Orthodontic possibilities on ceramic surfaces with 10-methacryloyloxydecyle dihydrogen phosphate

Shobha Sundareswaran, BDS, MDS¹
Ustad Usman, BDS, MDS²

Aim: To evaluate the shear bond strength of orthodontic brackets bonded to porcelain surfaces using a recently introduced adhesive containing 10-methacryloyloxydecyle dihydrogen phosphate (10-MDP) (Panavia F2) and comparing it with two other bonding systems, Transbond XT and Fuji Ortho LC. Methods: Three groups, each consisting of 20 porcelain premolars, were bonded with metal orthodontic brackets (0.022 MBT) using 10-MDP (group I), Transbond XT (group II), and Fuji Ortho LC (group III). All ceramic surfaces were etched with 9.6% hydrofluoric acid followed by application of a silane coupling agent prior to bonding. All specimens were stored in artificial saliva at 37°C for 24 hours and thermocycled between 5°C and 55°C for 500 cycles before debonding with an Instron universal testing machine. The shear bond strength, adhesive remnant index, and sites of bond failure were recorded. Differences between the groups were statistically analyzed using ANOVA, Tukey HSD, and Pearson chi-square tests. Results: Group I (12.52 ± 3.64 MPa) had the highest shear bond strength as compared with group II (9.45 ± 4.58 MPa) and group III (9.53 ± 2.55 MPa) (P < .05). The ARI scores of all the three groups showed no significant differences among the groups. However, porcelain damage was visible in some samples in all groups. Conclusion: Group I samples bonded with 10-MDP exhibited the highest mean shear bond strength, but the risk of porcelain damage necessitates caution. ORTHODONTICS (CHIC) 2012;13:e29–e36.

Key words: 10-methacryloyloxydecyle dihydrogen phosphate, ceramic, shear bond strength

Clinicians today are faced with large numbers of adults seeking orthodontic care. This has resulted in the need to bond orthodontic brackets and fixed retainers to a variety of restorations, including ceramic crowns, partial dentures, and veneer laminates. Bonding to porcelain has thus become a common procedure.

Direct bonding of orthodontic brackets to porcelain surfaces is a double challenge. On the one hand, optimum bond strength has to be achieved.¹ On the other, debonding must leave the porcelain surface as it was before the treatment—esthetically, structurally, and functionally perfect.²,³ Hence, an investigation into the orthodontic possibilities of a resin should address both these aspects.

The literature is replete with various adhesives and methods to provide adequate bond strength to porcelain. This includes surface preparation techniques...
to enhance the adhesion of resins to the ceramic surface by roughening using coarse diamond stone, sandpaper disks, or sandblasting. Although these procedures significantly increase bond strength, they also cause irreversible damage to porcelain glaze.

Etching the porcelain with 37% phosphoric acid, 9.6% hydrofluoric acid, and 4% acidulated phosphate fluoride (APF) have also been advocated, but 4% APF was reported to be less effective. Nd:YAG (neodymium-doped yttrium aluminum garnet) lasers have also been shown to be an acceptable substitute for hydrofluoric acid while etching ceramic surfaces. Another approach used to enhance bond strength to porcelain surfaces is to change the nature of the surface using a coupling agent, such as silane. Silanes are also known as adhesion promoters and function by absorbing onto and altering the surface of a solid material (in this case, porcelain) by either a chemical or physical process to increase its interaction with other materials. The portion of the silane molecule that is not absorbed presents a free surface that is easily wetted by adhesive materials.

Traditionally, light-cured composite resins such as Transbond XT (3M Unitek) and resin-modified glass-ionomer cements such as Fuji Ortho LC (GC) have been used for orthodontic bonding to ceramic surfaces with reasonable success. Another adhesive for bonding to porcelain surfaces is 10-methacryloyloxydecyldihydrogen phosphate (10-MDP) (Panavia 21, Kuraray Dental), a self-curing resin containing a phosphate monomer. However, because it is a self-cure adhesive, manipulation time is limited. More recently, a dual-cure version of the aforementioned adhesive containing the same 10-MDP has become available (Panavia F.2). The fact that this can be cured with any halogen, plasma arc, or light-emitting diode (LED) light may prove clinically useful for orthodontic bonding. The other claimed advantage of the version is that it releases fluoride. These adhesives are currently being used for cementation of restorations such as crowns, partial dentures, veneers, inlays and onlays of ceramic, metal, or composite resin. The use of 10-MDP has been recommended for bonding orthodontic brackets to ceramic surfaces.

Another matter of concern while bonding to porcelain surfaces is the potential for fracture at debonding. The literature is replete with various debonding protocols, all aimed at producing minimal damage to ceramic surfaces, as well as achievement of an ideally finished porcelain surface after debonding. This is an important consideration while evaluating a new resin for possible bonding to these surfaces.

There are no studies investigating the performance of 10-MDP in terms of orthodontic bracket bonding. Hence, this study was undertaken for investigating the possibility of using this adhesive for orthodontic bonding to ceramic surfaces considering the claimed advantages.

This study aimed to evaluate and compare the shear bond strength of metal brackets bonded to porcelain surfaces with three different adhesives—Panavia F.2, TransBond XT, and Fuji Ortho LC and compare the adhesive remnant index (ARI) scores among these three groups. The null hypothesis generated was that there would be no significant difference in the shear bond strength of metal orthodontic brackets bonded to porcelain surfaces using the three tested adhesives.

METHODS

Sixty porcelain-fused-to-metal crowns fabricated using feldspathic ceramic material (Vita, Zahnfabrik) with the morphologic characteristics of a natural premolar were used in this study. Each crown was embedded in a rectangular
acrylic block such that the buccal surface was parallel to one of the surfaces of the acrylic block. The samples were divided into three groups of 20 each as per the minimum number recommended for laboratory bond strength testing.\textsuperscript{33} Samples were color-coded (group I, black; group II, pink; and group III, white).

Surface preparation
All samples were prepared for bonding according to the following procedure:

- The labial surface of each crown was cleaned for 10 seconds with nonfluoride oil-free pumice paste in prophy cup attached to a low-speed handpiece, rinsed with water, and dried with an oil-free air spray.
- Etching was done with 9.6\% hydrofluoric acid (Pulpdent) for 1 minute, rinsed with water for 15 seconds, and dried with an oil-free air spray.\textsuperscript{20,27}
- Two to three layers of silane coupling agent (Clearfil Ceramic Primer, Kuraray Dental) were applied to the etched surface and dried for 30 seconds.

Bonding
Sixty metal 0.022-inch MBT prescription brackets (Gemini series, 3M Unitek) with a bracket base area of 12.35 mm\(^2\) were used for this study.

**Group I (black).** The metal brackets were bonded with adhesive containing 10-MDP to the ceramic surfaces. The kit consists of ED Primer II (adhesive primer—liquid A, 4 mL; liquid B, 4 mL); Panavìa F 2.0 paste (paste A, 2.3 mL; paste B, 2.3 mL); OxyGuard II (6 mL). The bonding procedure followed the manufacturer’s instructions. Following surface preparation, ED Primer A and B were mixed for 5 to 10 seconds. The mixed primer was then applied to porcelain surface and left for 30 seconds and dried using oil-free air spray. Equal amounts of paste A and paste B were dispensed and mixed for 20 seconds on the paper pad. The mixed paste was applied to the base of brackets, which were placed on the midbuccal surface of the crown and firm seating pressure was applied until bracket to tooth contact was achieved. Any excess material was immediately removed from around the bracket base using a sharp scaler.

**Group II (pink).** Brackets were bonded with Transbond XT according to the manufacturer’s instructions.

**Group III (white).** Brackets were bonded with Fuji Ortho LC as specified by the manufacturer.

All the specimens were then light cured (Mectron, Straight Pro) for 40 seconds by curing for 10 seconds each from the mesial, distal, gingival, and occlusal margins.

Storage and thermal cycling
Samples were stored in artificial saliva at 37\(^\circ\)C for 24 hours.\textsuperscript{34} Specimens were then cycled again for 500 cycles between water baths of 55\(^\circ\)C and 5\(^\circ\)C with dwell times of 30 seconds. Samples were then returned to storage conditions for 24 hours before bracket removal.

Debonding
Brackets were debonded using a universal testing machine (Instron 3365, Instron). Shear force was applied with a looped wire around the bracket in an occlusogingival direction parallel to the labial surface of the embedded tooth with a speed of 1 mm/min. The maximum load and breaking loads were recorded electronically in N, converted to MPa as a ratio of Newtons to surface area of the bracket, and expressed as MPa using the following formula:

\[
\text{Debonding force in kgs} \times 9.81 = \text{force in N}
\]
\[
\text{Force in MPa} = \frac{\text{force in N}}{\text{bracket base area in mm}^2}
\]
After debonding, the porcelain crowns were examined by the same operator under a light stereomicroscope at 10× magnification. Any adhesive that remained after the bracket removal was assessed and scored according to the modified ARI, which includes a score of 4 for samples with damaged porcelain surfaces.

This index consists of the following scoring: 0, no retained resin; 1, < 50% retained resin; 2, > 50% retained resin; 3, all resin retained with bracket imprint; and 4, damaged porcelain surface.

Statistical analysis was performed SPSS (IBM). Routine statistical functions such as mean, maximum, and minimum values; range, and standard deviations (SDs) were calculated and tabulated for each group. Mean values of shear bond strengths were compared with using one-way analysis of variance (ANOVA) followed by Tukey honestly significant difference (HSD) procedure (quantitative data). The Pearson chi-square test (nonparametric) was done to test the significance of the association between ARIs (qualitative data). \( P < .05 \) was considered statistically significant.

## RESULTS

The means and SDs of the shear bond strength values of the groups are given in Table 1. Samples in group I showed the highest mean bond strength. ANOVA and Tukey HSD (Tables 2 and 3) showed that there was a significant difference between groups I and II \( (P < .05) \) and between groups I and III \( (P < .05) \). No significant difference was found between groups II and III.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean ± SD shear bond strength values of the different study groups</th>
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<tbody>
<tr>
<td>Group</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>I</td>
<td>12.52 ± 3.64</td>
</tr>
<tr>
<td>II</td>
<td>9.45 ± 4.58</td>
</tr>
<tr>
<td>III</td>
<td>9.53 ± 2.55</td>
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SD, standard deviation.

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<tr>
<th>Table 2</th>
<th>One-way ANOVA test to calculate ( P ) value</th>
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<tbody>
<tr>
<td>Group</td>
<td>Sum of squares</td>
</tr>
<tr>
<td>Between groups</td>
<td>122.382</td>
</tr>
<tr>
<td>Within groups</td>
<td>776.812</td>
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<tr>
<td>Total</td>
<td>899.195</td>
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</tbody>
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\( df, \) degrees of freedom. *The mean difference is significant at .05.

<table>
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<tr>
<th>Table 3</th>
<th>Tukey HSD test to identify the significance of mean shear bond strength between different study groups</th>
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</thead>
<tbody>
<tr>
<td>Groups compared</td>
<td>Mean difference</td>
</tr>
<tr>
<td>I vs II</td>
<td>3.071</td>
</tr>
<tr>
<td>I vs III</td>
<td>2.986</td>
</tr>
<tr>
<td>II vs III</td>
<td>−0.0845</td>
</tr>
</tbody>
</table>

*The mean difference is significant at .05.
Percentage distribution and mean ARI scores for three groups is shown in Table 4. Group I samples showed the highest percentage of damage to porcelain surface (50%) followed by group II samples (40%) and group III samples (35%). The chi-square test (nonparametric test) showed no statistically significant differences between the means of ARI score among the three groups compared (Table 5).

**DISCUSSION**

The findings of the present study showed that shear bond strength of group I samples bonded with adhesive containing 10-MDP ranged between 5.52 MPa and 17.92 MPa with a mean of 12.52 ± 3.64 MPa. This was significantly greater than the values of groups II and III. Kuraray initially synthesized and patented the monomer 10-MDP. It is mainly used as an etching monomer, due to the dihydrogen phosphate group, which can dissociate in water to form two protons. Structurally, the long carbonyl chain renders this monomer hydrophobic. This monomer is capable of forming strong ionic bonds with calcium, due to the low dissolution rate of the resulting calcium salt in its own solution, which accounts for its chemical bonding to hydroxyapatite ions and many other metallic and nonmetallic surfaces.  

The mean shear bond strength of group II samples was 9.45 ± 4.58 MPa. This result correlates with some findings, but is higher than other previous studies. The shear bond strength of group III samples ranged between 3.31 to 13.57 MPa (mean range, 10.26 MPa) with a mean value of 9.53 ± 2.55 MPa. This result is in agreement with the findings of Lifshitz and Cardenas. Fuji Ortho LC requires three chemical reactions for the complete setting of the adhesive: (1) traditional glass-ionomer acid-based reaction; (2) light-activated radical polymerization of HEMA (hydroxyethyl methacrylate) and two other polymers to form a poly-HEMA matrix; and (3) self-cured resin monomers. This could probably explain the more narrow range and more consistent values of shear bond strength reported for group III (Table 1).

The clinically acceptable shear bond strength for orthodontic purposes on natural teeth is in the range of 6 to 8 MPa. Higher values of 14 MPa have been advocated. In the present study, the mean shear bond strength is in the middle of these values.
Conventional methods of orthodontic bonding to enamel are largely unsuccessful when employed with porcelain. The use of 37% phosphoric acid as an etchant for ceramic surfaces is found to be controversial in the literature. Some authors have recommended its use, while others say that porcelain does not respond to the application of 37% phosphoric acid when used to obtain micromechanical retention. Etching of porcelain with hydrofluoric acid is reported to be the most significant factor in achieving good bond strengths. Despite the effect of enhanced resin-porcelain bond strength, intraoral use of hydrofluoric acid must be undertaken cautiously, with use of rubber dam isolation, eye protection, and high-volume air evacuation.

The use of silane coupling agents has also been reported to enhance bond strength to porcelain. Silane application to a porcelain surface results in alteration of the surface tension, thereby improving wettability of the porcelain surface. Better penetration of the bonding resin into the microporosities of the porcelain results in an enhanced bond.

ARI
The ARI showed high incidences of porcelain surface damage at debond in all the three groups tested (Table 4). The higher the bond strength, greater was the incidence of damaged porcelain (Fig 1). Group I showed the highest damage (50%), and the composite resin group (group II) showed 40% damage. This is in agreement with a previous study. Group III exhibited the least damage in this study (35%), but the difference between the three groups was statistically insignificant. From a clinical perspective, therefore, it would appear prudent to warn patients about the risk of damage to porcelain surfaces prior to bonding and the need for possible repair/replacement following orthodontic treatment.

Apparently, while achieving optimum bond strengths, the need of the hour seems to be a clinically acceptable debonding protocol, which will allow easy clean up and leave the bond surface blemish-free and undamaged. Rather than focusing on the magnitude of the bond strengths, clinicians need to be continually mindful of possible iatrogenic damage at the debonded interfaces such as enamel fractures, tearing, and crazing. Opinions regarding use of tensile vs shear forces for debonding seems divided. Shear bond strength is reported to be three times higher than tensile bond strength implying lesser debonding force clinically, while removing brackets with tensile force than with shearing force. Tensile forces reportedly produced less damage to enamel. An earlier study, however, had reported higher stress levels with tensile mode as indicated by von Mises stress distribution and consequently recommended debonding with shear forces. While extrapolating the results of this study, it has to be kept in mind that tensile stress is not the only component responsible for increase in von Mises stress.
Ultimately, the safest way to remove brackets with respect to reducing the chances of enamel/ceramic surface damage is to use the debonding technique specifically designed for each bracket.\textsuperscript{29} Careful use of carbide burs for composite removal, followed by the use of the Shofu polishing ceramiste points, diamond-impregnated polishing wheels, and diamond polishing paste offers an almost ideal finish of the porcelain surface after debonding.\textsuperscript{13,32}

Results of the present study indicate that 10-MDP offers excellent shear bond strength and the values are significantly higher than conventional composite or resin-modified glass-ionomer cement but lower than that recommended by Newman et al.\textsuperscript{15} However, the risk of porcelain fracture necessitates caution during debonding and strict adherence to manufacturer instructions regarding the debonding protocol specified for each bracket.

This being an in vitro study, it may not closely mimic the clinical environment. However, it has been stated that an independent, unbiased laboratory based testing of all new biomaterials should form the basis of product selection in clinical orthodontic practice.\textsuperscript{38} A clinical study is later warranted to confirm these findings.

CONCLUSION

The following can be concluded from this study:

- The null hypothesis that there would be no significant difference in the shear bond strength of brackets bonded with 10-MDP, Transbond XT, and Fuji Ortho LC was rejected.
- The study showed that the shear bond strength of metal brackets bonded to ceramic surfaces with 10-MDP is significantly higher than those bonded with Transbond XT and Fuji Ortho LC.
- Brackets bonded with 10-MDP showed higher damage to porcelain surfaces as evidenced by the ARI scores. The difference was not statistically significant.

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REFERENCES