. A *t*-test was used to evaluate the statistical significance between the groups.
Results: No significant differences were found in SBS values, with the exception of surface roughening with a green stone prior to HFA and silane treatment. This protocol yielded slightly higher bond strength which was statistically significant.
Conclusion: Chemical treatment alone with HFA/silane yielded SBS values within an acceptable clinical range to withstand forces applied by orthodontic treatment and potentially eliminates the need to mechanically roughen the ceramic surface.
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Introduction

Since the number of adult patients seeking treatment has increased, the orthodontist is faced with the challenge of bonding brackets to porcelain restorations. It is common to band porcelain-crowned posterior teeth due to the difficulty in otherwise obtaining an efficient attachment that does not cause irreversible damage to the crown upon removal.[1] Banding requires an extra appointment to place separating alastics, which produces additional discomfort and the absence of the patient from work.

Two types of restorative porcelain commonly used in the posterior part of the mouth are feldspathic and lithium disilicate.[2] Feldspathic porcelain is used for porcelain fused to metal crowns, while lithium disilicate is used in all ceramic crowns.[1,3]

In order to bond brackets to porcelain, a series of chemical and/or mechanical pretreatment is often used. Four commonly used surface conditioning techniques are:

1. Preparation with hydrofluoric acid (HFA) to etch the porcelain surface.[4]
2. Use of silane coupling agents (gamma-methacryloxypropyl-trimethoxy silane). Silanes provide a chemical link between the porcelain and the composite resin which increases bond strength.[5,6]
3. Roughening the porcelain with a diamond bur.[7]
4. Sandblasting with aluminum oxide particles in a process of microetching.[4]

A study by Schmage et al. investigated an additional preparation technique that combined mechanical and chemical retention through silicazation, in which porcelain is sandblasted with aluminum oxide modified with silicic acid. The blasting pressure embeds silica particles in the ceramic surface, making the surface more reactive to the resin via a silane link. This technique was found to produce the highest bond strength and could potentially replace the other methods.[6]

Mechanical roughening with either sandblasting or diamond burs has been reported to provoke crack initiation and propagation within the porcelain.[6] Because the restorations are normally retained after orthodontic treatment, the amount of porcelain damage as a result of pretreatment conditioning and through debonding should be kept to a minimum.[3] Sandblasting is preferred compared with the use of diamond burs to remove the porcelain glaze because less surface is removed, which is more uniform.[8]

Türk and colleagues demonstrated that, in general, a higher shear bond strength (SBS) could be achieved on lithium disilicate ceramics. On feldspathic porcelain, pretreatment with 25 µm Al_2O_3 particles resulted in minimal porcelain damage while yielding sufficient bond strength.[9] On feldspathic porcelain, Transbond XT (3M Unitek, CA, USA) was shown to have a higher SBS than Fuji Ortho LC (GC America Inc., IL, USA), which are both popular bonding cements. It was further shown that longer etching times of 60 seconds compared with 20 seconds also increased SBS.[10] Furthermore, post-debonding finishing using Sof-Lex (3M ESPE, MN, USA) discs produced a smoother surface finish than the use of a porcelain polishing paste and wheel.[2]

To date, previous studies used incisor or premolar brackets to evaluate bond strength to porcelain.[1,3,4,6,7] However, molars are most commonly restored with porcelain crowns. The base on molar attachments is contoured differently and the surface area is larger than premolar or central incisor brackets. Therefore, the appropriate porcelain bonding protocol for use in the molar region is currently unknown. This is a significant deficiency because the majority of undesired attachment failures occur in the molar region.

Few studies have demonstrated differences between bond strengths of porcelain and enamel and new products have recently been developed to enhance bond strength. Therefore, the objective of the present study was to evaluate which of six bonding protocols yielded a clinically acceptable shear bond strength of metal orthodontic brackets to CAD/CAM lithium disilicate porcelain restorations while recording minimal damage to the porcelain finish upon debonding.

Materials and methods

Sixty lithium disilicate samples were constructed to replicate the facial surface of a mandibular first molar using a CEREC (Sirona, Salzburg, Austria) CAD/CAM machine. Shade A2 IPS EMAX CAD (Ivoclar Vivadent, NY, USA) blocks were used. The porcelain samples were constructed so that the replicated surface of the molar was surrounded by a flat area that could be stabilised during SBS testing with an Instron 5566 Universal Testing Machine (Instron, MA, USA) (Figure 1). The samples were randomly divided into six groups (N = 10). The sample size was based upon similar previous studies[6,9] and each group received a different pretreatment bonding protocol. Group 1 was treated with HFA and a silane application and served as a control group since this is the accepted minimum protocol for porcelain bonding. Porc-Etch (Reliance, IL, USA), a 9.6% HFA gel, and Porcelain Conditioner (Reliance, IL, USA), a silane primer, were used. An additional chemical pretreatment with a bond enhancer (Assure, Reliance, IL, USA) was used in Group 2 following the HFA and silane steps. The remaining groups received mechanical roughening. Group 3 and Group 4 samples were roughened with a green stone and a fine football shaped diamond bur at 25,000 rpm with the shaft parallel to the sample surface. Group 5 samples were sandblasted with 25 µm aluminum oxide particles at a distance of 10 mm for 10 seconds. Group 6 samples were sandblasted under the same conditions with Rocatec (3M ESPE, MN, USA) consisting of 100 µm aluminum oxide particles treated with silicon dioxide. After the

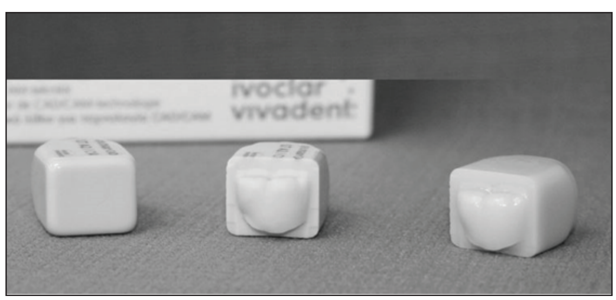

Figure 1. The porcelain samples constructed replicating surface of the mandibular molar.

roughening procedures, the HFA and silane protocol was followed.

All chemical reagents were used according to the manufacturer's recommendations. The 9.6% hydrofluoric acid was applied for 4 minutes, wiped off using a cotton roll and the ceramic surface thoroughly rinsed (Groups 1–6). The surface was subsequently air-dried and a thin coat of adhesive primer applied to all samples and allowed to dry for 60 seconds. After mechanical and chemical treatments, 0.022 Orthos mandibular left first molar attachments (Ormco, CA, USA) were bonded using Transbond XT (3M Unitek, CA, USA). The surface area of the molar attachment pad as provided by the manufacturer was 15.3 mm^2. To allow for standardised bonding of the brackets to the same location on each sample, a bonding jig was fabricated from A+ Essix material (Dentsply Raintree Essix, PA, USA) to adapt to the facial surface of the molar. The area of the bonding jig around which the bracket was to be bonded was cut out with a slight space to allow for the excess cement to be removed using an explorer. The brackets were light cured for 10 seconds from each direction, incisal, gingival, mesial, and distal.

To determine the difference between shear bond strength of enamel and porcelain, 10 extracted mandibular first molars were utilised as a control group. The teeth were embedded in an autopolymerising acrylic resin block with their facial surface exposed. The teeth were etched with 37% phosphoric acid for 30 seconds and rinsed. A self-etching, primer and adhesive system (Transbond Plus SEP, L-Pop, 3M ESPE, MN, USA) was applied for 3–5 seconds and lightly air dried for 1 second. Mandibular 0.022 Orthos left first molar attachments (Ormco, CA, USA) were bonded with Transbond XT (3M Unitek, CA, USA) and light cured for 30 seconds.

The shear bond strength at debonding was tested using an Instron 5566 Universal Testing Machine (Instron, MA, USA) at a crosshead speed of 1mm/minute. The SBS was converted into MPa using the formula MPa = F/A; where F is the maximum load, and A is bracket base area in mm^2. All specimens post-bonding were stored in PBS buffer solution at room temperature for one week and thermocycled 1000 times between 5°C and 55°C with a dwelling time of 30 seconds.[6]

All remaining adhesive resin was removed with a Reliance polishing bur (Reliance, IL, USA) and a polishing point was used to further smooth the surface.

The surface condition of the porcelain restoration following debonding and finishing was assessed via SEM images taken randomly of one sample from each group at 50×, 100×, and 200× magnification for visual inspection using an S-2700 Scanning Electron Microscope (Hitachi, Tokyo, Japan).

Results

The mean, maximum, minimum, and standard deviation SBS values for each sample group and the enamel control were calculated (Table I). A *t*-test was used to evaluate the significance (Table II).

The bond strengths of the attachments to the ceramic surface that were mechanically roughened with a green stone prior to bonding (Group 3) had a significantly higher bond strength (18.3 MPa, $p < 0.0158$) compared with the ceramic control group that received HFA and silane conditioning. This value

Table I. Mean SBS values for all groups.

Group	MPa	SD	Max	Min
Enamel	20.2	7.0	31.9	12.6
Group 1 Control	15.8	2.4	19.2	11.8
Group 2 Assure	17.4	1.8	20.1	14.1
Group 3 Green stone	17.2	3.8	20.4	7.1
Group 3 Green stone w/o outliers	18.3	1.6		
Group 4 Diamond bur	17.1	1.1	18.7	15.1
Group 5 Sandblasting	15.9	2.1	18.4	12.1
Group 6 Rocatec	16.4	2.4	19.7	11.8

Table II. *t*-test values determining significant differences between the porcelain control and test groups.

Control group vs.	*t*-value	Pr > |*t*|	Conclusion
Group 1 Enamel control	-1.88	0.0769	Not significantly different
Group 2 Assure	1.70	0.1055	Not significantly different
Group 3 Green stone	-0.96	0.3496	Not significantly different
Group 3 Green stone (after deleting outlier)	-2.68	0.0158	Significantly different
Group 4 Diamond bur	-1.49	0.1533	Not significantly different
Group 5 Sandblasting	-0.08	0.9399	Not significantly different
Group 6 Rocatec	-0.55	0.5888	Not significantly different

was calculated after the deletion of a single outlier. All other test groups fell within the same statistical range with bond strengths between 15.8 MPa for the ceramic control and 20.2 MPa for the enamel control. The variation in bond strengths for the enamel group was much higher than the ceramic groups (Standard Deviation: 7.0).

Upon visual inspection of the SEMs of the debonded and polished porcelain surfaces all test group samples subjectively appeared similar to the control group (Figure 2).

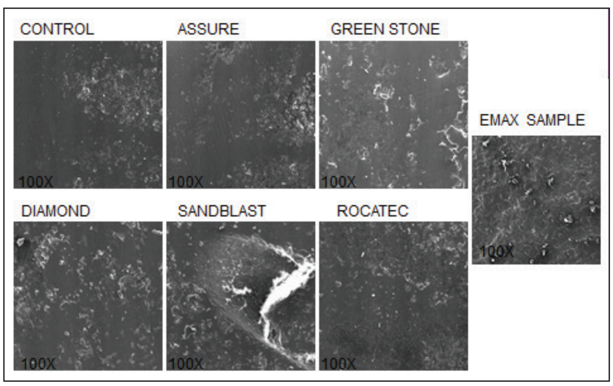

Figure 2. SEM images post-polishing under 100× magnification.

Discussion

The aim of the present study was to evaluate the effectiveness of different surface conditioning protocols on the SBS of molar brackets to lithium disilicate. The ideal strength for bonding attachments to porcelain may not be the maximum bond strength, but instead, a bond that is clinically sufficient to endure treatment, and which does not cause porcelain surface damage following attachment removal.[1]

Numerous studies have suggested that bracket bond strengths of 6–10 MPa are sufficient for clinical efficiency.[1,6,7] All SBS values in the present study fell well above this optimal range. No previous study assessed molar attachments but, rather, investigated either premolar or incisor brackets, which have a smaller pad surface area.

The protocol followed to bond to enamel has been well established and shown to be a clinically effective method.[11-13] In previous studies, which utilised extracted premolars preconditioned with Transbond Plus SEP (3M Unitek, MN, USA), the mean enamel SBS was found to be 12.2 MPa or 16.6 MPa.[12,13] The enamel experimental group in the present study served as a method of calibrating the SBS values between enamel and the different porcelain bonding protocols. All porcelain values fell within the range of values for the enamel control and were above the acceptable clinical threshold and so all values were considered to provide acceptable bond strengths.

Hydrofluoric acid gel for orthodontic purposes is widely used to etch ceramic restorations.[6] Current samples that received the HFA and silane treatment (Group 1) served as a control since the other groups received mechanical/chemical treatment in addition to the HFA and silane conditioning. Using the HFA and silane group as a control allowed for comparisons between the other groups to see whether additional procedures enhanced the bond strengths of the molar brackets to the porcelain. The roughening procedures, with the exception of the green stone, did not significantly increase SBS values, but it should be noted that the aesthetic and structural qualities of the porcelain may be irretrievably lost with surface roughening.[4]

The results of the present study indicate that the use of HFA and silane conditioning eliminates the need to mechanically roughen the restorative porcelain surface. Chemical treatment alone with HFA/silane yields SBS values within an acceptable clinical range to withstand orthodontic treatment. Since previous studies showed that silane alone is not an effective pretreatment without further mechanical or chemical treatment and hydrofluoric acid is very harmful to soft tissues, further investigation evaluating the SBS values without the HFA step, showing silane treatment in combination with the mechanical/chemical treatments, is warranted.[1,6,9]

Conclusion

The present in-vitro study found that SBS values for ceramic pretreatment all fell within an acceptable clinical range and similar to the bond strength of enamel. No significant differences were found in the SBS values, with the exception of roughening with a green stone prior to HFA and silane treatment, which yielded slightly higher bond strength. Microscopically, all surfaces were similar in appearance as a result of the differing roughening/chemical treatments.

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