Original Article

Tensile and Shear Bond Strength of Resin-Reinforced Glass Ionomer Cement to Glazed Porcelain

Yoshitaka Kitayama, DDS, PhD[a]; Akira Komori, DDS, PhD[b]; Rizako Nakahara, DDS, PhD[c]

Abstract: The purpose of this study was to measure the tensile and shear bond strength of resin-reinforced glass ionomer cement (RGIC) to glazed porcelain, to evaluate the durability of RGIC by thermal cycling, and to examine the RGIC remaining on the surface of the porcelain after the bond strength test to evaluate bonding conditions. Three adhesives were used in this study: Concise (CO) as a chemically cured composite resin, Fuji ORTHO (FO) as a chemically cured RGIC, and Fuji ORTHO LC (FOLC) as a light-cured RGIC. Tensile and shear bond strengths were measured 24 hours after bonding orthodontic brackets and also after thermal cycling. Tensile bond strength after 24 hours was 6.6 ± 3.2 MPa in CO, 7.3 ± 1.4 MPa in FO, and 8.6 ± 1.9 MPa in FOLC, and the strength significantly decreased after the thermal cycling test. Shear bond strength after 24 hours was 32.5 ± 8.9 MPa in CO, 23.3 ± 6.8 MPa in FO, and 24.7 ± 6.5 MPa in FOLC, and in contrast to tensile bond strength, no decreases in the strength were detected after the thermal cycling test. CO showed significantly higher shear bond strength than did FO and FOLC. When using the shear bond strength test and CO, destruction of porcelain surfaces frequently occurred after 24 hours and was observed in every specimen after the thermal cycling. RGIC was found to be an advantageous alternative to resin adhesive for bracket bonding to porcelain and to enamel. (*Angle Orthod* 2003;73:451–456.)

Key Words: Resin-reinforced glass ionomer cement; Glazed porcelain; Bond strength; Fracture; Crack

INTRODUCTION

To adhere orthodontic brackets to tooth surfaces by the direct bonding method, methyl methacrylate–based resin, bis-glycidyl methacrylate composite resin, cyanoacrylate adhesive, and resin-reinforced glass ionomer cements (RGIC) are used.[1–7] Because adhesion of resin and cyanoacrylate adhesives depends on mechanical interlocking, enamel decalcification with phosphoric acid etching is necessary to some extent.[8,9] Furthermore, the caries risk increases during orthodontic treatment because dental plaque is likely to adhere to orthodontic appliances.[10–12] Although the development of adhesives containing fluoride and enamel etching using a reduced concentration of phosphoric acid solution are considered to decrease caries risk, bonding systems that do not use phosphoric acid, in which tooth surfaces are not decalcified, are desirable from the perspective of preserving enamel.[13–15]

On the other hand, RGIC is a bonding material that does not depend on mechanical interlocking for adhesion. Clinical investigation of direct bonding using RGIC showed that the rate of orthodontic bracket dislodgement was similar to that obtained by the use of resin adhesive, and this suggests the usefulness of RGIC.[16–18] Furthermore, it has been reported that although the bond strength of RGIC was lower than that of resin adhesive in laboratory experiments, the bond strength of RGIC was sufficiently high for clinical use.[19] Therefore, RGIC has been accepted as a material to bond orthodontic brackets.

Orthodontic brackets are not bonded only to enamel surface. Particularly in adults, orthodontic brackets often need to be bonded to porcelain such as porcelain fused to metal cast crowns and porcelain jacket crowns. When using resin adhesives, it is possible to bond orthodontic brackets to porcelain by pretreating the surface of the porcelain with silane-coupling agents and etching with hydrofluoric acid, or in certain cases, sand blasting the porcelain surface is recommended.[20–22]

However, there are a number of unclarified points regarding the bonding of RGIC to porcelain in which, in particular, comparisons between the bond strength of RGIC to porcelain and that of conventional resin adhesives bonded to porcelain need to be done.

[a] Private practice, Gunma, Japan.
[b] Assistant Professor, Department of Orthodontics, The Nippon Dental University, Tokyo, Japan.
[c] Professor and Chair, Department of Orthodontics, The Nippon Dental University, Tokyo, Japan.
Corresponding author: Akira Komori, DDS, PhD, Department of Orthodontics, The Nippon Dental University, 2-3-16 Fujimi, Chiyoda-ku, Tokyo 102-8158, Japan
(e-mail: komo@msi.biglobe.ne.jp).

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TABLE 1. Adhesives Used in This Study[a]

Adhesive	Abbreviation	Description	Manufacturer
Concise	CO	Chemically cured bis-GMA composite resin	3M Unitek, Monrovia, Calif
Fuji ORTHO	FO	Chemically cured RGIC	GC Corporation, Tokyo, Japan
Fuji ORTHO LC	FOLC	Light-cured RGIC	GC Corporation

[a] bis-GMA indicates bis-glycidyl methacrylate; RGIC, resin-reinforced glass ionomer cement.

The aims of this study were to measure tensile and shear bond strength of RGIC to glazed porcelain and to evaluate the durability of RGIC by thermal cycling. Furthermore, the RGIC remaining on the surface of the porcelain after the bond strength test was examined to evaluate bonding conditions.

MATERIALS AND METHODS

Fabrication of test specimens

One hundred and eighty glazed feldspathic porcelain disks were fabricated from G-Cera COSMOTECH II PORCELAIN (GC Corporation, Tokyo, Japan). Porcelain disks, 10 mm in diameter and two mm in thickness, were prepared by conventional condensation methods from silicone die and fired in the vacuum oven. The firing cycle was as follows: dry, 10 minutes; preheat, 10 minutes; entry temperature, 550°C; and firing temperature, 890°C, and rate of temperature increase was 50°C per minute in a vacuum of 750 mm Hg. The surfaces of specimens were finished with #120 and #600 waterproof abrasive papers, using an automatic polishing machine under running water, and then final glazing was performed at 950°C for three minutes in the absence of vacuum.

The glazed porcelain disks, other than the surfaces bonded with orthodontic brackets, were fixed using self-curing resin to obtain stability during the bond strength test. The surfaces of the porcelain disks were exposed and positioned parallel to the rim of the mold, which enabled a standardized force direction to the bracket base when the specimens with the embedded disk were mounted onto the bond-testing machine later.

Bonding procedure

Porcelain surfaces were pretreated with 35% phosphoric acid gel (3M Unitek, Monrovia, Calif) for 30 seconds, and after rinsing and drying, the surfaces were treated using a silane-coupling agent (G-Cera COSMOTECH II Primer, GC Corporation). The three adhesives used in this study are shown in Table 1. For the Concise (CO) group, an equal amount of paste A and B was dispensed with a spatula. For the Fuji ORTHO (FO) and Fuji ORTHO LC (FOLC) groups, powder and liquid were measured with an electronic balance. The manufacturers' recommendations were followed for mixing and handling of CO, FO, and FOLC. The mixed adhesive was placed on the bracket base, which was then pressed onto the porcelain surfaces, and after removing excessive cement, the specimens were stored in an incubator at 37°C for 24 hours at 100% humidity. In FOLC, after removing excessive cement, the incisal and gingival margins of the brackets were exposed to light for 20 seconds using a light unit (New Light VL-II, GC Corporation).

Measurement of bond strength

The bond strength was measured 24 hours after bonding the orthodontic brackets and also after thermal cycling. Thermal cycling was carried out from 5°C to 55°C 24 hours after bonding the orthodontic brackets and was carried out again 2000 times with a 30-second dwell time in each bath.

Bond strength was examined based on the measurement of tensile and shearing bond strengths. A testing device (Autograph DCS-5000 Shimadzu, Kyoto, Japan) was used for measuring tensile bond strength, in which a custom bracket holder was designed to hold the bracket wing precisely, and was coupled to load cells so that the force was exerted in a uniform direction. A testing device (Autograph AGS-50A, Shimadzu, Kyoto, Japan) was used for measuring shear bond strength, in which a custom chisel-shaped rod was used, so that the force was exerted adjacent and parallel to the bracket base and applied to the bond interface.[23]

The load was applied with a crosshead speed of one mm per minute, and load values, when the brackets were dislodged, were recorded. An analysis of variance (ANOVA) was performed on the data obtained, and when significant differences were noted with a 5% significance level, a Scheffé test was carried out.

Evaluation of porcelain surfaces after bond testing

After the bond strength test, the conditions of the porcelain surfaces were evaluated using the adhesive remnant index (ARI).[24] When the porcelain surfaces were destroyed and ARI evaluation was impossible, a classification into material fracture and cracks was used for evaluation (Figures 1 and 2). The porcelain surfaces were observed using a stereomicroscope.

RESULTS

Bond strengths 24 hours after bonding brackets and after thermal cycling test are shown in Table 2. Tensile bond strength after 24 hours was 6.6 ± 3.2 MPa in CO, 7.3 ± 1.4 MPa in FO, and 8.6 ± 1.9 MPa in FOLC, and the strength significantly decreased after the thermal cycling

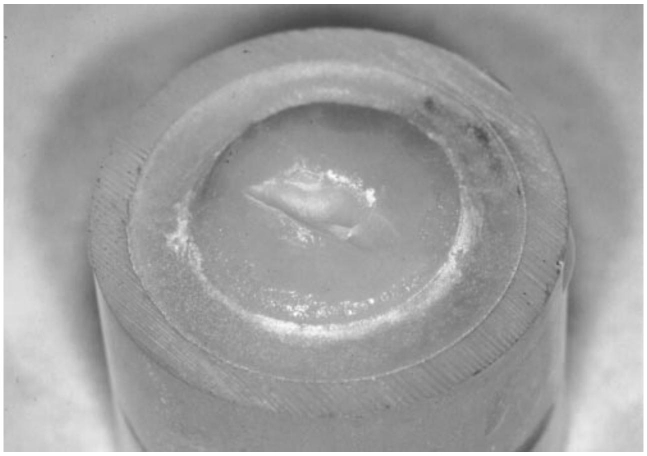

FIGURE 1. Surface destruction categorized as fracture, indicating obvious defect on porcelain surface.

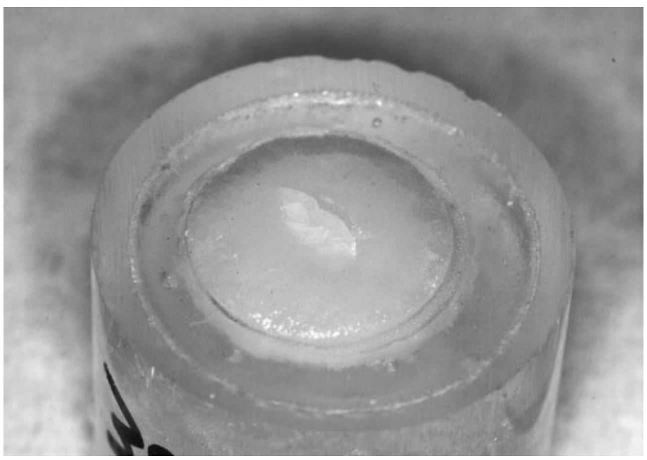

FIGURE 2. Surface destruction categorized as crack. Crack without defect can be recognized.

TABLE 2. Tensile and Shear Bond Strengths (MPa) (n = 15)[a]

	24 h		Thermal Cycling	
	Mean	SD	Mean	SD
Tensile bond strength				
CO	6.6	3.2	5.9	2.3
FO	7.3	1.4	4.8	1.4
FOLC	8.6	1.9	5.4	1.8
Shear bond strength				
CO	32.5	8.9	34.6	8.0
FO	23.3	6.8	22.6	4.8
FOLC	24.7	6.5	23.3	5.3

[a] CO indicates Concise; FO, Fuji ORTHO; and FOLC, Fuji ORTHO LC.

test (ANOVA, Table 3). No significant differences in the tensile bond strength were noted among the three types of adhesives. Shear bond strength 24 hours later was 32.5 ± 8.9 MPa in CO, 23.3 ± 6.8 MPa in FO, and 24.7 ± 6.5 MPa in FOLC and, in contrast to tensile bond strength, no decreases in the strength were detected after the thermal cycling test. Significant differences in the shear bond strength were confirmed among the three types of materials by ANOVA, and significant differences were noted between CO and FO and between CO and FOLC by the Scheffé test (Table 4).

The conditions of the porcelain surfaces after measuring bond strength are shown in Table 5. Measurements of tensile bond strength revealed that the adhesive tended to remain on the porcelain surfaces, and material destruction, recognized as fracture, was observed in a specimen of FOLC after 24 hours and in another specimen of FOLC after thermal cycling. Measurements of shear bond strength revealed that specimens of FO and FOLC tended to remain on the bracket base and not on the porcelain surfaces. On the other hand, specimens of CO showed marked destruc-

TABLE 3. Statistical Results for Tensile Bond Strength

	Degrees of Freedom	Sum of Squares	Mean Square	*F* Value	*P* Value
Adhesives (A)	2	15.585	7.792	1.768	.1769
24 h/thermal cycling (B)	1	104.329	104.329	23.674	<.0001
A × B	2	24.929	12.646	2.828	.0648
Error	84	370.187	4.407		

TABLE 4. Statistical Results for Shear Bond Strength

	Degrees of Freedom	Sum of Squares	Mean Square	*F* Value	*P* Value	Scheffé Test[a]
Adhesives (A)	2	2043.658	1021.829	21.699	<.0001	CO > FO, FOLC
24 h/thermal cycling (B)	1	0.003	0.003	<0.001	.9938	
A × B	2	50.329	25.165	0.534	.588	
Error	84	3955.646	47.091			

[a] CO indicates Concise; FO, Fuji ORTHO; FOLC, Fuji ORTHO LC.

TABLE 5. Conditions of Porcelain Surfaces after Measuring Bond Strength[a]

	24 h						Thermal Cycling					
	0	1	2	3	Crack	Fracture	0	1	2	3	Crack	Fracture
Tensile bond testing[b]												
CO	0	0	8	7	0	0	1	3	8	3	0	0
FO	0	0	4	11	0	0	0	0	1	14	0	0
FOLC	0	2	4	8	0	1	0	1	5	8	0	1
Shear bond testing												
CO	0	0	0	1	6	8	0	0	0	0	8	7
FO	9	5	1	0	0	0	10	5	0	0	0	0
FOLC	9	4	1	0	1	0	10	4	0	0	1	0

[a] ARI score of 0 indicates no adhesive left on porcelain surface; 1, less than half of the adhesive left on porcelain surface; 2, more than half of the adhesive left on porcelain surface; and 3, all adhesive left on porcelain surface, with distinct impression of the bracket mesh; when the porcelain surfaces were destroyed, a classification into material fracture and crack was used for evaluation.

[b] CO indicates Concise; FO, Fuji ORTHO; and FOLC, Fuji ORTHO LC.

tion of the porcelain surfaces, and destruction, recognized as material fractures or cracks, was confirmed in every specimen of CO after thermal cycling test, in particular.

DISCUSSION

The properties of the surfaces of bonded brackets, types of adhesive, bracket structure, applied force, and the clinicians' inappropriate technique are all considered as factors leading to bracket failure in clinical orthodontics. In this study, these factors were regulated as much as possible. To obtain standardized glazed surfaces, glazing treatment was performed after finishing the surfaces with #600 abrasive paper. To minimize the distance between bracket bases and bonding test surfaces, the test surfaces were flattened and brackets for upper central incisors with minimal curvatures were used. Furthermore, although the amounts of powder of FO and FOLC are usually measured using the attached measuring spoon, to avoid errors in the measurements, they were measured using an electronic balance.

Many variables such as porcelain type, bracket base designs, testing device, method and direction of debonding, and crosshead speed may affect the data in testing the bond strengths in these investigations. Even if an experimental study using the same bonding system and orthodontic brackets is carried out, it is difficult to compare the bond strengths among similar bond testing studies.

Because there is no consensus on the materials and methods for orthodontic bond strength tests, evaluations of bonding agents should be made by considering both laboratory tests and clinical trials. Previous in vitro study using RGIC demonstrated that tensile and shear bond strength to enamel surface was approximately 4 and 20 MPa, respectively.[19] These values were comparable with the bond strength to porcelain surface in the present study. Clinical evaluation using RGIC also revealed that there was no significant difference in failure rates between composite resin and RGIC.[25,26] These observations suggest that RGIC has the potential to resist forces that constantly change during orthodontic treatment.

Although the CO group showed markedly high shear bond strength, marked destruction of bond test surfaces also occurred. CO also showed significantly higher shear bond strength than did FO and FOLC. On the other hand, no significant differences in tensile bond strength were noted among the three types of adhesive in this study, and in all but a few specimens, no destruction of porcelain surfaces occurred after tensile bond testing. Therefore, it was considered that the destruction of porcelain surfaces depends on bond strengths and is closely related to the bond strength of RGIC. There was a slight risk of porcelain destruction with FOLC, a markedly high risk with CO, and no risk with FO. The results of this study revealed that the threshold value of porcelain destruction corresponded to the bond strength of FOLC and was estimated to be eight MPa for tensile bond strength and 24 MPa for shear bond strength.

In the CO group, bond failure after tensile bond testing mainly occurred at the resin-bracket interface. Removal of the composite resin may result in damage to the glazed porcelain surface. Although the smoothness of the porcelain can be obtained by polishing systems,[27] cracks and fractures of the porcelain surface cannot be restored, resulting in the need for fabrication of a new prosthesis. During the removal of brackets from the prostheses, destruction of the esthetic of the prostheses such as porcelain fused to metal crowns and porcelain jacket crowns is not permissible. To avoid the risk of destroying prostheses during bracket removal, the use of adhesives with less risk of porcelain destruction and the use of appropriate removal procedures are necessary. During the removal of brackets, tensile, shear, and torsional forces are applied to the interface between bond surfaces and bracket bases. The shear force is thought to be a risk factor for porcelain destruction, and therefore brackets bonded with RGIC and bracket removed by applying tensile forces are desirable.

Although brackets are finally removed after treatment, they are in the oral cavity for several years, and it is necessary to evaluate the durability of the adhesive also with in vitro bond strength tests. In this study, thermal cycling with 2000 repetitions between 5°C and 55°C was performed to simulate accelerated aging by thermally induced stress. Tensile bond strength after thermal cycling was significantly decreased in every group in comparison with that after 24 hours. However, because tensile bond strength to porcelain after thermal cycling was similar to tensile bond strength to enamel[19] and because shear bond strength did not significantly decrease after the thermal cycling, it was concluded that the durability of the adhesives was sufficient.

After measuring tensile bond strength, the failure sites for brackets bonded with FO appeared to be predominantly at the bracket-adhesive interface. Because most of FO remains on the porcelain surface, the bond between FO and the porcelain surface is stronger than the tensile bond strength recorded. Because ARI score was 2 or 3 in RGIC group (FO and FOLC) after tensile bond strength test, increases in bond strength are possible by improving the adhesion between brackets and adhesive, for example, by sand blasting bracket bases.[28,29] After measuring shear bond strength, the failure sites for brackets bonded with FO and FOLC appeared to be primarily at the adhesive-porcelain interface. Almost all specimens of CO in the shear bond strength test showed marked destruction of the porcelain surfaces. Because destruction of porcelain surfaces occurred in CO and FOLC groups, ARI scores were not obtained in those specimens, and statistical evaluation was not performed.

A recent article reported that RGIC showed all the qualities needed to bond brackets without requiring acid etching on enamel, and its usefulness as a bonding material for brackets has been established.[30] This study suggested that the adhesion of RGIC to porcelain surfaces was as good as that of resin adhesive with respect to bond strength and durability, and the study revealed that RGIC showed a better preservation of porcelain than did resin adhesive. RGIC, therefore, serves as an advantageous alternative to resin adhesive for orthodontic bracket bonding to both enamel and to porcelain surfaces.

CONCLUSIONS

- Tensile bond testing to porcelain surfaces after 24 hours showed no significant differences between RGIC and resin adhesive. However, after the thermal cycling, significant decreases in bond strength were noted.
- Shear bond strength to porcelain surfaces expressed no significant decreases between after 24 hours and after the thermal cycling. Resin adhesive showed higher bond strength than did RGIC.
- Destruction of bond surfaces frequently occurred after 24 hours using resin adhesive as shown by the shear bond strength test, and it was observed in every specimen after thermal cycling.
- When shear force is applied to resin adhesive during bracket removal, destruction of porcelain frequently may occur. Therefore, removal of brackets by applying tensile force is desirable.
- RGIC served as an advantageous alternative to resin adhesive for bracket bonding to porcelain and to enamel.

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