Original Article

In Vitro Evaluation of the Bond Strength of Metal Brackets Adhered to Different Dental Restorative Materials using Different Orthodontic Adhesives

S Özcan, M Nezir, E Topçuoğlu[1], AO. Atilla[2], A Yağci[1]

Department of Restorative Dentistry, Gazi University, Ankara, [1]Department of Orthodontics, Erciyes University, Kayseri, Turkey, [2]Department of Orthodontics, Cyprus International University, Nicosia, North Cyprus

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Abstract

Background: During orthodontic treatment, teeth with brackets may sometimes be restored with different restorative materials. In this case, the content of the orthodontic adhesive selected for bracket bonding may also be important. **Aim:** This study compared the bond strength of metal orthodontic brackets adhered to different resin composite and glass ionomer cement (GIC) restoration surfaces with glass ionomer-based and resin-based orthodontic adhesives to determine the best orthodontic adhesive for use in restored teeth. **Material and Methods:** This study prepared 80 discs. Four material groups of 20 discs were created: reinforced high-viscosity GIC, high-viscosity GIC, flowable bulk-fill resin composite, and nanohybrid resin composite. Specimens in each material group were divided into two subgroups that differed in the orthodontic adhesive used to bond the brackets to the prepared specimens. After 24 hours, the specimens were shear bond strength (SBS) tested at 1 mm/min using a universal tester. **Results:** The SBS of glass ionomer-based orthodontic adhesive differed significantly between metal brackets adhered to different bases ($P < 0.001$). The highest SBSs were observed between metal brackets and high-viscosity glass ionomer restorations (6.79 ± 2.38). The highest SBSs observed with a resin-based orthodontic adhesive were between metal brackets adhered to nanohybrid resin composite restorations (8.84 ± 2.10; $P = 0.030$). **Conclusions:** Glass ionomer-based orthodontic adhesive provided safer bond strength and demineralization prevention when applying metal brackets to teeth with glass ionomer restorations.

Keywords: *Glass ionomer material, orthodontic metal brackets, shear bond strength*

Introduction

After the discovery of enamel etching, composites began to be widely used to bond orthodontic brackets to the tooth surface. This technique has become the preferred technique because of its advantages in direct bracket fixation and clinically acceptable bond strength.[1] However, fixed orthodontic appliances make it difficult to perform oral hygiene procedures and remove food residues from tooth surfaces by interrupting the intraoral tissues' self-cleaning ability.[2]

Therefore, demineralization and white spot lesions (WSL) are inevitable side effects of poor oral hygiene in patients receiving fixed orthodontic treatment.[3] When using resin composites for bracket bonding, enamel loss may occur during pickling, residual resin removal by debonding, and rebonding.[4,5] These disadvantages have necessitated a search for materials with a similar bond strength to resin composites but less damaging to the tooth surface.[3]

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Address for correspondence: Dr. M Nezir,
No. 41st Street Emek, Gazi University, Faculty of Dentistry,
06490 Ankara, Turkey.
E-mail: mervenezir@gazi.edu.tr

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Glass ionomer cement (GIC) has been developed as an alternative to resin composites for bonding brackets.[6] Current commonly used restorative materials include resin composites and GIC.[7] Glass ionomer cements have direct adhesion to teeth and metals due to their cross-linking capacity with calcium ions found in dental hard tissues or clinical metals.[7,8] In addition, GIC's antibacterial and cariostatic properties are related to the amount of fluoride released.[9] They have a low shrinkage coefficient on the enamel surface and thermal compatibility with tooth enamel and dentin due to their tooth-like thermal expansion coefficient.[10] Compared to other dental restoration materials, GICs do not contain monomers or have a low monomer amount, resulting in low cytotoxicity and giving them a wide range of uses in modern dentistry.[11-13]

In light of recent developments, GIC use has increased as an alternative permanent restorative material to amalgam and resin composite.[14] One development was the introduction of high-viscosity GICs to the market, allowing GICs to be used for restorative purposes through adjustments to the conventional GIC structure.[15]

Significantly less WSL formation was reported when bonding with GICs.[16] While carrying out active treatment with fixed devices, the bracket attachment values must be at the desired level to prevent WSLs. The greatest disadvantage of fluoride-releasing cement is its lower shear and tensile strength and higher debonding risk than composites.[17]

Glass ionomer cements reinforced with different materials give them better esthetic compatibility, lower solubility in the oral environment, and higher tensile strength have emerged.[18] One is GIC reinforced with iron oxide particles, which has improved translucency and was indicated for stress-bearing and non-stress-bearing Class I and Class II restorations and Class V restorations.[19]

With recent increases in the need for orthodontic treatment,[20] the need for bracket bonding to resin composite and glass ionomer restorations has emerged.[21] Lai *et al*.[22] reported that bond strength was unaffected, and clinically acceptable bond strength was obtained when brackets were bonded to resin composite surfaces with light-cured resin composite and resin-reinforced GICs.

Many studies have examined the bond strength of conventional resin composite and different glass ionomer-based orthodontic adhesives to the composite restoration surface.[22–26] However, none have examined the bonding success of glass ionomer-based orthodontic adhesives with remineralization effects on the surfaces of glass ionomer restorations, which are increasingly used and have been strengthened with different materials to improve durability and aesthetics.[27]

This *in vitro* study aimed to evaluate the shear bond strength (SBS) of orthodontic metal brackets to composite-based (Estelite Bulk-Fill Flow; Gaenial A'CHORD) and glass ionomer-based (Equia Forte HT; Fuji IX GP) dental restoratives bonded with glass ionomer-based (Fuji Ortho LC Paste Pak Automix) and resin-based (Transbond XT Light Cure Adhesive Paste) orthodontic adhesives.

Material and Methods

Sample size calculations used the package program G*Power (v. 3.1.9.6.; Franz Faul, Universitat Kiel, Germany). Based on a 40% effect size, 80% power, 5% tolerance, and 25% possible data loss, each group comprised 10 specimens.

Plexiglass molds with a diameter of 6 mm and thickness of 4 mm were used to prepare specimens. Molds were placed in cold pink acrylic surrounded by a polyvinyl chloride cylinder for SBS testing. Eighty disc-shaped specimens were prepared using plexiglass molds as described: 20 for reinforced high-viscosity GIC (Equia Forte HT; GC Corp., Tokyo, Japan), 20 for high-viscosity GIC (Fuji IX GP; GC Corp., Tokyo, Japan), 20 for flowable bulk-fill resin composite (Estelite Bulk Fill flow; Tokuyama Dental Corp., Tokyo, Japan), and 20 for nanohybrid resin composite (Gaenial A'CHORD; GC Corp., Tokyo, Japan). The prepared resin composite specimens were polished with aluminum oxide coated discs (Soflex; 3M ESPE Dental Products, St. Paul, MN, USA) for 40 seconds. Each disc (coarse, medium, fine, and ultra-fine) was used for 10 seconds for all specimens. The specimens were kept in distilled water at 37°C for 24 hours. Then, bonding the brackets to the disc-shaped specimens was started [Table 2].

When bonding the brackets (Mini Master; American Orthodontics, USA) to the prepared specimens, the specimens in each material group were divided equally into two subgroups for which a different orthodontic adhesive was used [Table 1].

Glass ionomer-based orthodontic adhesive (Fuji Ortho LC Paste Pak Automix; GC Europe, Leuven, Belgium) and resin-based orthodontic adhesive (Transbond XT Light Cure Adhesive Paste; 3M Unitek, Monrovia, CA, USA) were applied to bracket surfaces according to the manufacturer's instructions before the brackets were placed on the specimen's surface.

In Fuji Ortho LC Paste Pak Automix groups, a surface conditioner (Ortho gel conditioner; GC Europe, Leuven, Belgium) was applied to the specimen surface according to the manufacturer's instructions. After waiting for 10 seconds, it was rinsed with air-water spray and dried slightly. Next, the orthodontic adhesive pastes were mixed for 10 seconds with the help of a plastic spatula on the mixing paper. Then, the bracket surface was covered with orthodontic adhesive, placed in the appropriate position on the specimen surface, and bonded by slight pressing. The overflowing orthodontic adhesive was gently cleaned and polymerized for 20 seconds using an light-emitting diode (LED) light device (D-Light Pro LED Light Device; GC, Leuven, Belgium) mesially and distally.

In Transbond XT groups, 37% orthophosphoric acid was applied to the specimen surface for 15 seconds, which was then thoroughly rinsed with air-water spray and dried slightly. Next, an adhesive primer (Transbond XT Primer; 3M Unitek, Monrovia, CA, USA) was applied to the specimen surface according to the manufacturer's instructions and polymerized with an LED light device for 10 seconds. Then, the bracket surface was covered with cement, placed in the appropriate position on the specimen surface, and bonded by slight pressing. The overflowing orthodontic adhesive was gently cleaned and polymerized with an LED light device from mesial and distal directions for 20 seconds.

Table 1: Groups formed for bonding the brackets to the prepared specimens with two different orthodontic adhesives.

	Glass Ionomer-Based Orthodontic adhesive	Resin-Based Orthodontic adhesive
Reinforced High-Viscosity Glass Ionomer	Group 1a	Group 1b
High-Viscosity Glass Ionomer	Group 2a	Group 2b
Flowable Bulk-Fill Resin Composite	Group 3a	Group 3b
Nanohybrid Resin Composite	Group 4a	Group 4b

The specimens were kept in distilled water at 37°C for 24 hours after the brackets were bonded. After 24 hours, specimens underwent the SBS test using a universal tester (Shimadzu IG-IS; Kyoto, Japan) at 1 mm/min. The Newton values obtained were converted to Megapascal (MPa) values by calculating the specimens' surface area, and the obtained data were recorded for statistical analysis.

Results

Shear bond strengths for metal brackets on different bases are shown in Table 3. Significant differences were observed in the SBSs of metal brackets adhered to different bases with a glass ionomer-based orthodontic adhesive ($P < 0.001$). The highest SBS values were in Group 2a (6.79 ± 2.38). The lowest SBSs were in Group 3a (3.93 ± 1.46). There were also significant

Table 2: Materials used in the study and their contents

Material Name	Manufacturer	Content
Equia Forte HT	GC Corp., Tokyo, Japan	Powder: Fluoroaluminosilicate glass, polyacrylic acid, iron oxide Liquid: Polybasic carboxylic acid, water
Fuji IX GP	GC Corp., Tokyo, Japan	Powder: Aluminosilicate glass, polyacrylic acid Liquid: Polyacrylic acid, water
Estelite Bulk-Fill Flow	Tokuyama Dental Corp., Tokyo, Japan	Filler content/56% by vol% 70% by weight New organic–inorganic hybrid filler, surpranano spherical filler (SiO2-ZrOs), Bis-GMA, TEGDMA, BisMPEPP, CQ, Radical-Amplified Photopolymerization initiator
Gaenial A'CHORD	GC Corp., Tokyo, Japan	Bis-MEPP, 82% by weight filler: glass filler (300 nm barium glass) 16 nm (fumed silica), organic filler (300 nm barium glass; 16 nm fumed silica)
Fuji Ortho LC Paste Pak Automix	GC Europe, Leuven, Belgium	Fluoroaluminosilicate glass, copolymer of acrylic acid and maleic acid, HEMA (2-hydroxyethylmethacrylate), water, KK, activator
Ortho Gel Conditioner	GC Europe, Leuven, Belgium	Polyacrylic Acid
Transbond XT Light-Cure Adhesive Paste	3M Unitek, Monrovia, California, USA	70–80% by weight silanated quartz, 10–20% Bisphenol A Diglycidyl Ether Dimethacrylate (Bis-GMA), 5-10% Bisphenol A Bis (2-Hydroxyethyl Ether) Dimethacrylate and <2% silanated silica and <0.2% Diphenyliodoniumhexafluorophosphate
Transbond XT Primer	3M Unitek, Monrovia, California, USA	45–55% by weight Bisphenol A Diglycidyl Ether Dimethacrylate (Bis-GMA), 45–55% Triethylene Glycol Dimethacrylate (TEGDMA) and less than 1% Triphenylantimone, 4-(Dimethylamino)-Benzeneethanol, DL-Camphoroquinone and Hydroquinone
i-GEL Phosphoric Acid Etching Gel	i-Dental, Siauliai, Lithuania	37% Ortho-phosphoric acid

Table 3: Mean and Standard Deviation of the Shear Bond Strength (SBS) (MPa) of the Different Groups

	Reinforced High Viscosity Glass Ionomer	High Viscosity Glass Ionomer	Flowable Bulk-Fill Resin Composite	Nanohybrid Resin Composite	*P*
Glass Ionomer-Based Orthodontic Adhesive	5,04±2,28	6.79±2,38	3,93±1,46	4,05±1,77	<0,001^{KW}
Resin-Based Orthodontic Adhesive	3.53±1.90	4,05±1,77	8,09±3,16	8,84±2,10	0,030 ^{KW}
P	0.125^{It}	0.009^{It}	0,001^{MW}	0,001^{MW}	

It: Independent Specimens-*t*-test; MW: Mann-Whitney *U*-test; KW: Kruskall-Wallis test

Table 4: Adhesive remnant index evaluation used a four-point scale in which

Score	Meaning
0	The entire adhesive left on the bracket base
1	More than half of the adhesive left on the bracket base
2	Less than half of the adhesive left on the bracket base
3	No adhesive left on the bracket base

differences in the SBSs of metal brackets adhered to different bases with a resin-based orthodontic adhesive (*P* = 0.030). The highest SBSs were in Group 4b (8.84 ± 2.10). The lowest shear binding strengths were in Group 1b (3.53 ± 1.90).

Significant differences were observed in the SBSs of metal brackets adhered to the flowable bulk-fill resin composite and nanohybrid resin composite base materials based on the orthodontic adhesive used (*P* = 0.001). The bond strengths of brackets bonded with a resin-based orthodontic adhesive (Transbond XT) were significantly higher than those with a glass ionomer-based orthodontic adhesive (Fuji Ortho LC Paste).

While there were no significant differences between Groups 1a and 1b (*P* = 0.125), there were significant differences between Groups 2a and 2b (*P* = 0.009). The bond strengths of brackets adhered to glass ionomer surfaces with a glass ionomer-based orthodontic adhesive were significantly higher than those bonded with a resin-based orthodontic adhesive. Significant differences were observed between Groups 3a and 3b based on the orthodontic adhesive used. Similarly, significant differences were observed between Groups 4a and 4b based on the orthodontic adhesive used.

The surface where the fracture occurred in all specimens was examined using a stereomicroscope (Olympus SZ-40; Tokyo, Japan) at 30 × magnification. Fracture types were determined according to the scores in Table 4, and these data were recorded.[28]

The four groups' adhesive remnant indices (ARIs) are listed in Table 5.

Significant differences in ARIs were observed between brackets attached to different bases with a glass ionomer-based orthodontic adhesive (*P* = 0.002). Adhesive remnant indices of zero were seen most often in Group 1a (70%), while ARIs of two were observed most often in Group 4a (80%). Similarly, the ARIs of brackets adhered to different restorative materials with a resin-based orthodontic adhesive differed significantly between restorative materials (*P* < 0.001). Adhesive remnant indices of zero were seen most often in Groups 1b (100%) and 2b (100%), while ARIs of two were seen most often in Group 3b (50%).

Discussion

The increasing average age of patients treated in orthodontic clinics increases the number of teeth with restorations.[29] The surface of different materials, such as resin composite, amalgam, and glass ionomer, differs from enamel's surface structure. This difference highlights the necessity of choosing an appropriate adhesive agent to be used in the bonding process.

Resin composite restorations have become popular over the last half a century because they can have shades more similar to enamel.[30] The aesthetic and durability of resin composites have made them a frequently used filling material in anterior and posterior restorations.[31] Composite resin restorations are used in patients needing anterior restorative procedures. They have become a suitable alternative with advantages such as satisfactory aesthetic results and minimum wear on the tooth structure.[32] However, their disadvantages include cost, treatment time, and technique-sensitive adhesive procedures.[33,34] In addition, Brunthaler *et al*.[35] showed that one of the main reasons for composite restoration failures is secondary caries. With the increasing use of fixed orthodontic appliances, composites have been used frequently in bracket applications.[36] However, this system's shortcomings include enamel loss after acid etching,[5] potential enamel fractures during the debonding procedure,[37] and no remineralization effect, prompting the search for materials with a similar bond strength to composites but less damaging to the tooth surface.[5] Such disadvantages are less likely to occur with glass ionomer-based orthodontic adhesives.

Table 5: Distribution of Adhesive Remnant Index (ARI) Scores

	Score	Reinforced High Viscosity Glass Ionomer	High Viscosity Glass Ionomer	Flowable Bulk-Fill Resin Composite	Nanohybrid Resin Composite	*P*
Glass Ionomer-Based Orthodontic Adhesive	0	7 (70,0)	2 (20,0)	5 (50,0)	1 (10,0)	
	1	3 (30,0)	4 (40,0)	4 (40,0)	1 (10,0)	0,002
	2	0 (0,0)	4 (40,0)	1 (10,0)	8 (80,0)	
	3	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)	
Resin-Based Orthodontic Adhesive	0	10 (100,0)	10 (100,0)	2 (20,0)	2 (20,0)	<0,001
	1	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)	
	2	0 (0,0)	0 (0,0)	5 (50,0)	4 (40,0)	
	3	0 (0,0)	0 (0,0)	3 (30,0)	4 (40,0)	

Glass ionomer cements offer an alternative to resin composites used in bracket bonding. Glass ionomer cements continue to evolve as an orthodontic adhesive with unique and exceptional properties that compete with composite resins for durability but do not cause enamel damage.[38] Compared to other restorative agents, the limited use of glass ionomer restorations as a permanent restorative material is increasing with current development.[14] More esthetic results can be obtained with GICs than amalgam restorations. Therefore, their use in clinical practice is increasing.[39]

The advantages of glass ionomer restorative materials, such as their anticariogenic potential due to fluorine in their structure, good biocompatibility with mineralized tissue, chemical bonding ability, low cost, increased color options, and ease of application, have increased their use for restorative purposes.[40] In addition, their durability has been improved by adding materials such as glass and reactive fiber to their structure.[41,42]

This study aimed to ensure that all conditions were identical for different restoration discs and adhesives by performing *in vitro* experiments and providing standardization with bond strength and ARI analyzes. All specimens were prepared *in vitro* and kept in distilled water at 37°C for 24 hours to stimulate the aging process. One reason for conducting this study *in vitro* was that not every patient can achieve the same oral hygiene efficiency. In addition, the different force amounts brackets would experience in the oral environment may affect bond strength and result reliability. Since, there is no standard protocol for the thermal cycle procedure in the artificial aging process, this study did not perform this process.[43]

Fixed orthodontic appliances placed in the mouth encounter forces such as shearing, pulling, bending, and their combination, and it is difficult to quantify these forces.[44] Reynolds and Von Fraunhofer reported that shearing forces of 5.9–7.8 MPa would be sufficient for most orthodontic treatments since the maximum long-term shear force is not required for orthodontic treatment.[45] In this study, while SBSs were found to be sufficient on the high-viscosity glass ionomer restoration surface with glass ionomer-based orthodontic adhesive, they were insufficient on the reinforced high-viscosity glass ionomer restoration surface. These findings show that increasing glass ionomer viscosity can positively affect bond strength.

While the resin composite bonds to the old composite surface via macro-mechanical undercut and micromechanical locking onto the prepared composite surface, it chemically bonds to fillers and organic matrix.[46] In this study, the bond strengths of brackets applied to different composite surfaces using resin-based orthodontic adhesive were significantly higher, consistent with previous studies.[47-50] This finding shows that using a resin-based orthodontic adhesive in bracket bonding in teeth with resin composite restorations provides safer bond strength.

The bonding between the glass ionomer and the composite material is micromechanical.[51] Few studies have examined resin-based orthodontic adhesives to glass ionomer surfaces.[52] In this study, the bond strength of brackets applied to glass ionomer surfaces using resin-based orthodontic adhesive was insufficient. This finding may be due to the different chemical structures of resin composite and glass ionomer, with bonds between them mainly being micromechanical.

No studies have examined bonding brackets with a glass ionomer-based orthodontic adhesive to the glass ionomer restoration surface. In this study, the bond strengths of brackets adhered to different glass ionomer restoration surfaces with glass ionomer-based orthodontic adhesive were higher than those adhered with resin-based orthodontic adhesive.

The ARI results indicate that 20% of the adhesive remained on the bracket in the high-viscosity glass ionomer restoration group in which glass ionomer-based orthodontic adhesive was used. This finding indicates that a successful bond was achieved between the orthodontic adhesive and the restoration, consistent with the bond strength test results. When a resin-based orthodontic adhesive was used, 100% remained on the bracket in both glass ionomer restoration groups, indicating that bond failure occurred at the restoration and orthodontic adhesive interface.

When a resin-based orthodontic adhesive was used to adhere brackets to resin composite surfaces, 20% remained on the bracket, consistent with the bond strength test results. When glass ionomer-based orthodontic adhesive was used to bond brackets to resin composite surfaces, the amount remaining on the bracket was significantly lower in the nanohybrid resin composite group than in the flowable bulk-fill resin composite group. This finding shows that for restorations made of nanohybrid resin composite, glass ionomer-based orthodontic adhesive provides better bond strength than flowable resin composites.

Conclusions

In this study, average bond strengths for metal brackets adhered to glass ionomer restoration surfaces were clinically acceptable in the glass ionomer-based orthodontic adhesive groups compared to resin-based orthodontic adhesive groups. Among the tested methods, metal bracket groups applied with resin-based orthodontic adhesive to different glass ionomer restoration surfaces showed the lowest adhesion values and remained below acceptable limits. This finding suggests that it is an unreliable method for bonding metal brackets to glass ionomer surfaces.

The bracket bonding method with resin-based orthodontic adhesive on the nanohybrid resin composite surface provided the highest SBSs. The highest SBS was obtained using high-viscosity glass ionomer restorations in the groups using glass ionomer-based orthodontic adhesive. According to this study's results, glass ionomer-based orthodontic adhesive provided safer bond strength and demineralization prevention when applying brackets to teeth with glass ionomer restorations.

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Conflicts of interest

There are no conflicts of interest.

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