Fluoride Prophylactic Agents Effect on Ceramic Bracket Tie-Wing Fracture Strength

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ABSTRACT
Objective: To test the hypothesis that fluoride prophylactic agents do not affect the fracture strength and fracture morphology of the tie-wing complex of ceramic brackets.

Materials and Methods: The fracture strength of the distal incisal tie-wing of two polycrystalline brackets, Clarity and Mystique, and a monocrystalline bracket, Inspire, was measured after the brackets were exposed to either Prevident, Phos-flur gel, or distilled water (control). Scanning electron microscopy was used to qualitatively evaluate the tie-wing intact and fractured surfaces.

Results: A two-way analysis of variance and Fisher-Hayter post hoc test indicated a significant decrease in tie-wing fracture strength following both fluoride treatments when compared with the distilled water control only with the monocrystalline bracket. None of the bracket brands exhibited any qualitative differences in the tie-wing intact or fracture surfaces as a function of fluoride treatment.

Conclusions: The hypothesis is rejected. Based on the results, using topical fluoride agents with monocrystalline brackets might be contraindicated because of increased tie-wing fracture susceptibility.

KEY WORDS: Topical fluoride treatments; Fracture resistance

INTRODUCTION

There is a growing trend toward nonmetallic, almost invisible orthodontic brackets, with ceramic brackets as a popular option because of their acceptable aesthetic appearance. Unlike metallic brackets, ceramic brackets have the potential for fracture and thus are more prone to complications for the orthodontist. Ceramic materials used for orthodontic brackets are made from aluminum oxide (alumina). All currently available ceramic brackets are composed of polycrystalline or monocrystalline alumina. Polycrystalline alumina differs from monocrystalline alumina in that it contains a crystal or grain boundary phase. Magnesia, a sintering aid for alumina, facilitates the growth of these boundaries. Monocrystalline brackets are manufactured from a single crystal rod milled into the shape and dimension of the bracket, while polycrystalline brackets are injection molded or machined.

When comparing mechanical properties, monocrystalline brackets are harder than polycrystalline brackets. However, surface defects produce greater decreases in monocrystalline strength as compared to changes in polycrystalline strength. This is a reflection of the higher fracture toughness of polycrystalline alumina, whereby crack propagation occurs more slowly because of crack interaction with grain boundaries, while monocrystalline alumina fractures all at once because of a lack of such boundaries.

Because poor oral hygiene of orthodontic patients is a primary concern to the practitioner, topical fluorides are frequently recommended to help prevent demineralization of enamel surrounding orthodontic brackets. However, topical fluoride agents may act as corrosive agents, producing surface damage and...
strength reduction in dental materials such as implant and orthodontic alloys, composite resins, and restorative porcelain ceramics. Although monocristalline and polycristalline alumina ceramics are reported to be susceptible to corrosion and associated strength reduction following exposure to either humidity or acidic conditions, to date, there have been no investigations focusing on the effect of commonly used topical fluorides on ceramic bracket mechanical properties, such as fracture strength. Mechanical property degradation could lead to bracket fracture and, more specifically, tie-wing fracture, a persistent problem with ceramic bracket use.

The purpose of this study is to test the hypothesis that fluoride prophylactic agents will affect the fracture strength and associated fracture morphology of the tie-wing complex of ceramic brackets.

MATERIALS AND METHODS

Three alumina ceramic brackets, Clarity (3M Unitek, Monrovia, Calif), a polycrystalline bracket with true-twin tie-wing configuration; Mystique (GAC International, Bohemia, NY), a polycrystalline bracket with semi-twin tie-wings; and Inspire (ORMCO, Orange, Calif), a monocristalline bracket with true-twin tie-wings, were used (Figure 1). Maxillary right central incisor brackets with 0.018-inch archwire slots were used. The high fluoride-ion concentration gels used were Phos-flur gel (1.1% acidulated phosphate fluoride [APF], 0.5% w/v fluoride, pH 5.1; Colgate Pharmaceuticals, Canton, Mass) and Prevident 5000 (1.1% sodium fluoride neutral agent, 0.5% w/v fluoride, pH 7; Colgate Pharmaceuticals). Fluoride concentration and pH information were provided by the manufacturer.

Specimen Preparation

Ceramic brackets were bonded to stainless steel cylinders. To ensure that bracket debonding would not occur before bracket fracture, cylinders were roughened with 50-μm Al₂O₃ particles (Micro-Cab; Danville Engineering, San Ramon, Calif). After cleaning with acetone, Siloc Pre metal surface conditioner (Heraeus Kulzer, Armonk, NY) was applied to the abraded cylinder and dried for 1 minute. The cylinder was placed in an oven for 4 minutes at 350°C. After a 5-minute cooling at room temperature, both the cylinder and bracket mesh were coated with Scotchbond Ceramic Primer (3M ESPE, St Paul, Minn) and dried for 1 minute. Scotchbond Multipurpose Adhesive (3M ESPE) was applied to both the cylinder and bracket mesh using a brush, and each surface was photopolymerized for 40 seconds (curing light output, 600 mW/cm²). The bracket was placed on the cylinder following the application of Transbond composite resin cement (3M ESPE) to the bracket mesh. Care was taken to ensure no composite was under the tie-wing or in the archwire slot. The composite was photopolymerized from five directions (mesial, distal, gingival, incisal, and facial) for 40 seconds each.

Each ceramic bracket/cylinder specimen was placed in a 25-mL plastic vial (Fisher Scientific, Hanover Park, Ill) cut to 21-mm height, allowing suspension of the bracket/cylinder in either 2 mL of one of the fluoride solutions or distilled, deionized H₂O (dH₂O), control. All bracket/cylinder specimens were incubated at 37°C for 4 hours. Following incubation, specimens were removed from their respective solutions, rinsed with dH₂O for approximately 30 seconds, and placed in a new dH₂O vial. Based on a power analysis of preliminary data, a sample size of 10 brackets for each experimental condition (fluoride or distilled water) allowed detection of a mean difference of 20% with parameters of α = .05 and 1 − β = .80.

Mechanical Testing

Bracket specimens were tested with a universal testing machine (1125/5500; Intron Corp, Canton, Mass). A 0.014-inch stainless steel ligature tie wire was looped under the distal incisal tie-wing and tied around a steel pulley attached to the mechanical tester load cell (Figure 2). A 0.014-inch wire was necessary because wires with a smaller diameter are prone to fail before bracket failure. The distal incisal tie-wings were tested to failure at 10 mm/min cross-head speed with tensile force/load at failure recorded with Merlin software (version 5.53; Intron Corp). Fracture stress or strength (MPa) was calculated by dividing the force (N) by the contact area between the ligature wire and tie-wing.

Figure 1. Ceramic bracket facial and distal views. (A) Clarity. (B) Mystique. (C) Inspire. The arrow in (A) indicates the orientation of the distal incisal tie-wing used for mechanical testing.
Figure 2. Mechanical testing setup. (A) Cylinder/bracket/ligature with pulley attached to load cell. (B) A 0.014-inch steel ligature wire was looped under the distal incisal tie-wing.

A two-way analysis of variance (ANOVA; \( \alpha = .05 \)) evaluated whether there was a significant interaction between the experimental condition and bracket brand. In addition, separate one-way ANOVAs were used to analyze the fracture strength of each bracket brand as a function of the three experimental conditions. If there was a significant difference between groups, a Fisher-Hayter post hoc test (\( \alpha = .05 \)) was used to identify which groups were significantly different from the \( \text{dH}_2\text{O} \) control.

**Bracket Surface Characterization**

Following mechanical testing, three representative specimens were selected from each bracket/experimental condition group for scanning electron microscopy (SEM) analysis to characterize the intact mesial incisal tie-wing topography and the fractured distal incisal tie-wing surface. Specimens were observed with an XL30 field-emission SEM (Philips Electron Optics, Hillsboro, Ore) at 15.0 kV.

**RESULTS**

Statistical analysis of the tie-wing fracture strength results (Table 1) indicated a significant interaction effect (\( P = .040 \)) between the fluoride treatment and bracket brand on tie-wing fracture strength. The post hoc test indicated a significant decrease (\( P = .017 \)) in the tie-wing fracture strength of the monocrystalline Inspire brackets following exposure to both Phos-flur and Prevident fluoride gels as compared with the \( \text{dH}_2\text{O} \) control. In contrast, there was no significant effect (\( P > .05 \)) of either fluoride treatment on the polycrystalline brackets' (Clarity, Mystique) tie-wing fracture strength. However, it should be noted that even with fluoride treatment, the monocrystalline brackets still have a significantly higher (\( P = .001 \)) tie-wing fracture strength than the polycrystalline brackets.

Representative SEM images of the polycrystalline Clarity and Mystique intact and fractured tie-wings exposed to \( \text{dH}_2\text{O}, \) Prevident, and Phos-flur gel are presented in Figures 3 and 4, respectively. With both brackets, there were no surface changes on the intact mesial incisal tie-wing surfaces on any of the fluoride-treated specimens as compared with the \( \text{dH}_2\text{O} \) control. Clarity and Mystique fractured tie-wing surfaces, irrespective of treatment, demonstrated fractures propagated along grain boundaries (intergranular), with minimal transgranular fracture observed in some of the Clarity specimens. However, with Mystique, the untested, mesial incisal tie-wing was partially fractured in all specimens; this is related to the bracket’s semitwin design with ceramic material connecting the mesial and distal aspects of the incisal and gingival tie-wings.

<table>
<thead>
<tr>
<th>Bracket Brand</th>
<th>Condition (N = 10)</th>
<th>Fracture Strength, MPa</th>
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<tbody>
<tr>
<td>Clarity</td>
<td>( \text{dH}_2\text{O} ) (control)</td>
<td>81.23 ± 12.10</td>
</tr>
<tr>
<td></td>
<td>Phos-flur gel</td>
<td>88.54 ± 9.18</td>
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<tr>
<td></td>
<td>Prevident</td>
<td>89.25 ± 6.65</td>
</tr>
<tr>
<td></td>
<td>( \text{dH}_2\text{O} ) (control)</td>
<td>125.38 ± 21.05</td>
</tr>
<tr>
<td>Mystique</td>
<td>Phos-flur gel</td>
<td>118.54 ± 11.43</td>
</tr>
<tr>
<td></td>
<td>Prevident</td>
<td>125.13 ± 16.01</td>
</tr>
<tr>
<td></td>
<td>( \text{dH}_2\text{O} ) (control)</td>
<td>248.05 ± 22.39</td>
</tr>
<tr>
<td>Inspire</td>
<td>Phos-flur gel</td>
<td>189.80 ± 74.22*</td>
</tr>
<tr>
<td></td>
<td>Prevident</td>
<td>191.62 ± 82.20*</td>
</tr>
</tbody>
</table>

* Significantly different from control, \( P < .05 \).

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In contrast, true-twin brackets such as Clarity have all four tie-wings separate from one another.

Representative SEM images of the monocrystalline Inspire brackets are presented in Figure 5. There were no observable changes on the mesial incisal tie-wing intact surface, irrespective of treatment. The fractured surface morphologies, cathedral-type fracture mirror (Figure 5B), faceted-curved pattern (Figure 5D), and river lines pattern (Figure 5F), were not unique to the control or fluoride conditions and are typical for monocrystalline alumina.29

Collectively, the qualitative topographic analysis suggests that neither Prevident nor Phos-flur topical fluoride agent affected the intact mesial incisal tie-wing surface of the polycrystalline or monocrystalline brackets or produced a change in the distal incisal tie-wing fracture patterns.

DISCUSSION

Topical fluorides cause corrosion of dental implants, orthodontic wires, and other orthodontic devices.14–16,18,19 Corrosive surface changes from topical fluorides have also been reported with restorative porcelain ceramics.22 This would suggest that topical fluoride might also affect ceramic brackets. Unlike metallic corrosion, an electrochemical process, ceramic corrosion occurs by either dissolution of the entire surface or by preferential dissolution of sintering agents, leading to a po-
arious surface layer with inferior mechanical properties.\textsuperscript{25} If topical fluoride causes a similar interaction with monocrystalline or polycrystalline alumina of ceramic brackets, a concomitant degradation of bracket mechanical properties might be expected.

In this investigation, three different ceramic brackets were exposed to a neutral or acidic fluoride agent for 4 hours, equivalent to approximately 8 months of 1-minute daily fluoride applications. As compared with the \( \text{dH}_2\text{O} \) control, both the APF and neutral fluoride agents produced a statistically significant decrease in the tie-wing fracture strength of the monocrystalline Inspire brackets. Although there are no previous ceramic bracket fracture strength studies related to fluoride exposure, similar strength-reduction results were reported following Ringer’s solution exposure of a monocrystalline alumina being considered for prosthetic heart valves.\textsuperscript{30} Despite alumina’s presumed inertness in physiological environments, alumina crack-growth rates in Ringer’s solution were significantly higher than those in a humid environment. Increased crack growth in Ringer’s solution was potentially explained by a chemical interaction between Ringer’s \( \text{Cl}^- \) ions and alumina crystal \( \text{Al}^{3+} \) ions, leading to a strain of the alumina Al-O bonds.\textsuperscript{30} Accordingly, a similar interaction of alumina \( \text{Al}^{3+} \) ions might occur with \( \text{F}^- \) ions. Moreover, because \( \text{F}^- \) ions are more electronegative than \( \text{Cl}^- \) ions,\textsuperscript{31} fluoride-alumina interactions might be even stronger. Such interactions could potentially also cause alumina Al-O bond strain and be linked to the monocrystalline tie-wing fracture-strength degradation seen with the fluoride treatments.

Because acidic environments cause increased alumina crack growth as compared with crack growth in water,\textsuperscript{32} it was expected that there might be more fluoride-related alumina damage with an acidic fluoride agent. However, the monocrystalline bracket exhibited similar decreases in fracture strength with both the neutral and APF agents. Despite the pH difference between tested topical fluorides, both agents have an identical fluoride ion concentration (0.5% w/v). The same concentration of fluoride ions interacting with alumina ions could help explain the similar fracture strength change with both fluoride products.

Contrary to the monocrystalline bracket results, the APF or neutral fluoride gel did not significantly affect the tie-wing fracture strength of the polycrystalline brackets (Clarity and Mystique). As previously explained, monocrystalline alumina differs from polycrystalline alumina with a crystal or grain boundary phase.\textsuperscript{6} Polycrystalline alumina strength deteriorates in chemical environments primarily because of stress-enhanced chemical reactions with microstructural stress concentrators, such as grain boundaries.\textsuperscript{25,33} Because of the potential grain boundary reactivity, it was speculated that fluoride-treated polycrystalline brackets might be more susceptible to fracture-strength degradation than monocrystalline brackets. However, only the monocrystalline brackets exhibited a decrease in tie-wing fracture strength following APF or neutral fluoride agent exposure.

Nonetheless, the current results agree with those of a previous study comparing monocrystalline and polycrystalline alumina corrosion fatigue in an isotonic sodium chloride (NaCl) solution.\textsuperscript{34} Monocrystalline alumina strength was severely degraded in the NaCl environment, while polycrystalline strength was not affected. As described previously, there is a potential interaction between \( \text{Cl}^- \) and \( \text{Al}^{3+} \) ions that causes strain in the alumina Al-O bond. However, despite the chloride-alumina interaction, only the monocrystalline alumina exhibited decreased strength. Presumably, these differences in monocrystalline and polycrystalline alumina behavior following NaCl exposure were related to grain boundary crack propagation inhibition in the polycrystalline structure.\textsuperscript{34} A similar situation probably also existed with the monocrystalline and polycrystalline brackets exposed to fluoride. Although the fluoride-alumina surface interaction potentially produced strain in the surface bonds of polycrystalline and monocrystalline alumina brackets, the presumed bond strain adversely affected only the fracture strength of the monocrystalline alumina, with no grain boundaries to inhibit crack propagation. To confirm potential fluoride-alumina chemical interactions with either bracket monocrystalline or polycrystalline alumina, future investigations with x-ray diffractometry and spectroscopy are necessary.

Regardless of the statistically significant difference in monocrystalline bracket tie-wing fracture strength following fluoride treatment, there was no qualitative difference in the intact mesial incisal tie-wing or fractured distal incisal tie-wing surfaces. Thus, the SEM analysis could not explain the differences in monocrystalline alumina fracture strength as a function of fluoride treatment. Any alumina-fluoride surface interaction would occur at the molecular level, and as a result, it does not appear to produce a perceptible change in the surface characterization analysis. Not surprisingly, there were no qualitative differences in the intact and fractured surfaces of the polycrystalline brackets; these results support those of a previous study that reported no qualitative surface changes of polycrystalline brackets exposed to topical fluorides.\textsuperscript{35}

This laboratory study, while limiting confounding variables, does not account for additional clinical variables, such as occlusal cyclic loading forces, temperature or pH variations, and bracket scratches from repeated wire ligation that might possibly amplify the corrosive effects of fluoride treatment. In the current
study, the monocristalline brackets, even with fluoride treatment, still exhibited higher tie-wing fracture strength than the polycristalline brackets; however, monocristalline brackets are reported to be more susceptible to fracture strength decreases following purposeful scratch placement than polycristalline brackets. Therefore, future relevant laboratory studies could include combinations of fluoride exposure with repeated ligation to replicate what occurs in the typical orthodontic treatment period.

The results of this in vitro study suggest that using topical fluorides with monocristalline brackets might increase tie-wing fracture susceptibility under clinical conditions. If tie-wing fracture occurs, the system is less efficient, requiring bracket replacement, which is a difficult, time-consuming, and costly process. Because polycristalline alumina brackets did not exhibit decreased tie-wing fracture strength following fluoride exposure, these brackets might be more appropriate for patients requiring a high-concentration fluoride regimen.

CONCLUSIONS

• There was no qualitative change in the topography of intact or fractured tie-wing surfaces of the monocristalline or polycristalline brackets following APF or neutral fluoride agent exposure.

• Tie-wing fracture strength of the monocristalline bracket, Inspire, was significantly reduced following exposure to APF or neutral fluoride gel, whereas neither fluoride agent adversely affected the tie-wing fracture strength of the polycristalline brackets, Clarite and Mystique.

ACKNOWLEDGMENTS

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