Evaluation of a resin-reinforced glass ionomer cement for use as an orthodontic bonding agent

Akira Komori, DDS, PhD; Haruo Ishikawa, DDS, MSD, PhD

During orthodontic therapy there is a potential for enamel decalcification associated with use of brackets and bands,[1,2] particularly in patients who consistently exhibit poor oral hygiene. Decalcification associated with plaque accumulation may be prevented in many instances by proper plaque control and fluoride applications in the form of mouthrinses.[3,4]

Buonocore[5] introduced the concept of phosphoric acid pretreatment of the enamel surface prior to the placement of orthodontic brackets, which has since become a widely accepted procedure. However, pretreatment of the enamel surface with phosphoric acid may promote decalcification due to concurrent enamel loss. The amount of enamel loss due to acid etching has been estimated at 50 to 60μm.[6] Additional enamel loss may occur during removal of the orthodontic brackets and composite resin adherent to the enamel due to micro- or macrofracturing. And composite resin that penetrates the etched enamel surface during bonding may remain within the enamel after debonding, leading to increased staining of the tooth surface after the completion of orthodontic treatment. Diedrich[7] estimated that up to 150 to 160 μm of enamel loss can occur after debonding. This is equivalent to 10% of the original enamel surface, as the average thickness of facial enamel is 1000 to 1500 μm. Therefore, alternative bonding procedures that do not require enamel etching would clearly be preferable.

Abstract

A resin-reinforced glass ionomer cement, distributed commercially as "Fuji Ortho" (FO), has recently been developed for orthodontic bracket bonding procedures. The purposes of this study were to determine the tensile and shear bond strength of FO, to measure the amount of cement remaining on the enamel after bracket removal, and to evaluate the effects of experimental strain on the enamel surface. SEM evaluation demonstrated that polishing with 2400-grit waterproof abrasive paper followed by treatment with polyacrylic acid produced a smooth enamel surface without debris. No significant differences were seen in bond strengths between 24 hours and thermal cycling. Tensile and shear strengths of FO were significantly higher after thermal cycling than with conventional glass ionomer cement, at 3.4±0.7 MPa and 17.9±4.5 MPa, respectively. The Adhesive Remant Index (ARI) indicated that FO adhered firmly to the unetched enamel surface and its scores showed 2 to 3 after thermal cycling. Results of this investigation suggest that FO may serve as an advantageous alternative to composite resin for the bonding of orthodontic brackets.

Key Words

Resin-reinforced glass ionomer cement • Unetched enamel • Bond strength • Bracket bonding • Bovine teeth

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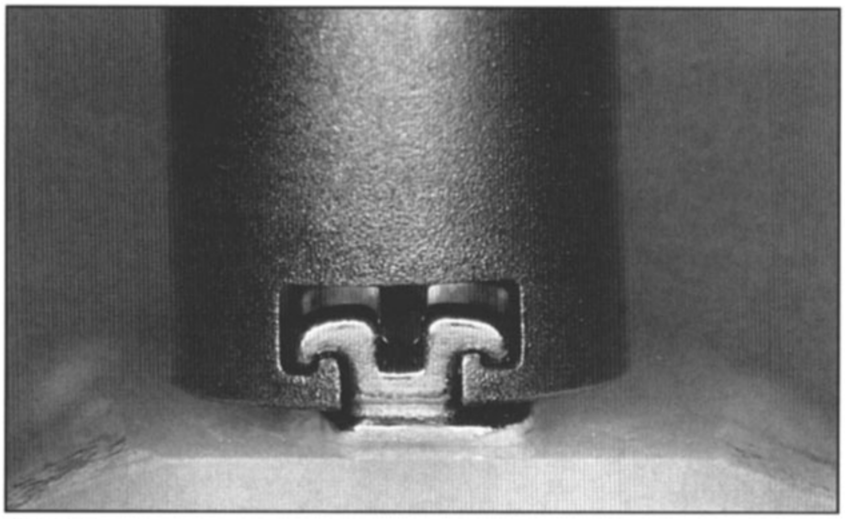

Figure 1

Figure 1
Custom bracket holder designed to hold the bracket wing precisely. It was coupled to load cells so that the force was exerted in a uniform direction.

Glass ionomer cement (GIC) may be a superior alternative to composite resin for the placement of orthodontic brackets because it is less harmful to dental enamel. GIC was first developed by Wilson and Kent.[8] It possesses many favorable characteristics, including low solubility, excellent hardness, fluoride release, and good adhesive properties.[9] Also, GIC has the ability to absorb fluoride from topical fluoride applications.[10] This feature allows it to act as a long-term fluoride releasing agent. GICs have also been used for lining and core buildup in dental restorations. Although GICs produce a bond that is strong enough for these restorative uses, the bond strength of GIC is significantly lower than that of composite resin.[11,12] Fricker[13] reported that 20% of the brackets included in his investigation exhibited bond failure prior to the completion of orthodontic treatment. This high failure rate is unacceptable for both the patient and the clinician and may prolong the course of treatment.

A light-cured GIC has been reported by Silverman et al.[14] Although the mechanical properties of this cement were an improvement over conventional GIC, visible light exposure is required for curing. Recently, a new chemically cured GIC, "Fuji Ortho" (FO), has been developed for easier handling in the placement of orthodontic brackets. It has not yet been determined, however, how FO will perform during clinical use. The purpose of this study was to determine, in vitro, the tensile and shear bond strengths of this new bonding agent. Additional aims were to determine the amount of cement left on the enamel surface after debonding as well as to investigate the effect of grinding the enamel surface under experimental strain. Comparisons were made between this new bonding agent, a composite bonding resin, and a conventional GIC.

Materials and methods

Preparation of teeth

Bovine mandibular incisors were collected after sacrifice of the specimens. The crowns of the extracted teeth were intact, with no signs of enamel fractures or caries. The teeth were thoroughly washed in tap water and all blood and adherent tissue were removed. A diamond disk was used to section the crowns of the teeth from the roots.

Examination under scanning electron microscope (SEM)

Each crown was divided into three sections and the middle third was examined for morphological characteristics of the enamel surface. The enamel surface was ground and smoothed with a polishing device (#5629, Marumoto, Tokyo, Japan) under running water. Progressively finer polishing of the enamel surface was performed with 120- to 2400-grit waterproof abrasive paper. The crown samples were divided into three groups: one group received no further treatment, the second received surface conditioning with 10% polyacrylic acid, and the third underwent etching with 37% phosphoric acid. Each specimen was prepared with sputtering to a thickness of 10 nm in an ion sputtering unit (E-1030, Hitachi, Tokyo, Japan) and then observed with a SEM (S-4000, Hitachi, Tokyo, Japan).

Tensile and shear bond strength

The 84 teeth were randomly divided into 12 groups of 7 teeth each. In order to standardize the enamel surface characteristics, the bonding area was finished with a polishing device under running water. Initial polishing of each tooth was performed on the labial surface with 120-grit waterproof abrasive paper. In the shear test group, the teeth were embedded, excluding the crown surface, into autopolymerizing acrylic resin and then progressively polished with 600-, 1500-, and 2400-grit waterproof abrasive paper. In the tensile test group, the teeth were not embedded but were progressively polished up to the same 2400-grit abrasive paper. Three bonding adhesives were used in this study: FO, Ketac-Cem (Espe-premier Dental Products, Norristown, Penn, USA), and Rely-a-Bond (Reliance Orthodontic Products, Itasca, Ill, USA). FO was developed by GC Corporation (Tokyo, Japan). Ketac-Cem was used to represent the conventional GICs. Rely-a-Bond is a no-mix autopolymerizing composite resin and was included for comparison. Stainless steel orthodontic brackets with mesh backing were selected for this study on the basis of their widespread clinical use. Brackets were maxillary central incisor brackets with standard edgewise 0.018 x 0.025 slots (Mini-diamond brackets, Ormco, Glendora, Calif, USA).

For both the FO and the Ketac-Cem groups, enamel surfaces were pretreated with an application of 10% polyacrylic acid for 20 seconds and then air-water rinsed. Enamel surfaces bonded with Rely-a-Bond were first acid-etched with a solution of 37% buffered phosphoric acid for 30 seconds, air-water rinsed for 30 seconds, and then thoroughly dried. Manufacturers' recommendations were followed for mixing and handling of Ketac-Cem and Rely-a-Bond. After placing the brackets, excess bonding material was carefully removed with a scalpel. All bonded teeth were left exposed to room atmosphere for 5 minutes and then stored at 37°C for 24 hours at 100% humidity. After 24 hours, 5 groups of 7 teeth were tested for tensile and shear bond strength. For the tensile bond test, each specimen was attached to a measuring device (Autograph DCS-5000, Shimadzu, Kyoto, Japan) and loaded with a cross-head speed of 1 mm/minute. A custom bracket holder was designed to hold the bracket wing precisely and coupled to load cells so that the force was exerted in a uniform direction (Figure 1). The force required to dislodge the bracket was recorded on the X-Y plotter (Dataletty 401, Shimadzu, Kyoto, Japan). For the shear bond test, each specimen was mounted in a measuring unit (Autograph AGS-50A, Shimadzu, Kyoto, Japan) and loaded with a cross-head speed of 1 mm/minute. For the remaining groups, thermal cycling was performed between 5°C and 55°C as an accelerated aging test. After thermal cycling, tensile and shear bond tests were repeated, with data recorded in a similar fashion.

Adhesive remnant index

The amount of residual adhesive was classified using the adhesive remnant index (ARI) developed by Årtun and Bergland.[15] This consists of a 4-point scale of 0 to 3: a score of 0 indicates no adhesive left on the tooth, 1 indicates less than half of the adhesive left on the tooth, 2 indicates more than half of the adhesive left on the tooth, and 3 indicates all of the adhesive left on the tooth including a distinct impression of the bracket mesh. The surfaces of the debonded teeth were inspected with an optical stereomicroscope (magnification, x40).

Table 1
Distribution of adhesive remnant index

Adhesive type	ARI scores 0	1	2	3
Shear test: 24 hours				
Rely-a-Bond	0/7	4/7	3/7	0/7
Fuji Ortho	0/7	0/7	5/7	2/7
Ketac-Cem	1/7	5/7	1/7	0/7
Shear test: Thermal cycling				
Rely-a-Bond	0/7	4/7	3/7	0/7
Fuji Ortho	0/7	0/7	4/7	3/7
Ketac-Cem	1/7	4/7	2/7	0/7
Tensile test: 24 hours				
Rely-a-Bond	0/7	2/7	0/7	5/7
Fuji Ortho	0/7	0/7	2/7	5/7
Ketac-Cem	0/7	6/7	1/7	0/7
Tensile test: Thermal cycling				
Rely-a-Bond	1/7	3/7	1/7	2/7
Fuji Ortho	0/7	0/7	1/7	6/7
Ketac-Cem	0/7	7/7	0/7	0/7

The ARI distribution is shown in Table 1.

Statistical analysis

Means and standard deviations were calculated for tensile and shear bond strength for each bonding agent. An analysis of variance (ANOVA) and Scheffe test were performed with a 0.01 level of confidence to identify statistically significant differences in bond strength between the types of bonding agents, with or without exposure to thermal cycling. The Kruskal-Wallis test was used to determine any statistical differences in the ARI scores between the three bonding agents.

Results

Enamel surfaces ground with 2400-grit abrasive paper were smoother than those ground with 600-grit abrasive (Figures 2 and 3). A slight amount of debris was also seen on the surfaces polished with 2400-grit abrasive. In contrast, the enamel surface that had been ground with 2400-grit followed by a pretreatment of polyacrylic acid produced a smooth surface without debris and without evidence of prism-like etching patterns (Figure 4). Figure 5 illustrates an enamel surface pretreated with phosphoric acid in which the etching appears to create prism-shaped patterns.

The means and standard deviations of the tensile and shear bond strengths (MPa) of each group are shown in Figures 6 and 7. Tables 2 and 3 summarize the statistical results of two-way ANOVA. There was a statistically signifi-

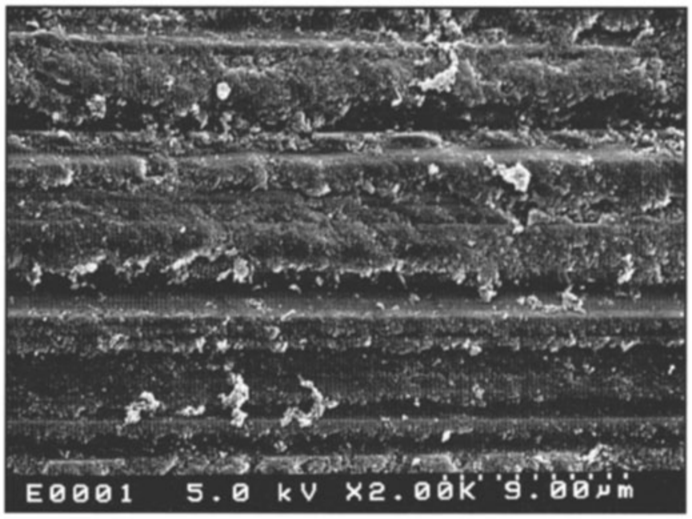

Figure 2

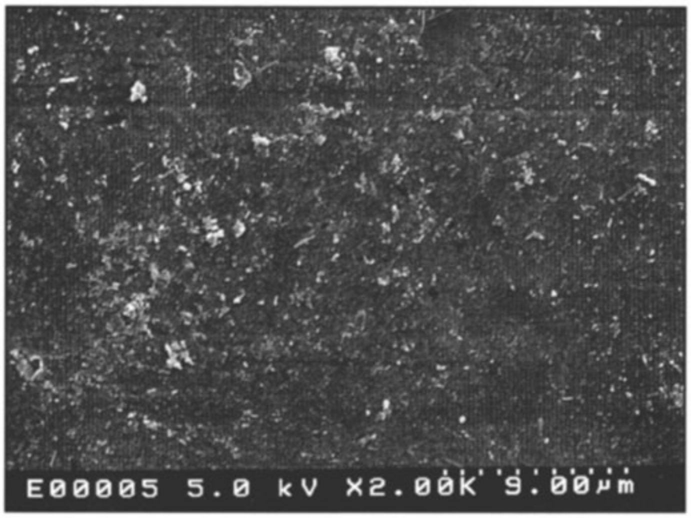

Figure 3

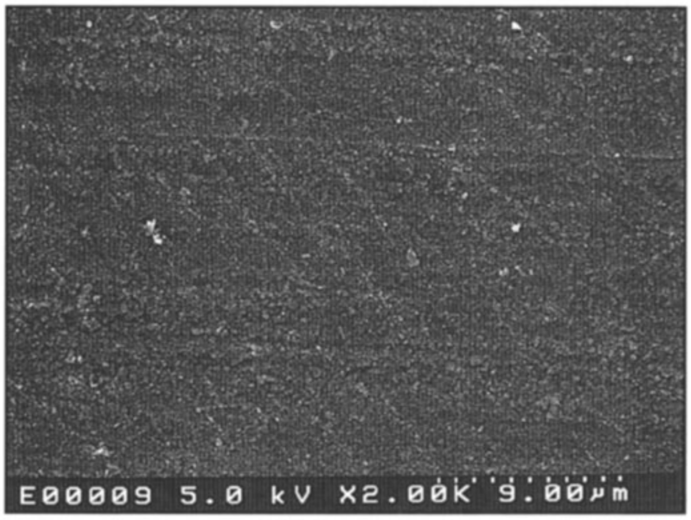

Figure 4

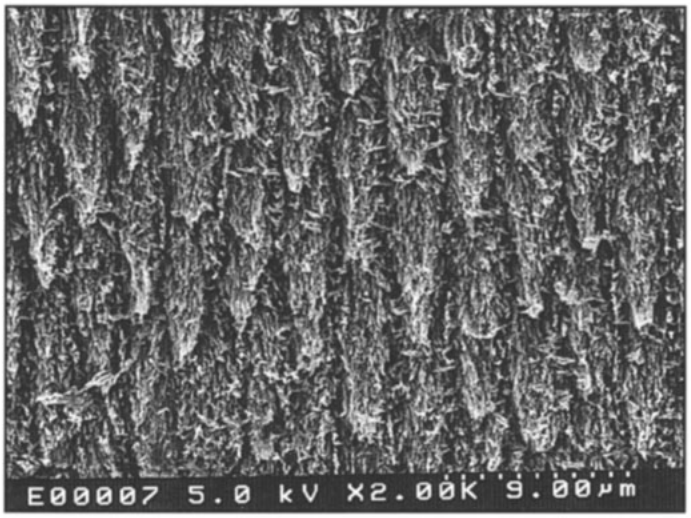

Figure 5

Figure 2
Enamel surface polished with 600-grit abrasive (x2000).

Figure 3
Enamel surface polished with 2400-grit abrasive (x2000).

Figure 4
Enamel surface polished with 2400-grit abrasive followed by pretreatment with polyacrylic acid, (x2000).

Figure 5
Enamel surface polished with 2400-grit abrasive, followed by pretreatment with phosphoric acid, (x2000).

cant difference in the bond strength between the three bonding agents ($P<0.01$) in both tensile and shear bond tests. Ketac-Cem was significantly weaker than FO and Rely-a-Bond. The Rely-a-Bond group after thermal cycling had the highest mean shear strength at 25.7±3.6 MPa. The Rely-a-Bond group at 24 hours exhibited slightly lower shear strength at 24.5±5.9 MPa, although it did not represent a statistically significant difference. The Scheffe test resulted in no significant differences between bonds cured for 24 hours and bonds processed with thermal cycling ($P=0.64$ on shear bond test, $P=0.09$ on tensile test). Tensile and shear strengths of FO after thermal cycling were significantly higher than Ketac-Cem at 3.4±0.7 MPa and 17.9±4.5 MPa, respectively.

The ARI scores of each group after 24 hours and after thermal cycling are presented in Table 1. The Kruskal-Wallis test showed a high statistically significant difference between the ARI scores of the three bonding agents ($P<0.01$). No damage to the enamel surface was observed after debonding in any group.

Discussion

Many investigators have explored alternatives that would reduce the risk of enamel decalcification initiated by etching prior to placement of orthodontic brackets. Although the procedures of topical fluoride application after etching[16] and the use of a reduced concentration of phosphoric acid[17,18] may decrease the risk of decalcification, they are unable to completely prevent enamel decalcification. In addition, there is a case report of a 14-year-old male who developed an allergic reaction to a composite bonding agent used for the placement of his orthodontic brackets.[19] Although an allergic reaction to an orthodontic composite resin is very rare, this case report illustrates that it must be considered as a risk.

The results of this investigation suggest that

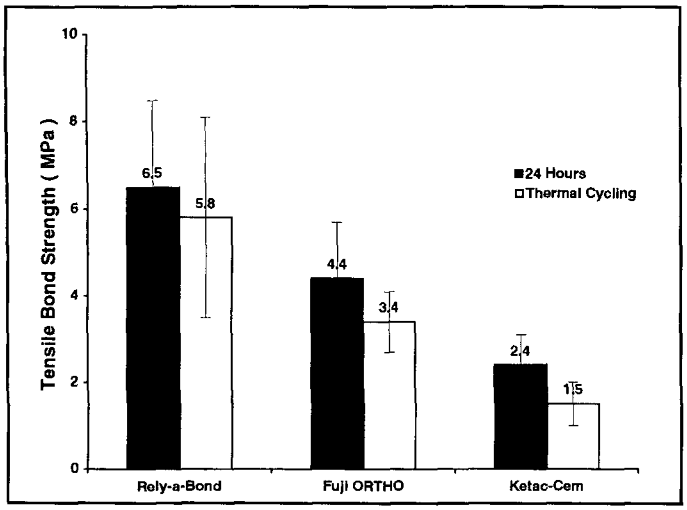

Figure 6

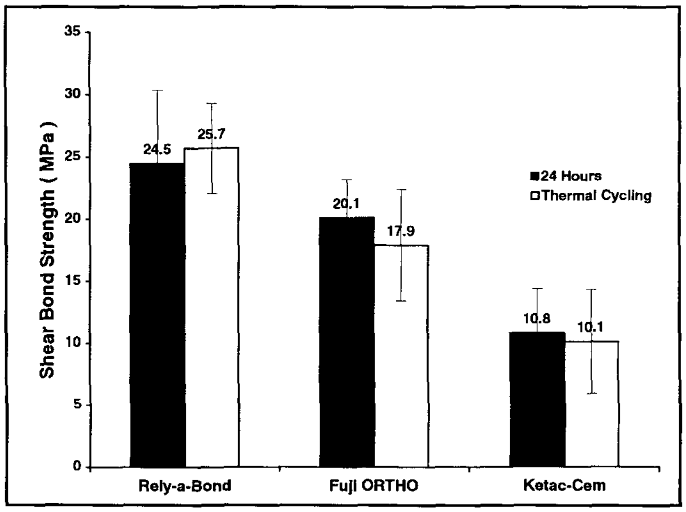

Figure 7

Table 2
Statistical results of two-way ANOVA for tensile bond testing, bonding agents with and without thermal cycling

Source	DF	SS	MS	F ratio	P value
Bonding agents (A)	2	124.030	62.015	30.639	<0.0001
With, without thermal cycling (B)	1	6.172	6.172	3.049	0.0893
(A) and (B) interaction	2	0.083	0.042	0.021	0.9726
Error	36	72.866	2.024		

DF, degrees of freedom; SS, sum of squares; MS, mean square

Table 3
Statistical results of two-way ANOVA for shear bond testing, bonding agents with and without thermal cycling

Source	DF	SS	MS	F ratio	P value
Bonding agents (A)	2	1516.363	758.182	45.708	<0.0001
With, without thermal cycling (B)	1	3.602	3.602	0.217	0.6440
(A) and (B) interaction	2	20.679	10.339	0.623	0.5419
Error	36	597.154	16.588		

DF, degrees of freedom; SS, sum of squares; MS, mean square

FO is a useful alternative to composite resin for the bonding of orthodontic brackets. Conventional GICs have been developed that provide prolonged fluoride release to increase the resistance of enamel to demineralization and to promote remineralization.[20] However, conventional GICs possess remarkably less bond strength and lower viscosity than composite resins. The bond strength of FO was significantly greater than that of a conventional glass ionomer cement (Ketac-Cem). FO is classified as a resin-modified GIC. It combines the fluoride-releasing properties and adhesion of a conventional GIC with the added benefits of improved clinical properties and higher bond strength. FO also displays a dual setting reaction: the normal glass ionomer cement acid-base reaction as well as a free-radical polymerization process. Clinical properties of this cement were optimized specifically for use as an orthodontic bracket bonding agent, i.e., elevated bond strength to resist displacement forces, increased viscosity to prevent bracket drift, and a modified curing reaction using chemical polymerization. FO is manufactured as a mixable powder and liquid: the powder is a finely ground fluoroaluminosilicate glass, while the liquid contains a copolymer of acrylic acid and maleic acid, hydroxyethylmethacrylate and water. The small amount of resin present in the glass ionomer material is included to enhance the bonding properties of FO.

During bracket placement, bonding cement thickness is not uniform due to irregular tooth surface morphology and variations in bracket base seating. In this investigation an attempt was made to standardize the enamel surfaces in order to obtain reproducible in vitro experimental strain. The thickness of human enamel is also inadequate for producing the flat standardized surfaces prior to bonding. Previous

Figure 6
Means and standard deviations for tensile bond strength. The results of two-way ANOVA are represented in Table 2.

Figure 7
Means and standard deviations for shear bond strength. The results of two-way ANOVA are represented in Table 3.

studies have shown that bovine and human enamel are similar in their physical properties, composition, and bond strength.[21,22,23] Thus, bovine enamel was used because of greater enamel thickness, more abundant supply, and the close morphological similarity to human enamel.

Many investigators have used bovine enamel finished with 600-grit abrasive in bond strength studies.[24,25] Figure 2 illustrates the irregular surface present after polishing with 600-grit abrasive. Since minor surface irregularities may affect bond strength, the enamel surfaces in this study were polished with up to 2400-grit abrasive. SEM provides visual evidence that a flat, smooth surface is obtained after polishing with a 2400-grit abrasive. Some debris was noted on the enamel surface after completion of polishing; therefore, pretreatment with polyacrylic acid for complete surface cleansing was performed prior to bonding with GIC. As evident in Figure 4, it appears that pretreatment with polyacrylic acid did not disrupt the integrity of the enamel surface.

The bond strength of composite resin was found to be significantly higher than that of the glass ionomer groups. This observation also confirms the findings of Fajen et al.,[26] who concluded that the bond strength of GIC was significantly lower than that of composite resin. Bond strength testing is a sensitive experimental procedure, and the same bonding materials can yield different results due to variations in experimental conditions. Although FO showed lower bond strength compared with composite resin in this investigation, the result may be due to the stringent experimental design using a finely ground enamel surface. McCourt et al.[27] concluded that GIC did not exhibit a significantly different shear bond strength than BIS-GMA. However, it did become significantly weaker after a 4-week incubation period. The bond strength of FO in the present study indicated no statistically significant difference between 24 hours and thermal cycling. This observation suggests that FO has the potential to resist forces that consistently change during the course of orthodontic treatment.

Pretreatment with 37% phosphoric acid roughens the enamel surface prior to bonding, allowing for a mechanical bond between the cement and the enamel. Mechanical bonding cannot be expected when using FO because pretreatment with polyacrylic acid does not alter the fundamental configuration of the polished enamel surface. However, since intact enamel surfaces are normally not flat and smooth, mechanical interdigitation may be obtained to a certain extent when bonding brackets with FO in clinical practice. Consequently, FO may exhibit a higher bond strength during clinical use than during in vitro evaluation.

The Kruskal-Wallis test revealed that the ARI score is dependent upon the type of bonding agent. The ARI scores indicate that bond failure with FO occurred at the adhesive-bracket interface in most cases during the tensile bond test. These findings provide evidence that FO adheres firmly to the enamel surface and that bonding performance does not diminish after thermal cycling. Consequently, an improvement in adhesive qualities between FO and the bracket pad will lead to a higher resistance to the forces exerted throughout the course of orthodontic treatment.

Bonded brackets are subjected to a combination of tensile, shear, and torsion forces during orthodontic treatment. It is difficult to measure and quantify these forces precisely. Maijer and Smith[28] reported that a bond strength of 10 kgf was adequate for successful orthodontic treatment. This strength is equivalent to 8.5 MPa in this study. In comparison, though, Keizer and his associates stated that the maximum average bond strength of adhesion to the bracket material was 53 kg per square centimeter.[29] This is equivalent to 5.2 MPa in this study. In conclusion, the bond strength of FO may surpass the clinically required threshold. Therefore, FO may be useful as an alternative to composite resin for the bonding of orthodontic brackets.

Further attention should be given to the bracket pad conditioning procedure and to the alteration of bracket base design in order to enhance bond strength between this adhesive agent and the stainless steel orthodontic bracket.

Author Address

Haruo Ishikawa, DDS, MSD, PhD
Department of Orthodontics, Nippon Dental University
2-3-16 Fujimi, Chiyoda-ku, Tokyo 102 Japan
Phone: 81-3-3261-5511
Fax: 81-3-3261-5891
E-mail: haruishi@tokyo.ndu.ac.jp

A. Komori is an instructor and research fellow in the Department of Orthodontics at Nippon Dental University.

H. Ishikawa is a professor and chairman in the Department of Orthodontics at Nippon Dental University.

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