Objective: To investigate the effects of different surface conditioning methods on shear bond strength (SBS) of metal brackets bonded to porcelain surfaces and the influence of silane coupling agent in altering the bond strength.

Materials and methods: A total of 80 feldspathic porcelain specimens were used. They were divided into eight different groups based on different surface conditioning methods and combinations: Sandblasting (SAB), hydrofluoric acid (HFA), diamond bur (DB) and air abrasion (AA). Silane coupling agent was used in five groups. Metal brackets were bonded and subjected to SBS testing. The efficiencies between the five individual methods used were analyzed. ARI scoring was done after debonding.

Results: The SBS range was between 3.19 and 14.38 (MPa) with a mean of 8.89 ± 3.25 (MPa). The difference between mean SBS between different groups was significant (p < 0.001). As compared to DB-based group (10.46 ± 0.69 MPa) the non-DB based group were lower (8.66 ± 3.40 MPa) but the difference was not significant (p > 0.001). When compared to AA group (9.03 ± 0.59 MPa) the non-AA group were lower (8.87 ± 3.46 MPa) but again the difference was not significant (p > 0.001). ARI score 0 was observed in 47 instances (58.8%), score 1 was observed in 25 instances (31.2%).

Conclusion: The results indicated that surface conditioning alone without silanation produced significantly low SBS. Air abrasion followed by silanation produced favorable bond strength and might have the potential to replace alternative methods.

Keywords: Porcelain, Shear bond strength, Surface conditioning, Silane and air abrasion.

INTRODUCTION

With an increased number of adults seeking orthodontic treatment, clinicians often have to bond orthodontic brackets to teeth that have different types of restoration like amalgam, gold, composite and porcelain. Among the various restorative materials, porcelain restorations has manifold advantages from an esthetic and biocompatible perspective. However, ceramic materials demonstrate a great deal of diversity in composition to suit various clinical situations.  

There has always been an ongoing debate on the various modalities of orthodontic bonding to porcelain surfaces. Moreover, the introduction of various types of ceramics, such as glass ceramic and lithium disilicate have added ambiguity for a standard procedure for orthodontic bonding to it. The purpose of mechanical alteration of the porcelain surface is to remove the glaze and roughen the surface to provide sufficient mechanical retention for the adhesives and retention of orthodontic bracket. This alteration of the porcelain surface has been achieved by hydrofluoric acid (HFA), sandblasting (SAB), diamond bur (DB), air abrasion (AA), sandpaper disks, etc. Although the changes introduced by this approach have sufficiently increased the bond strength for orthodontic purposes, they can also cause damage to the porcelain glaze which require finishing after completion of orthodontic treatment. The efficiency of various methods to improve bracket bonding on ceramic has been well investigated.  

To improve bond strength of composite resin to porcelain, a combination of mechanical and chemical conditioning methods are recommended. Previous investigations have also shown that chemical conditioning such as silanation increases the adhesion of the composite resin to the ceramic. Air polishing systems have been used in dentistry for removal of stains, pit and fissure preparation and cleaning around orthodontic fixtures. Very few studies have been done to establish its use in orthodontic surface conditioning. The efficiency of this system as a surface conditioning agent in
providing optimal bond strength to retain brackets on porcelain crowns has not been evaluated elaborately. It is conceivable that if this method is efficient, the intraoral use of hazardous chemical agents or other mechanical roughening methods can be avoided.7

The objectives of this study were to determine the effects of different surface conditioning methods on shear bond strength (SBS) of metal brackets bonded to porcelain surfaces and the influence of silane coupling agent in altering the bond strength. We hypothesize that DB and/or AA system are clinically a better option to other surface conditioning methods in terms of SBS.

MATERIALS AND METHODS

Specimen Preparation

Five individual methods based on surface conditioning were classified into: (a) Silane based, (b) sand blasted (SAB) based, (c) hydrofluoric acid based, (d) diamond bur based (e) air abrasion (AA) based and dichotomized as Yes/No.

The samples were divided into the following eight groups based on combination which were routinely used clinically: SAB, sandblasting and silane (SSi), SAB and HFA and silane (SHS), SAB and HFA (SH), HFA, HFA and silane (HSi), DB and silane (DSi) and AA and silane (ASI).

Convenient sampling of 10 in each group was done. A total of 80 samples, 3 mm thick and 10 × 10 mm square form were fabricated from the base alloy Wiron 88 (Bego, Germany) consisting of 64% Ni, 24% Cr and 10% Mo. Feldspathic porcelain (IPS design, Ivoclar-Vivadent, Schaan, Liechtenstein) at a thickness of 2 mm was fired onto the metal disks.

Methodology

SBS was performed vertically from a uniform distance of 20 mm at a pressure of 2.5 bar for 10 seconds with an intraoral sandblasting device using aluminum oxide with size of 50 microns.8

The ceramic surfaces were etched with 5% HFA for 120 seconds in a ventilated laboratory. The etchant was washed with oil-free water. HFA with low concentration was chosen as it had reduced health risks.8

The cylindrical diamond burs, with their shafts parallel to the surface of the sample were rotated at constant speed of 50,000 rpm with a force of about 1N.3

ProphyJet is an air polishing prophylaxis system which uses sodium bicarbonate powder, air and water as a slurry to remove soft debris, stain and simultaneously polishing tooth surface. Sodium bicarbonate with a size of 50 µm was blasted vertically on the sample with a distance of approximately 10 mm at a pressure of 2.5 bar.7

Monobond-S, silane coupling agent (Ivoclar, Vivadent AG, Bendererstrasse 2, FL-9494 Schaan Principality of Liechtenstein) which contains 1% 3-methacryloxypropyl-trimethoxysilane, 50 to 52% ethanol, water, saline and acetic acid was used.8

Profilometry

All the porcelain samples were examined under a 2D non-contact profilometer after surface conditioning to check for any gross changes.9 This procedure was carried out to eliminate any sample with major porcelain fracture.

Bonding

A total of 80 mandibular first premolar metal brackets were divided into eight groups with 10 samples each (3M—Unitek Corporation, USA) and were bonded to each conditioned porcelain sample using light cure composite resin (3M Transbond XT, USA) according to the manufacturer’s instructions.

In this study, brackets for the mandibular premolar were used due to their concave bases that ensure optimal adaptation to the prepared convex ceramic surface. The bracket base retention onto the tooth surface relied on mechanical interlocking principle. The porcelain surface was cleaned and dried with oil-free compressed air, after they were conditioned. The composite was applied to the bracket base and placed on the porcelain sample with a force of 5N. Excess composite was removed and all samples were cured with a conventional Light Cure Unit (3M Unitek, USA) for 20 seconds.

Thermocycling (TC)

To simulate the oral condition all the samples were stored in 0.9% NaCl solution for 24 hours.10 All samples were thermocycled 5,000 times between 5ºC and 55ºC with a dwelling time of 30 seconds as recommended by IOS (International Organization for Standardization).11

Shear mode Testing

The porcelain samples were mounted on a jig and the brackets were vertically oriented. Specimens were then subjected to shear forces by attaching a steel wire loop under the occlusal tie wings of the bracket in a universal testing device (LR 100K, Lloyd Instruments, England) with a crosshead speed of 2 mm/minute at a scale load of 100 N until bond failure occurred12 (Fig. 1). The force required to shear the bracket was recorded and the SBS was calculated in MegaPascals (MPa).13

ARI Scoring

Following bond failure the crowns were examined under light stereomicroscopy at ×20 magnification to establish the amount of composite resin left behind according to the adhesive remnant index (ARI).14
Statistical Analysis

All data were entered and analyzed using SPSS Version 17 (IBM, IL, USA). Descriptive statistics are presented for groups as well as ARI scores. The groups were cross-tabulated for each ARI score and the difference between them was assessed using chi-square test. Comparison of mean between silane, SAB, HFA, DB, AA based method were done using independent t-test. A p-value of less than 0.05 was considered significant.

RESULTS

Five different modes of surface conditioning were performed and the descriptive results were summarized in Table 1. The SBS range was calculated from the 80 samples and it was 3.61 to 13.98 (MPa) with mean 8.8934 ± 3.25 (MPa). The difference between mean SBS between different groups was significant. Mean and standard deviation of SBS with each ARI score is summarized in Table 2.

ARI score 0 was observed in 47 instances (58.8%), score 1 was observed in 25 instances (31.2%), score 2 was observed in 7 instances (8.8%) and score 3 was observed in 1 instance (1.2%). Graph 1 shows the distribution of ARI score in each study group.

As compared to silane-based technique (10.99 ± 1.94 MPa) the SBS in nonsilane-based technique was lower (5.41 ± 1.51 MPa) and the difference was significant (p < 0.001). As compared to the SAB-based group (9.49 ± 3.81 MPa) the non-SAB group was lower (8.28 ± 2.46 MPa) and the difference was not significant (p > 0.001). As compared to HFA-based group (6.82 ± 2.65 MPa) the non-HFA-based group

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**Table 1: Different groups with their mean shear bond strength**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean shear bond strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAB</td>
<td>4.56 ± 0.85</td>
</tr>
<tr>
<td>SSt</td>
<td>12.57 ± 0.84</td>
</tr>
<tr>
<td>SHS</td>
<td>13.26 ± 0.72</td>
</tr>
<tr>
<td>SH</td>
<td>7.31 ± 0.83</td>
</tr>
<tr>
<td>HFA</td>
<td>4.33 ± 0.72</td>
</tr>
<tr>
<td>HSi</td>
<td>9.21 ± 0.76</td>
</tr>
<tr>
<td>DSt</td>
<td>10.62 ± 0.59</td>
</tr>
<tr>
<td>ASi</td>
<td>9.04 ± 0.59</td>
</tr>
</tbody>
</table>

SAB—sandblast; SSt—sandblast + silane; SHS—sandblast + hydrofluoric acid + silane; SH—sandblast + hydrofluoric acid; HFA—hydrofluoric acid; HSi—hydrofluoric acid + silane, DSt—diamond bur + silane; ASi—air abrasion + silane; MPa—megapascal

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**Table 2: ARI scoring with minimum and maximum values**

<table>
<thead>
<tr>
<th>ARI score</th>
<th>Mean and std. deviation of bond strength in MPa</th>
<th>Minimum (MPa)</th>
<th>Maximum (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score 0</td>
<td>7.0490 ± 2.64984</td>
<td>3.19</td>
<td>12.67</td>
</tr>
<tr>
<td>Score 1</td>
<td>10.9273 ± 1.75130</td>
<td>8.86</td>
<td>13.83</td>
</tr>
<tr>
<td>Score 2</td>
<td>13.2976 ± 1.45096</td>
<td>11.00</td>
<td>14.38</td>
</tr>
<tr>
<td>Score 3</td>
<td>13.9000</td>
<td>13.90</td>
<td>13.90</td>
</tr>
</tbody>
</table>

ARI—adhesive remnant index; MPa—megapascal
was higher and the difference was significant (p ≤ 0.001). As compared to DB-based group (10.46 ± 0.69 MPa) the non-DB-based group was lower (8.66 ± 3.40 MPa) but the difference was not significant (p ≥ 0.001). As compared to AA group (9.03 ± 0.59 MPa) the non-AA group was lower (8.87 ± 3.46 MPa) but again the difference was not significant (p ≥ 0.001). As compared to AA group results further, it was observed that 95% confidence interval (CI) was wide; mean 8.67 ± 3.41; 95% CI was 7.86 to 9.49 and a range of 3.19 to 14.38 MPa. Whereas the DB-based group results yielded a mean: 10.47 ± 0.69; 95% CI: 9.97 to 10.96 and a range of 9.48 to 11.46 MPa. The wide difference in the non-DB-based technique has probably contributed to the absence of significance of p-value. On examining the AA group results further it was observed that 95% confidence interval was significant (mean: 9.03 ± 0.59; 95% CI: 8.6-9.45 and a range: 8.02-10.15 MPa). The AA has a good mean SBS (10.40 ± 0.69 MPa) only second to HFA based (10.98 ± 1.93 MPa).

### DISCUSSION

The aim of this study was to find the most reliable method for bonding metal brackets onto porcelain fused metal ceramic crowns. The use of AA was intended for clinical application with several core advantages namely, (1) versatility, (2) less technique sensitivity, (3) avoidance of hazardous material, with high SBS that can be comparable to existing surface conditioning methods.15,16 The bond strength is also influenced by a number of environmental factors which has to be taken into consideration.17,18 In the present investigation the specimens were subjected to TC to simulate ageing as in oral conditions.15 TC of at least 500 cycles is required to test the bond strength of brackets to porcelain and shear bond testing after TC has been the standard method of measuring the bond strength of brackets to different substrates. The next important preparation is the surface roughening of the sample which is a pre-requisite for achieving sufficient bond strength on metal or porcelain. Surface roughening increases the surface area available for chemical and mechanical retention and has been proposed by several authors as an effective way to increase the bond strength between composite and porcelain.19,20 Removal of the glaze by grinding with stones reduces the transverse strength of porcelain thereby increasing crack propagation.21 Hence, in this study deglazing of the samples were done by SAB. Ten samples which were subjected to SAB alone were treated as control group.

The retention of the bracket to acid-etched enamel relies on penetration of bonding composite into the etched enamel by formation of resin tags. The glazed surface of porcelain crown do not permit such resin tag formation. Previous research has shown that surface conditioning followed by silane application significantly improved the bond strength.22 In the porcelain-composite bond, silane functions as a coupling agent. The role of a coupling agent is to adsorb onto and alter the surface of porcelain, facilitating interaction.23 In this study the samples in which silane was not used, yielded very low SBS (≤ 6 MPa) (SAB, SHS, and HFA). Superior bond strength was observed in samples following the use of silane coupling agent (SSI, SHS, DSI, and ASI).24

Another important factor to be taken into consideration is the kind of bond failure. Cohesive failures within the ceramic indicate that the composite resin-ceramic compound was stronger than the ceramic layer itself.25 Cohesive failures occur when SBS is higher than 13 MPa.26 An ARI score of 3, only in one sample (SSI) is reminiscent of the fact that there was no cohesive failure in the study. In clinical practice the incidence of ceramic damage while debonding the brackets are stated to be very low, since peeling forces are predominant and are different from shear testing in laboratory.3 Introral SAB with aluminium oxide exhibited high surface roughness which results in more repair work, like polishing after debonding.27,28 Given the convenience of eliminating the hazards associated with using HFA without a rubber dam during bonding orthodontic brackets, it would be of interest to determine whether an alternative system produces acceptable SBS.29 So in our study we made an effort to alter the porcelain surface with AA sprays, which contained sodium bicarbonate as an abrasive.30 Owing to its toxicity and handling issues HFA is less preferred for chairside application. Hence, in our opinion AA-based methods are more clinically relevant and the ease of handling will facilitate us to use the advantage of high SBS. Therefore, AA conditioning can be considered for surface treatment before bracket bonding.

### Table 3: Groups based on individual methods

<table>
<thead>
<tr>
<th>Groups</th>
<th>Yes (Mean SBS in MPa ± Confidence Interval)</th>
<th>No. (Mean SBS in MPa ± Confidence Interval)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower bound</td>
<td>Upper bound</td>
<td>Lower bound</td>
</tr>
<tr>
<td>Silane based</td>
<td>10.98 ± 1.93</td>
<td>8.03</td>
<td>14.38</td>
</tr>
<tr>
<td>SAB based</td>
<td>9.49 ± 3.81</td>
<td>3.19</td>
<td>14.38</td>
</tr>
<tr>
<td>HFA based</td>
<td>6.82 ± 2.65</td>
<td>3.50</td>
<td>11.00</td>
</tr>
<tr>
<td>DB based</td>
<td>10.46 ± 0.69</td>
<td>9.48</td>
<td>11.46</td>
</tr>
<tr>
<td>Air abrasion based</td>
<td>9.03 ± 0.59</td>
<td>8.03</td>
<td>10.15</td>
</tr>
</tbody>
</table>

SAB—sandblast; HFA—hydrofluoric acid; DB—diamond bur; *—significant
CONCLUSION

Within the limitations of this study the following conclusions were made:

1. The results indicated that surface conditioning alone without silanation produced significantly low SBS. The use of silane was the single most important factor in determining satisfactory bond strength.
2. It was not necessary to use HFA which is highly toxic and corrosive, to achieve satisfactory bond strength.
4. AA followed by silanation produced favorable bond strength and might have the potential to replace alternative methods.

REFERENCES