

The evaluation of shear bond strength of resin-modified glass ionomer cement with the addition of 45S5 bioactive glass using two conventional methods.

La evaluación de la resistencia al cizallamiento del cemento de ionómero de vidrio modificado con resina con la adición de vidrio bioactivo 45S5 utilizando dos métodos convencionales.

Maryam Shirazi.¹
Mahsa Sadeghi.²

Affiliations:

¹Assistant Professor of Orthodontics, Dental Caries Prevention Research Center, Qazvin University of Medical Sciences, Qazvin, Iran.

²General Dentist, Student Research Committee, Qazvin University of Medical Sciences, Qazvin, Iran.

Corresponding author: Maryam Shirazi. Dental Caries Prevention Research Center, Qazvin University of Medical Sciences, Bahonar Blvd. Qazvin, Iran. **Phone:** (98-28) 33353064. **E-mail:** : dr.maryam_shirazi@yahoo.com

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Abstract: Introduction: There is a high prevalence of enamel caries around brackets due to the young age of the majority of orthodontic patients, and to the difficulty of plaque removal in presence of orthodontic appliances. Recently, protective agents such as bioactive glasses (BGs) were introduced to enhance remineralization and prevent demineralization of tooth structures. This study aimed to assess the shear bond strength (SBS) of resin-modified glass ionomer cement (RMGIC) with addition of 45S5 BG to enhance its remineralizing potential using two conventional methods.

Material and methods: This *in-vitro* experimental study evaluated three groups (n=20) of orthodontic brackets bonded to enamel using Transbond XT (group 1), light-cure RMGIC (group 2) and RMGIC with BG added (group 3). Samples underwent 7000 thermal cycles and their SBS was measured. The adhesive remnant index (ARI) score was also determined. Quantitative data were analyzed using one-way ANOVA while qualitative data were analyzed using a chi-square test. **Discussion:** The results showed no significant difference in SBS between study groups, however the ARI scores were significantly different among the groups. The RMGIC group showed the highest ARI while RMGIC doped with BG showed the lowest ARI score. **Conclusion:** Addition of 30% w/v 45S5 BG to RMGIC does not cause a significant change in SBS of orthodontic brackets bonded to enamel, while resulting in less amount of luting agent remnants on the enamel surface after debonding.

Keywords: Glass ionomer cements; resin cements; shear strength; transbond xt; orthodontic brackets; protective agents.

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Resumen: Introducción: Existe una alta prevalencia de caries del esmalte alrededor de los brackets debido a la corta edad de la mayoría de los pacientes de ortodoncia y a la dificultad de remoción de la placa en presencia de aparatos de ortodoncia. Recientemente, se introdujeron agentes protectores como los vidrios bioactivos (VB) para mejorar la remineralización y prevenir la desmineralización de las estructuras dentales. Este estudio tuvo como objetivo evaluar la resistencia al cizallamiento (RC) del cemento de ionómero de vidrio modificado con resina (CIVMR) con la adición de 45S5 BG para mejorar

su potencial remineralizante utilizando dos métodos convencionales. **Material y Métodos:** Este estudio experimental *in vitro* evaluó tres grupos (n = 20) de brackets de ortodoncia adheridos al esmalte usando Transbond XT (grupo 1), CIVMR fotopolimerizable (grupo 2) y CIVMR con VB agregado (grupo 3). Las muestras se sometieron a 7000 ciclos térmicos y se midió su RC. También se determinó la puntuación del índice de restos de adhesivo (IRA). Los datos cuantitativos se analizaron mediante ANOVA de una vía, mientras que los datos cualitativos se analizaron mediante una prueba de chi-cuadrado. **Discusión:** Los resultados no mostraron diferencias significativas en la RC entre los grupos de estudio, sin embargo, los puntajes

IRA fueron significativamente diferentes entre los grupos. El grupo CIVMR mostró el ARI más alto mientras que CIVMR dopado con VB mostró el puntaje IRA más bajo. **Conclusión:** La adición de un 30% p/v de 45S5 VB a CIVMR no causa un cambio significativo en la RC de los brackets de ortodoncia adheridos al esmalte, mientras que resulta en una menor cantidad de remanentes de agente de fijación en la superficie del esmalte después del desprendimiento. Resistencia al Corte.

Palabra Clave: Cementos de ionómero vítreo; cementos de resina; resistencia al corte; transbond xt; soportes ortodóncicos; sustancias protectoras.

INTRODUCTION.

Several luting agents with different filler percentages, chemical composition and consistency are used for bonding of orthodontic brackets to the tooth structure. The popularity of most of these agents is related to their easy and fast application. There is a high prevalence of white spot lesions and mild to severe caries around the bonded brackets due to the absence of protective effects of the luting agents used.¹ This is a major limitation of the conventional luting agents used for bracket bonding.

Glass ionomer cement (GIC) was first introduced by Kent & Wilson as a tooth-colored restorative material for esthetic dental restorations.² GICs are biocompatible and can chemically bond to dental structure. Moreover, they release fluoride and enable ion exchange with the adjacent mineral tissues. Thus, they are considered as a material with remineralization potential.² Despite the afore-mentioned advantages, clinical and laboratory evidence shows that the conventional GICs do not have adequate strength for long-term efficient bonding of orthodontic brackets to enamel.³

In the recent years, resin modified glass ionomer cements (RMGICs) were introduced to the market in order to overcome some of the limitations of conventional GICs. RMGICs contain photo-initiators and are polymerized by light. Also, they have higher mechanical properties and lower water sorption than conventional GICs due to their resin content.⁴ RMGICs have become increasingly popular for several dental applications due to lower technical sensitivity, higher adhesive and cohesive strength and significant fluoride release potential compared to the conventional GICs.⁵

Bioactive glasses (BGs) are a group of materials implantable in the human body, which were first introduced to the medical community in 1971. High biocompatibility of these compounds and their ability for use in defects with high microbial load have further added to their uniqueness. Different BG compounds have variable volume percentage of calcium, sodium, phosphorus and silica oxides.⁶ Depending on the weight percentage of the constituents, BG materials show different behaviors in different bio-environments.⁷ The 45S5 BG is among the most commonly used BG compounds; it has a chemical composition of 46.1 mol% SiO₂, 26.9 mol% CaO, 24.4 mol% Na₂O and 2.5 mol% P₂O₅. One major advantage of this BG is its bioactivity, which causes hydroxyapatite deposition on the surface of materials. This results in a chemical bond of this biomaterial to the adjacent mineral tissues.⁸ The antibacterial effects of this BG against supra- and sub-gingival plaque have been previously confirmed.

Moreover, some studies have mentioned the buffering capacity of this compound in presence of acids produced by the cariogenic bacteria. Due to these advantages, BG is now considered a compound for prevention of demineralization and enhancement of remineralization of tooth structures.⁹

Considering the shortcomings of the conventional luting agents used for orthodontic bracket bonding, especially in young patients with poor oral hygiene, the need for protective agents to prevent demineralization during the course of orthodontic treatment is obvious. Several compounds such as amorphous calcium phosphate, fluoride releasing compounds and calcium

phosphate compounds have been added to resin luting agents.¹⁰

Addition of any compound to the luting cements used for orthodontic bracket bonding aiming to improve bioactive properties (*i.e.* reduction in demineralization and enhancement of remineralization) is justified only if long-term adequate cohesive and adhesive bond strength as well as clinical usefulness are guaranteed.¹¹ This study aimed to assess the shear bond strength (SBS) of orthodontic brackets to human enamel using a RMGIC doped with 45S5 BG nanoparticles.

MATERIALS AND METHODS.

This study had an *in vitro*, experimental design.

Selection and preparation of teeth

Sixty human premolars extracted for orthodontic purposes were used in this study. The teeth were inspected under a stereomicroscope (MBC-2, Russia) at x20 magnification, and those with enamel cracks, caries and white spot lesions were excluded. Immediately after extraction, the teeth were immersed in 0.5% chloramine-T solution for 48 hours. Tissue residues were removed using a periodontal curette and the teeth were cleaned with water and pumice paste using a rubber cup. The teeth were randomly divided into three groups (n=20 each) and stored in distilled water at 4°C until needed. Table 1 presents the study groups. Table 2 shows the chemical composition of the luting agents used in this study.

Preparation of RMGIC doped with BG

The BG used composed of SiO₂ (45.1% mol), CaO (26.9% mol), Na₂O (24.4% mol) and P₂O₅ (2.6% mol), prepared by the melt-derived technique (APATECH bioactive glass 45S5, batch #T2018220006, Pardis Pajouhesh Phanavaran, Yazd, Iran). The mean particle size was 50 µm (30 to 50µm). The required amount of powder according to the standard mixing protocol of RMGIC was weighed by a digital scale (FX300L) with 0.001 g accuracy. Next, 30% of its weight was removed and replaced with the same weight of BG, which was mixed with the remaining 70% powder. To ensure complete mixing of the two powders, the final compound was placed in an amalgam capsule and mixed in an amalgamator for 20 seconds (Ultrammat 2, SDI Limited, Bayswater, Victoria, Australia).

Sample preparation

After cleaning of the buccal surface of the teeth, the surface of samples in group 1 was etched with

37% phosphoric acid for 30 seconds, rinsed with water for 30 seconds and gently air dried.¹² Transbond™ XT adhesive was then applied on the surface of teeth with an applicator and light-cured for 30 seconds using a LED light-curing unit (Demetron, SDS, Kerr, USA) at 470 nm wavelength with a light intensity of 1100 mW/cm². Next, composite was applied on the bracket base (edgewise) and the bracket was placed at the center of the tooth surface using a bracket positioner. Excess material was removed using the sharp tip of an explorer and the composite was cured for 40 seconds (10 seconds at each side of the bracket). In group 2, etching was performed and then one scoop of powder was mixed with 2 drops of liquid (in 2.3 to 1 weight ratio) of RMGIC for the purpose of standardization of bonded surfaces. For this purpose, the powder was divided into two portions and each portion was mixed with the liquid for 10 seconds using a plastic spatula until obtaining adequate consistency and viscosity. The final compound was applied on the bracket base and it was placed on the tooth surface. In group 3, all procedures mentioned for group 2 were repeated using RMGIC. For mounting of brackets, in order to ensure the standard position of brackets on the enamel surface, a standard holder was used and all teeth were then mounted in auto-polymerizing acrylic resin 1 mm below their cemento-enamel junction while the bracket base was perpendicular to the horizon. The prepared samples were immersed in distilled water for 24 hours and incubated at 37°C.¹³ The samples then underwent aging by thermocycling for 7000 cycles in a thermocycler between 5-55°C with a dwell time of 30 seconds and transfer time of 15 seconds.

Measurement of SBS

In this study, due to the nature of brackets, a shear test was used for assessment of bond strength. A stainless steel blade with 0.5 mm thickness was used to apply shear load in a universal testing machine (Santam, Iran). The load was applied to the bracket-tooth interface at a crosshead speed of 1 mm/minute. The debonding load was recorded in Newtons (N). Using Test Xpert V software, the load in Newtons was divided by the bracket surface area in square millimeters (12.6 mm²) to report the SBS in megapascals (MPa).

Adhesive remnant index (ARI) score

The debonded surfaces were inspected under a stereomicroscope (MBC-2, Russia) at x20 magnification and scored in terms of the amount of adhesive remaining on the enamel surface using a qualitative scale (Table 3).

Statistical analysis

The measures of central dispersion including the mean, standard deviation, standard error and upper and lower bounds of the 95% confidence interval of the

mean for SBS of orthodontic brackets to enamel surface were reported and analyzed using one-way ANOVA. The ARI scores were analyzed using the chi-square test.

Table 1. Study groups and luting agent used in each group.

Groups	Luting system used	Luting agent used
1	Resin	Transbond™ XT Light Cure Adhesive
2	Light-cure resin modified glass ionomer cement	Fuji II LC
3	Light-cure resin modified glass ionomer cement doped with bioglass	Fuji II LC containing 45S5 bioactive glass

Table 2. Chemical composition of the luting agents used in this study.

Manufacturer	Composition	Brand name
3M Unitek Orthodontic Products, Monrovia, CA.	Silane treated quartz: 70–80% Bisphenol A diglycidyl ether dimethacrylate (Bis-GMA), Bisphenol A bis (2-hydroxyethyl ether) dimethacrylate (Bis-EMA), Silane treated silica.	Transbond™ XT Light Cure Adhesive.
GC; Tokyo, Japan.	Liquid: Polyacrylic acid, 2-hydroxyethyl methacrylate (HEMA), dimethacrylate, camphorquinone, water. Powder: Al ₂ O ₃ -SiO ₂ -CaF ₂ glass and HEMA urethane dimethacrylate.	Fuji II LC.
Own lab made for the present study.	Liquid: polyacrylic acid. Powder: Al ₂ O ₃ -SiO ₂ -CaF ₂ glass and HEMA urethane dimethacrylate(70%W) + 45S5 bioactive glass (30%W)	Modified Fuji II LC.
Ultradent Products Inc., S Jordan, Utah.	35% phosphoric acid with silica. pH=0.02.	Ultra-Etch 35% phosphoric acid.
Pouyan Teb, Iran.	Edgewise/Standard/Metal/American orthodontics (0.018-inch).	Metal Bracket.

Table 3. Qualitative scale used for calculation of ARI score.

Score	Adhesive remained on the tooth surface	Mode of failure
0	No luting agent remained on the tooth surface	Adhesive failure at the tooth-luting agent interface.
1	Less than half of the debonded surface was covered with the luting agent	A mixture of adhesive failure at the bracket/tooth/luting interface and cohesive failure within the luting agent.
2	More than half of the debonded surface was covered with the luting agent	A mixture of adhesive failure at the bracket/tooth/luting interface and cohesive failure within the luting agent
3	All luting agent remained on the tooth surface and the impression of bracket mesh was obvious.	Adhesive failure at the bracket/luting interface

RESULTS.

The mean shear bond strength of brackets to the enamel surfaces bonded with resin composite was 12.18 ± 4.89 MPa. When bonded with RMGI, these values were 10.8 ± 4.79 MPa, and 10.69 ± 4.33 MPa for those bonded with RMGI + 30 wt% of BAG (Table 4).

According to the results of one-way analysis of variance, no significant difference was noted in SBS of the groups ($p=0.53$). It means that the use of RMGIC doped with BG can show a clinical behavior similar to that of conventional RMGIC.

In the resin composite group, 2 teeth (10%) have ARI of zero, 7 teeth (35%) have ARI of 1, 7 teeth (35%) have ARI of 2, and 4 teeth (20%) also 3. In the RMGI group, ARI of zero, 1, 2, and 3 exist in 2 teeth (10%), 1 tooth (5%), 11 teeth (55.5%), and 6 teeth (30%), respectively, and in RMGI + 30 wt% of BAG group, the ARI of zero, 1, 2 and 3 in 4 teeth (20%), 10 teeth (50%), 3 teeth (15%) and 3 teeth (15%) were observed, respectively (Table 5).

The results showed a significant effect of the method of application and type of luting agent on the ARI score ($p < 0.01$).

DISCUSSION.

According to the current findings, the SBS of orthodontic brackets bonded with RMGIC doped with 45S5 BG had no significant difference with that of other luting agents regarding bond shear strength. Several compounds are used as luting agents for bonding of orthodontic brackets to enamel. Resin compounds and glass ionomers are the most commonly used products for this purpose. Glass ionomers are preferred to resins due to their fluoride release potential. Evidence shows that RMGICs have higher mechanical properties than conventional GICs.¹⁴

For instance, the flexural strength of RMGICs, in case of adequate curing, is twice that of conventional GICs.¹⁵ In general, lower solubility in oral fluids, the ability to bond to tooth structure, acceptable SBS, easy applicability, and fluoride release potential have made RMGICs an ideal luting agent for bonding of orthodontic bands and brackets.¹⁶

As mentioned earlier, an efficient luting agent should be able to provide adequate retention and SBS during the entire course of treatment. Several studies have evaluated the bond strength of resin luting agents and RMGICs. Sfondrini et al. reported that resin luting agents provided a bond strength higher than that of RMGICs.¹⁷ Irrespective of the type and brand of luting agent used, the numerical

values obtained in our study were higher than the values reported in the previous studies. It means that if the protocol described in our study is strictly followed, different types of luting agents can be selected based on the site. For instance, RMGICs can be used in areas with low possibility of ideal isolation and high risk of caries (after ensuring adequate bond strength). BG can also be added to further add to the value.¹⁸ In our study, the amount of BG added was determined based on previous studies. Studies on several types of fissure sealants modified with 45S5 BG have shown that BG in the mentioned values can enhance the buffering capacity while maintaining the mechanical properties in an acceptable range.¹⁹

Some other studies on other types of BG have shown that this particular weight percentage of BG can cause significant ion release while having antibacterial activity against *Streptococcus mutans*.²⁰

Two parameters are believed to play a role in enhanced mechanical properties of RMGICs:

(I) a cross-linked resin network with glass powder particles embedded in it²¹ and

(II) increased amount of fillers added to its methacrylate part (such as acidic and non-acidic monomers) that result in optimal strength of the final compound.²² However, mechanical properties are enhanced only if the filler particles are spread homogeneously and form strong bonds with the surrounding matrix. If this condition is not met, a drop in mechanical properties such as compressive strength and modulus of elasticity may occur despite an increase in filler content.²³ On the other hand, replacing fluoroaluminosilicate glass fillers with other glasses can decrease the mechanical properties due to decreased cross-linking of aluminum and subsequently decreased interlocking of three-dimensional resin network.²⁴

However, a decreased amount of aluminum cations creates an alkaline environment, which causes further release of calcium ions from the BG. These ions, when released, are responsible for the bioactive behavior of material. They create chemical bonds between glass fillers and the matrix, participating in acid-base reactions with carboxylic acids (although weak).²⁵ This can explain higher frequency of mixed failures in group 3 in our study.

Previous research that compared the strength of an orthodontic bracket to enamel surfaces following the use of RMGI and resin composites have reported different results.²⁶⁻²⁷ In the present study, the shear bond strength of orthodontic brackets to the enamel surfaces when using the resin composite was slightly higher than that

of the RMGI. In a study by Sfondrini *et al.*,¹⁷ the use of resin composites created higher shear bond strength than RMGI. Carvalho *et al.*,²⁸ also examined the shear bond strength of metal and ceramic orthodontic brackets bonded with resin composite and RMGI, and showed that RMGI had a lower shear bond strength compared to composite resin.

These observations are consistent with the results of the present study. However, the shear bond strength of brackets in all three groups in the present study was higher than the values determined by the researchers. Therefore, resin composite will be a good choice for bonding purposes in cases with good oral hygiene and controllable conditions of oral contamination and moisture.

However, when bracket bonding is more difficult to access, and there is a possibility of salivary and moisture contamination or decalcification, RMGI or RMGI containing 30% wt BG can be used (to take advantage of the release properties of fluoride, anti-corrosion, biocompatibility effects, and chemical bonding to enamel without the need for acid etching).²⁹⁻³⁰

Amirabadi *et al.*,³¹ showed a significant drop in flexural strength of RMGIC doped with BG. This finding was in agreement with the frequency of modes of failure in our study. The difference between their results and ours, however, can be due to the fact that a number of factors are involved in bond strength of orthodontic brackets. Problems in two areas can lead to bond failure:

(I) fracture within the luting material or any of the substrates,

(II) fracture at the interface of substrate and luting agent. Evidence shows that the lower the thickness of the luting agent applied, the smaller would be the role of its cohesive strength in the final bond strength value. This can explain lack of a significant difference in SBS of group 3 compared to the other two groups in our study.

Several hypotheses have been suggested to explain the behavior of BG. In general, BGs show different biological behaviors when placed in different environments.⁷ The behavior of these compounds in the oral environment may also change when exposed to continuous acidic challenges. Considering the effects of different environments on mechanical and physical properties of these materials, it is recommended to limit their application to situations where their bioactivity is required such as filling of cavities on root surfaces with erosion, endodontic sealers, base and liners and in areas where cohesive strength is not that important.²³

In orthodontic treatment, the cement remaining on enamel surfaces should be removed after completion of orthodontic treatment. The amount of luting agent remaining on the surface is quantified using the ARI score.³² This is particularly important to support the tooth structure. In order to prevent enamel fracture or crack, it is ideal that some luting agent remains on the enamel surface after debonding.³³

However, removal of the remaining luting agent may also damage the enamel surface. Thus, ideally, the luting agent should remain in place during the course of treatment and is easily removed with slight force at the time of debonding, without damaging the enamel surface. The current results showed that the highest amount of luting agent remaining on the surface was noted in the RMGIC group, which may be attributed to chemical bonds at the enamel-cement interface. Etching prior to application of luting agent can further cause micromechanical interlocking of GIC.¹²

Combination of these two adhesion mechanisms can explain non-significant difference in bond strength of different groups in our study. After RMGIC, group 1 had the highest ARI scores followed by group 3. There is a possibility that presence of 45S5 BG containing calcium in luting agent prevents establishment of bonds between enamel and methacrylate acidic monomers in a competitive manner and affects the bond strength in this area.³⁴

Based on the results of the present study, there were significant differences between the groups studied in terms of the ARI index.

In a study by D'Attilio *et al.*,³⁵ in both groups, RMGI and Transbond XT, the greatest frequency of ARI score observed was 3 with bond failure occurring mostly at the adhesive-bracket interface. For Transbond XT, 95% of the specimens displayed ARI scores of 2 or 3, suggesting a trend for Transbond XT to display a cohesive failure within the adhesive. This points to the influence of other variables in determining the type of bond failure, such as the bracket retention mechanism.

In a study by Cheng *et al.*,³⁶ according to ARI analysis, the debonded interfaces of the RMGIC surfaces were mainly scored 2 (50%–90% of the adhesive remaining on the bracket base) while in approximately 76 percent of the sample, the debonded surfaces of the Transbond composite resin group were scored 3 (more than 90% of the adhesive remaining on the bracket base) for 50% of the sample. These results indicate that more resin remained

on the bracket base when using RMGIC and Transbond composite resin for bonding.

In orthodontic treatment, the goal is not to achieve durable restorations with maximum bond strength. Orthodontic bracket bonding is not permanent and the bond strength should be high enough to resist possible debonding of appliance and low enough to be easily separated with no excess force and no damage to the enamel surface. The minimum bond strength for orthodontic brackets is 6-8 MPa³³ and the maximum safe bond strength to prevent enamel damage is 14 MPa.³⁷ It should be noted that simulation and prediction of bond strength required during the course of treatment in the clinical setting is difficult *in vitro*.

However, Lopez reported acceptable SBS to be 7 MPa.³⁸ Accordingly, all three groups in our study provided acceptable bond strength. Laboratory research, like the present study, has one major limitation: The multifactorial environment in the mouth cannot be simulated by current research and laboratory methods because there are several factors such as the role of saliva, behaviors related to the patient, or other factors. Jurubeba et al. examined the influence of number of thermal cycles on the bond strength of metallic brackets to ceramic, and they concluded that, for *in vitro* testing, the use of at least 7,000 cycles is advised in order to result in significant fatigue on the bonding interface.³⁹ In the present study, all samples were stored in an incubator for 24 hours at 37°C and then subjected to 7,000 thermal cycles at temperatures of 5-50°C (to simulate clinical conditions).

The aging protocol adopted in our study had the highest number of thermal cycles, which was a strength of this study. This was done to assess the durability and quality of bonding in long orthodontic treatment courses.¹³

CONCLUSION.

Based on the current results, it may be concluded that addition of 45S5 BG at 30 wt% to RMGIC does not cause a significant change in bond strength of orthodontic brackets to the enamel. On the other hand, it results in less amount of luting agent residues on the enamel surface after debonding. Thus, enamel damage during removal of luting residues would be minimized. Therefore, this compound can be used for orthodontic bracket bonding in situations where adequate isolation is difficult and there is high risk of caries in order to ensure adequate bond strength and benefit from its protective bioactive effects.

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