Journal of Lasers in Medical Sciences

J Lasers Med Sci 2026;17:e52025

Original Article

https://journals.sbmu.ac.ir/jlms

doi:10.34172/jlms.52025

The Effects of Various Surface Preparation Methods on the Shear Bond Strength of Composite Resin to Resin-Modified Glass Ionomer

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Received: May 9, 2026
Accepted: August 26, 2026
ePublished: November 7, 2026

Abstract

Introduction: This study aimed to evaluate the influence of various surface preparation methods, including air abrasion and laser treatment, as well as the co-curing technique, on the shear bond strength (SBS) of composite resin to resin-modified glass ionomer (RMGI).

Methods: Forty-eight RMGI cylinders were prepared and randomly allocated into four groups (n = 12) according to the treatment applied: Group 1: control (no treatment); Group 2: air abrasion using 30-μm Al_2O_3 particles; Group 3: Er: YAG laser irradiation (2940 nm, 300 mJ, 10 Hz); and Group 4: co-curing technique (simultaneous curing of the adhesive system and RMGI). Composite resin was subsequently bonded to RMGI specimens. After thermocycling, SBS at the RMGI–composite resin interface was measured using a universal testing machine, and failure modes were determined. Data were analyzed by one-way ANOVA and Tukey's post hoc test.

Results: Significant differences in SBS were observed between the groups ($P < 0.001$). Co-curing (11.83 ± 2.72 MPa) and Er: YAG laser treatment (10.55 ± 2.16 MPa) produced comparable SBS values ($P > 0.05$), which were significantly higher than those of the control and air-abrasion groups ($P < 0.05$). No significant difference in SBS was detected between the air-abrasion (3.60 ± 1.44 MPa) and control (5.67 ± 1.30 MPa) groups ($P > 0.05$). A significant difference was observed in the distribution of failure modes among the groups ($P = 0.003$).

Conclusion: The co-curing technique and Er: YAG laser irradiation significantly enhanced the bond strength of composite resin to RMGI, whereas air abrasion provided no bonding advantage.

Keywords: Adhesion, Air abrasion, Bond strength, Composite resin, Dental cements, Dental restoration, Er: YAG laser, Glass ionomer, Laser therapy, Surface treatment

Introduction

Composite resins are currently considered the most appropriate materials for restoring anterior and posterior teeth due to their excellent aesthetics and optimal physico-mechanical properties. However, polymerization shrinkage remains a major challenge in composite resin restorations, contributing to microleakage and reduced restoration longevity.[1,2] Microleakage is especially important in gingival margins of class II and class V cavities, as these margins are frequently located in dentin or cementum, where composite resin adhesion is weak.[3,4] In addition, the risk of contamination with blood or saliva is high in such locations, further compromising the adhesion strength.[4,5]

The sandwich technique was proposed by McLean et al. to overcome the polymerization shrinkage of resin composites.[6,7] This approach combines two restorative materials for a single restoration so that the favorable properties of each can be used while their individual limitations are reduced.[8] The procedure uses a material with a low resistance to elastic deformation (low elastic modulus), such as glass ionomer (GI) or resin-modified glass ionomer (RMGI), as the base layer, and the composite resin as the final restorative material to enhance esthetics and mechanical strength.

In the original sandwich technique, conventional GI was used as the base because it provides fluoride release, chemical adhesion to tooth structure, favorable biocompatibility, and a thermal expansion coefficient close to that of dental tissues.[9,10] Despite its advantages, the conventional GI cement does not provide a chemical bond with the composite resin, and it also shows low tensile strength, leading to frequent cohesive fractures within GI.[11]RMGI is now commonly selected as the base material in sandwich restorations because of its improved mechanical properties and stronger bonding to composite resin than conventional GI.[12–15]

The success rate of dental restorations in the sandwich technique mainly depends on achieving a strong bond between the two restorative materials.[16,17] In addition to the stresses in the oral cavity, the differences in the thermal

Please cite this article as follows: Sekandari S, Rezaei M, Shegarf Nakhaei A, Langari SF, Sekandari F, Ahrari F. The effects of various surface preparation methods on the shear bond strength of composite resin to resin-modified glass ionomer. J Lasers Med Sci 2026;17:e52025. doi:10.34172/jlms.52025

expansion coefficients between the two materials in the sandwich technique may contribute to a reduction in bond strength over time.[18]Adhesion at the RMGI–composite resin interface involves both micromechanical retention and chemical interaction. One method to enhance bond strength is to increase surface roughness and create microporosities on the cured RMGI surface. This can be achieved through surface-treatment procedures such as acid conditioning, air abrasion, or laser irradiation.[7,19]

Air-abrasion is frequently employed in dentistry to increase micromechanical retention on tooth tissues or dental materials. This technique involves abrasive particles, typically aluminum oxide, on the surface, resulting in microscale irregularities such as grooves, pits, and plastic-deformation streaks. These changes increase surface energy and surface area for bonding, thereby enhancing the adhesion of resin cements and adhesive systems.

With the advent of laser dentistry, it is possible to use a high-tech device to prepare tooth cavities and to increase microretentive areas in tooth tissues and dental restorative materials. Erbium family lasers, including erbium: yttrium aluminum garnet (Er: YAG) and erbium, chromium: yttrium scandium gallium garnet (Er, Cr: YSGG), show high absorption in water and hydroxyapatite. These lasers can create a micro-roughened surface with increased porosity,[20–22] thereby improving adhesion without causing thermal damage to the irradiated substrate.[23–26]

Another technique to enhance bond strength between RMGI and resin composite is "co-curing", in which two different light-cured materials are concurrently polymerized. It is believed that the use of the co-curing technique can enhance bond strength between RMGI and composite resin by enabling simultaneous photopolymerization, which promotes chemical interdiffusion of methacrylate monomers at the interface.[27,28]

There is limited and inconsistent evidence concerning the effects of air abrasion, laser treatment, and co-curing technique on the RMGI–composite resin interface. Some studies reported that air-abrasion was the most effective method for enhancing mechanical interlocking.[16] In contrast, others highlighted the role of lasers in creating microscopic irregularities and improving bond strength.[3,29] Therefore, the most effective approach for improving the RMGI-composite resin adhesion remains unclear. This study aimed to assess the effects of air abrasion, Er: YAG laser treatment, and the co-curing technique on the shear bond strength (SBS) between RMGI and composite resin in the sandwich technique.

Materials and methods

Study design and sample size calculation

The protocol of this in vitro study was approved by the ethics committee of Mashhad University of Medical Sciences, Mashhad, Iran (IR.MUMS.DENTISTRY.REC.1402.057). The sample size was calculated based on the study by Ghubaryi et al,[19] using G*Power software (v3.1.9.2, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Assuming an alpha level of 0.05 and 80% power, the calculated sample size was 12 specimens per group, resulting in a total of 48 specimens.

Sample preparation

Forty-eight cylindrical RMGI specimens (Riva Light Cure; SDI Limited, Bayswater, Victoria, Australia) were prepared using custom-made acrylic molds. To fabricate the molds, acrylic resin (Acropars; Marlic Medical Industries Co., Tehran, Iran) was poured into a plastic mold measuring 20 mm in diameter and 15 mm in height. During polymerization, a plastic cylinder (3 mm in diameter and 2 mm in height) was inserted into the resin and then removed after setting, creating a cavity for RMGI placement.

The powder and liquid components of RMGI were combined according to the manufacturer's recommended protocol, and the mixture was placed inside the acrylic molds. A celluloid strip and glass slab were placed over the material to obtain a smooth RMGI surface. Each specimen was cured for 20 seconds with an LED curing unit (Guilin Woodpecker Medical Instrument Co., Ltd., Guilin, Guangxi, China) at an irradiance of 1000 mW/cm2.

Study groups

The specimens were randomly allocated to four groups of 12 according to the treatment applied to the RMGI surface. The study groups were as follows:

Group 1 (Control): No surface treatment was applied to RMGI. The specimen surface was rinsed for 10 seconds and air-dried for 5 seconds. Then, a self-etch adhesive system (Clearfil Liner Bond F; Kuraray Noritake Dental Inc., Tokyo, Japan) was applied to RMGI according to the manufacturer's protocol and light-cured for 20 seconds.

Group 2 (Air-abrasion): The RMGI cement was roughened with 30-μm aluminum oxide (Al2O3) particles using an Al2O3 microblaster (Foshan Snyder Medical Equipment Co., Ltd., Foshan, Guangdong, China). Sandblasting was performed for 10 seconds at a distance of 1 cm from the RMGI surface. The specimens were then irrigated for 10 seconds, air-dried for 5 seconds, and covered with a self-etch adhesive, similar to the control group.

Group 3 (Er: YAG laser): The RMGI cement surface was roughened using an Er: YAG laser (wavelength: 2940 nm; Smart 2940 D; DEKA MELA srl, Florence, Italy). The laser operated at 300 mJ, 10 Hz, and a 230 μs pulse duration (very short pulse mode) under air and water spray. A non-contact laser handpiece with a 1-mm spot size was positioned perpendicular to the RMGI at a 5-mm working distance and scanned the surface for 10 seconds. The specimens were then rinsed with water for 10 seconds and dried with compressed air for 5 seconds. The self-etch adhesive was subsequently applied in the same manner as in the control group.

Group 4 (Co-curing): After placing the RMGI mixture in the mold, no light curing was performed. The samples were kept in a dark environment for 1 minute to allow partial chemical curing. The self-etch adhesive was then applied, and both the RMGI and adhesive were polymerized simultaneously (co-curing) for 20 seconds.

Composite resin bonding to RMGI

A transparent mold, measuring 3 mm in diameter and 2 mm in height, was placed over the RMGI. Then, composite resin (A2 shade, Clearfil Majesty Esthetic; Kuraray Noritake Dental Inc.) was inserted into the mold and polymerized for 20 seconds with the curing tip positioned perpendicular to the composite surface. Afterward, the plastic mold was cut with a surgical blade. All procedures were performed by a single operator.

Shear bond strength (SBS) measurement

The RMGI-composite resin restorations were stored in distilled water at 37°C for 24 hours to allow full polymerization. Subsequently, they underwent 10,000 thermal cycles between 5°C and 55°C to simulate temperature fluctuations in the oral environment, with a 30 s dwell time in each bath. Shear bond strength (SBS) was measured using a universal testing machine (Santam, STM-20, Tehran, Iran) with a chisel-like loading head at the bonding interface. The force was applied at a crosshead speed of 0.5 mm/min until fracture occurred (Figure 1). The peak load at fracture was recorded in newtons (N) and converted to megapascals (MPa) by dividing the load by the bonded surface area (mm^2).

Failure mode analysis

Fractured surfaces were examined under a stereomicroscope (Carl Zeiss, Jena, Germany) at 20 × magnification to assess the debonded interface. The failure types were classified as follows:

- Adhesive failure: Adhesive failure was defined as separation occurring at the RMGI–composite resin interface.
- Cohesive failure: Cohesive failure was defined as fracture occurring within either the RMGI cement or the composite resin, without involvement of the adhesive interface.
- Mixed failure: Mixed failure was defined as a combination of interfacial separation and cohesive fracture within the RMGI cement or composite resin.

Statistical analysis

The normality of the data distribution was assessed using the Shapiro-Wilk test, and the homogeneity of variances was evaluated using Levene's test. Both tests demonstrated that the data met the assumptions of normality and homogeneity of variance ($P > 0.05$). One-way analysis of variance (ANOVA) was run to compare SBS values among the four groups, followed by Tukey's honestly significant difference (HSD) post hoc test for pairwise comparisons. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY, USA). A P value < 0.05 was considered statistically significant.

Table 1. Mean and standard deviation (SD) values of shear bond strength (MPa) in the study groups

Group	Type of surface treatment	Mean*	SD
1	Control (no treatment)	5.67[a]	1.30
2	Air-abrasion	3.60[a]	1.44
3	Er: YAG Laser	10.55[b]	2.16
4	Co-curing	11.83[b]	2.72
P value	0.0001		

*Different superscript letters indicate statistically significant differences between groups at $P < 0.05$

Results

Table 1 presents the means and standard deviations (SD) of SBS values (MPa) in the study groups. The co-curing group exhibited the highest mean bond strength (11.83 ± 2.72 MPa), followed by the Er: YAG laser group (10.55 ± 2.16 MPa), whereas air-abrasion treatment produced the lowest mean SBS (3.60 ± 1.44 MPa). The control group showed an SBS value of 5.67 ± 1.30 MPa.

ANOVA revealed a statistically significant difference in SBS between the four groups ($P < 0.001$; Table 1). Pairwise comparisons revealed that the co-curing and Er: YAG laser groups showed comparable bond strength values ($P > 0.05$), which were significantly higher than those of the air-abrasion and control groups ($P < 0.05$). No significant difference in SBS was found between the air-abrasion and control groups ($P > 0.05$; Table 1). The comparison of SBS among the study groups is illustrated in Figure 2.

Table 2 presents the frequencies and percentages of failure modes across the groups. Adhesive failure was more prominent in the air-abrasion (83.3%) and control (66.7%) groups. In the Er: YAG laser group, 58.3% of the specimens displayed adhesive failure, whereas 41.7% showed cohesive and mixed fractures. The co-curing group exhibited cohesive and mixed failure in all specimens (100%). The cohesive failures were exclusively observed within the RMGI cement. The chi-square test indicated a significant difference in the frequency of failure modes between the study groups ($P = 0.003$).

Discussion

This investigation compared the effects of three strategies,



Figure 1. A specimen mounted in a universal testing machine, with a chisel-shaped blade positioned at the interface between RMGI and composite resin

Table 2. The frequency (number) and percentage (%) of failure modes in the study groups

Group	Adhesive failure	Cohesive failure in RMGI	Cohesive failure in composite resin	Mixed failure
		Number (%)	Number (%)	Number (%)
Control	8 (66.6%)	2 (16.7%)	0 (0%)	2 (16.7%)
Air-abrasion	10 (83.4%)	1 (8.3%)	0 (0%)	1 (8.3%)
Er: YAG laser	7 (58.3%)	3 (25%)	0 (0%)	2 (16.7%)
Co-curing	0 (0%)	8 (66.6%)	0 (0%)	4 (33.4%)
Total	25 (52.1%)	14 (29.2%)	0 (0%)	9 (18.7%)

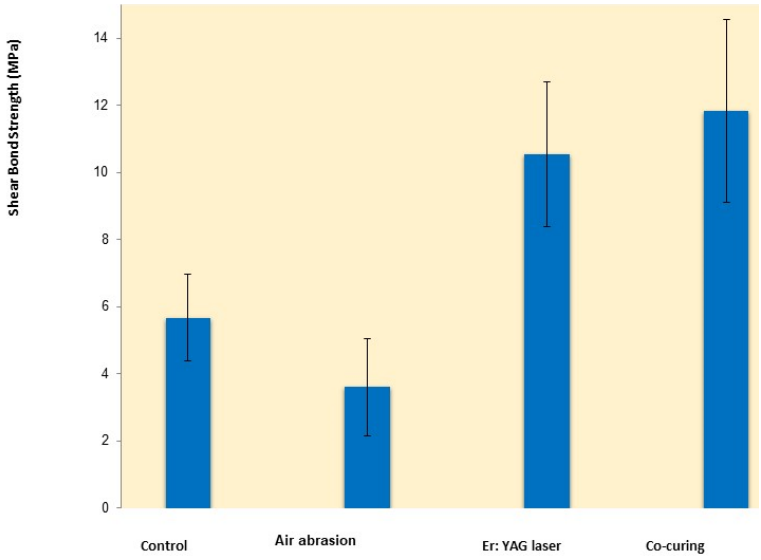


Figure 2. A bar chart comparing shear bond strength among the study groups

including air abrasion, Er: YAG laser treatment, and the co-curing technique, on the shear bond strength (SBS) of composite resin to RMGI. The specimens underwent 10,000 thermal cycles to simulate aging and temperature fluctuations in the oral environment. The results showed that co-curing (11.83 ± 2.72 MPa) and Er: YAG laser irradiation (10.55 ± 2.16 MPa) produced comparable SBS values, and both performed significantly better than the control (5.67 ± 1.30 MPa) and air-abrasion (3.60 ± 1.44 MPa) groups.

A self-etch adhesive was used in this study because previous studies have demonstrated that self-etch adhesives provide higher SBS values for RMGI than total-etch systems.[27,30] Although phosphoric acid etching is commonly used for conditioning enamel and certain restorative materials, it may remove the superficial layer of RMGI, potentially compromising SBS.[2,16] The use of self-etch adhesives also simplifies the bonding procedure by reducing the number of clinical steps, thereby minimizing the risk of contamination, particularly in deep cavities.

Among the tested protocols, air abrasion produced the lowest numerical SBS, although its value remained comparable to that of the untreated control group. Air abrasion was performed using 30-μm alumina particles for 10 seconds at a distance of 1 cm from the sample surface. The lower bond strength observed in the air-abrasion group may be related to surface damage and disruption of the fragile surface matrix of RMGI, which contains unreacted monomers crucial for composite resin adhesion. Air abrasion may also create microcracks that weaken the substrate rather than strengthening the interface.[19]

The outcomes of the present study differ from those reported by Zakavi et al,[16] who evaluated the effects of different surface pretreatment methods on the SBS of resin composite bonded to RMGI. They found that the acid-etch group exhibited the lowest SBS, whereas the air-abrasion group showed the highest value.[16] Scanning electron microscopy (SEM) analysis revealed homogeneous microporosities on the RMGI surface after air abrasion, which were suggested to facilitate the formation of resin micro-tags by the adhesive resin.[16] Other studies have also demonstrated increased surface irregularities and bond strength following air abrasion of various dental materials.[31–35] However, the present findings suggest that increased micromechanical retention alone does not necessarily result in improved bond strength, particularly in materials such as RMGI. In addition to the substrate characteristics, procedural parameters, including alumina particle size, air pressure, angle of application, and duration of abrasion, may influence the resulting surface roughness and bond strength after air abrasion.[33,34,36]

In the present study, an Er:YAG laser was applied at 300 mJ and 10 Hz for 10 seconds with scanning movements. The high affinity of the Er:YAG laser for water leads to the expansion of water content, followed by micro-explosions that eject substrate particles, a process that is called thermomechanical ablation.[37–40]The favorable SBS after Er:YAG laser treatment suggests that laser ablation created

a surface suitable for micromechanical retention without substantial damage to RMGI. It should be noted that the initial RMGIC setting occurs through the formation of a polymerization matrix, followed by a slower chemical reaction that strengthens the material. Accordingly, the fully set RMGI comprises two matrices: an ionic matrix formed through acid-base reactions and a polymerization matrix resulting from free-radical reactions. It is assumed that the Er:YAG laser can penetrate the ionic matrix of RMGI through interactions with water and hydroxyl groups in the structure of the cement.[3] This selective removal of the polyacrylic acid-rich layer causes micro-irregularities at the RMGI surface that enhance resin penetration, thus increasing bond strength between RMGI and composite resin.[3]

The findings of this study are consistent with those reported by Navimipour et al,[3] who demonstrated that the bond strength between RMGI and composite resin was significantly greater in specimens treated with an Er, Cr: YSGG laser than in those subjected to phosphoric acid etching. Kunhappan et al.[41] evaluated the depth of adhesive resin penetration into RMGI following three surface treatment methods (no pretreatment, etching with 37% phosphoric acid, and Er, Cr: YSGG laser) using the sandwich technique. They observed a significantly greater depth of resin penetration in the laser-treated group compared to the other groups.[41] Ghubaryi et al.[19]also proposed Er, Cr: YSGG laser irradiation as a useful approach for surface conditioning of RMG cement. In contrast, Zakavi et al.[16] found no significant differences in SBS among the control, acid-etch, Er:YAG laser, and Er, Cr: YSGG laser groups; all of these groups exhibited significantly lower SBS values than the bur and Al_2O_3 air-abrasion groups.

In the co-curing group, RMGI specimens underwent partial chemical setting in a dark environment for 1 minute, followed by simultaneous light curing with the adhesive resin. Co-curing yielded the highest mean SBS, although its value remained statistically comparable to that of the Er:YAG laser-treated group. This finding suggests that chemical bonding effectively enhances adhesion to RMGI and may serve as a viable alternative to surface treatments applied to pre-cured cement. RMGI contains glass ionomer as the main component, along with resin components such as 2-hydroxyethyl methacrylate (HEMA), bisphenol A-glycidyl methacrylate (BisGMA), and urethane dimethacrylate (UDMA). The presence of unreacted HEMA increases surface wettability and facilitates adhesive penetration and resin tag formation within the RMGI cement. Furthermore, covalent bonds may form between the resin bonding agent and the unreacted methacrylate groups present within the RMGI resin matrix during polymerization. The co-curing technique enables interdiffusion and co-polymerization of reactive methacrylate monomers between the RMGI surface and the overlying adhesive resin during light activation.[27] This process results in the formation of a chemically integrated interphase rather than a distinct interface and may reduce the weak boundary layer commonly observed in sequentially cured systems.

In agreement with the findings of this study, Boruziniat and Gharaei[27] demonstrated that the co-curing technique, combined with a self-etch adhesive, improved the bond strength between the RMGI and the composite resin. A systematic review by Manihani et al.[30] showed that the co-curing technique using self-etch adhesives over uncured RMGI resulted in greater bond strength than adhesive application over cured RMGI. In contrast, Kimyai et al.[42] reported that applying self-etch adhesive resin to set glass ionomer resulted in significantly higher bond strength in the sandwich technique compared with the group in which the self-etch adhesive was applied before the initial setting of the glass ionomer was completed.

From a clinical perspective, co-curing may be a preferred approach for sandwich restorations when the RMGI and adhesive resin can be polymerized simultaneously. However, when complete setting of the RMGI is required before composite resin placement (e.g., in deep proximal boxes), Er:YAG laser treatment may serve as a viable alternative for surface treatment. Air abrasion is not recommended for conditioning RMGI surfaces, as it may adversely affect the substrate and reduce the bond strength of the overlying composite resin.

The analysis of failure modes revealed a significant difference in the distribution of failure patterns between the study groups. A bond is generally considered acceptable when failure occurs within one of the materials rather than at the bonded interface, resulting in cohesive instead of adhesive failure.[3] In the present study, adhesive failure occurred most frequently in the control (66.7%) and air-abrasion (83.3%) groups, indicating interfacial debonding due to weak adhesion between the two materials. In contrast, the co-curing group exhibited only cohesive (66.7%) and mixed (33.3%) failures, representing the positive effect of this technique on adhesion. The exclusive occurrence of cohesive and mixed failures suggests that the bond strength between the two materials exceeded the RMGI's cohesive strength, indicating a stronger adhesive interface. In the Er:YAG laser group, 58% of specimens exhibited adhesive failure, whereas 42% showed cohesive and mixed failures. These findings suggest that although laser treatment may improve micromechanical retention, it may not fully compensate for the limited chemical interaction between fully set RMGI and composite resin. All cohesive failures occurred within the RMGI cement.

This study has several limitations inherent to its in vitro design. Although thermocycling was used to simulate temperature changes in the oral environment, it does not fully replicate the complex thermal variations that occur in vivo. Furthermore, factors such as cyclic masticatory forces, continuous exposure to saliva, pH variations, enzymatic activity, and interactions with oral biofilms were not reproduced. Additionally, only one RMGI and one adhesive system were evaluated in this study. Therefore, the findings may not be directly generalizable to other commercially available materials, which may differ in composition, setting reactions, and bonding behavior. Finally, bond strength

was evaluated at a single short-term time point. Therefore, the results mainly reflect initial bond strength and may not represent long-term clinical performance under functional loading and aging conditions. Future studies should include long-term aging protocols and microscopic evaluation of the adhesive interface to better investigate the effects of different surface treatment modalities on bond strength in the sandwich technique. Well-designed clinical trials are also needed to validate the long-term durability and clinical relevance of these findings.

Conclusion

The method used to condition RMGI significantly influenced its bond strength to composite resin. The co-curing technique and Er:YAG laser treatment produced significantly greater SBS than the control and air-abrasion groups. Co-curing resulted in the most favorable failure pattern, suggesting a stronger interfacial bond. Co-curing may be a preferred approach for sandwich restorations when the RMGI and adhesive resin can be polymerized simultaneously. Er:YAG laser irradiation may serve as an alternative surface conditioning method when RMGI must be allowed to set before composite resin placement.

Acknowledgments

We express our gratitude to the Vice-Chancellor for Research at Mashhad University of Medical Sciences for their financial support of this project, granted under reference number 4020820. The findings presented in this study are derived from a student thesis.

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Competing Interests

The authors declare that they have no competing interests.

Consent for Publication

No consent for publication applies to this study.

Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval

The protocol of this in vitro study was approved by the ethics committee of Mashhad University of Medical Sciences, Mashhad, Iran (IR.MUMS.DENTISTRY.REC.1402.057).

Funding

Financial support for this research was provided through a grant from the Vice-Chancellor for Research at Mashhad University of Medical Sciences.

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