

Effect of the Er: YAG laser on the shear bond strength of conventional glass ionomer and Biodentine™ to dentine

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ABSTRACT

Objectives: The purpose of this study was to determine if Er: YAG laser etching improves the shear bond strength (SBS) of Biodentine™ and GC Fuji IX® to dentine. **Materials and Methods:** Forty human dentine specimens were standardized and embedded in stone. The specimens were randomized into four groups ($n = 10$). Twenty samples were treated with the Er: YAG laser radiation and 10 of these restored with GC Fuji IX® and 10 with Biodentine™. The remaining 20 specimens acted as controls (no laser treatment); 10 were restored with GC Fuji IX® and 10 with Biodentine™. All samples were then stored in an incubator at 37.5°C and 100% humidity for 7 days. The SBS was determined using a Zwick universal testing machine. A two-way analysis of variance test was used to evaluate the statistical difference in SBS between the groups. An independent sample *t*-test was used to determine the statistical significance of differences between control and lased groups within the same material. **Results:** A highly statistically significant difference in SBS was found with the laser treatment ($P = 0.0001$) and material (i.e., Biodentine™ or Fuji IX® ($P = 0.0001$)). The GC Fuji IX® group recorded the highest mean SBS required to dislodge the material from the laser-treated dentine surface (1.77 ± 0.22 Mega-Pascal [MPa]). The mean SBS of Biodentine™ to dentine following the laser radiation (1.12 ± 0.16 MPa) was significantly greater compared to the nonlased dentine (0.53 ± 0.09). Pearson Chi-square test indicated a nonsignificant relation between shear strength and mode of failure ($P = 0.467$). **Conclusion:** Laser etching of the dentine surfaces yielded a significant increase in the bond strength for both GC Fuji IX® and Biodentine™. The SBS of Biodentine™ to dentine is greater than with conventional glass ionomer (Fuji IX®).

Key words: Biodentine™, dentin, Er: YAG laser, shear bond strength

INTRODUCTION

The proper preparation of the dentine surface before applying the restoration is an important step ensuring a good seal, decreased microleakage, a strong bond, and successful restoration.^[1] Er: YAG laser energy is well absorbed by water and hydroxyapatite, with

a minimal thermal impact on the tooth and the surrounding tissues, particularly when a water spray is applied. This laser tends to produce an irregular appearance of the irradiated dentine surface, and the

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retention of resin restorative materials has been shown to be improved.^[2,3] This study examined whether the retention of other materials (GC Fuji IX[®] and Biodentine[™]) might also be improved.

Biodentine[™] and GC Fuji IX[™] have different mechanisms of bonding to dentine. The adhesion of Biodentine[™] to the dentinal tissue is mainly micromechanical and is not ionic-exchange based as with GC Fuji IX[™].^[4] Biodentine[™] is a calcium silicate material that is recommended as a permanent dentine restoration material. It has been described as a good dentine substitute and its easy handling properties make it a popular material among clinicians. It is a highly biocompatible material.^[4] Glass ionomer is widely employed in restorative dentistry, despite its limited adhesion to tooth structure and microleakage.^[5,6] Alternative techniques aiming to improve the adhesion of restorative materials to enamel and dentine have been suggested.^[7-9] Er: YAG laser irradiation of dental surfaces is among those techniques.^[10,11]

In an early, multicentric, randomized, prospective clinical study of Biodentine[™] as a restorative material, Koubi *et al.*,^[12] found that Biodentine[™] was able to restore posterior teeth for up to 6 months. Different results were obtained in a recent randomized control trial by Hayes *et al.*,^[13] who found that of the 151 Biodentine[™] adult root surface restorations placed, 74 (52%) failed after 1 year. Most of the failures were due to a lack of restoration retention. The limited duration of the experimental period in both studies restricts the conclusions that can be made.

Our aim was to investigate whether lasing the dentine surface would increase the shear bond strength (SBS) of Biodentine[™] and GC Fuji IX[™], due to the increased area available for bonding to dentine. EL-Ma'aita *et al.*^[14] showed that removing the smear layer may have a detrimental effect. A mineral infiltration zone has been observed between the dentine and Biodentine[™]^[15] which may be important in providing a retentive bond. This would imply that the smear layer may be critical to the formation of calcium silicate cement bonding and laser-treating the dentine, which removes this layer, may produce an unfavorable bond.

The Er: YAG laser is used successfully for the efficient removal of caries in primary teeth, with no unacceptable increase in pulpal temperature.^[16] Where pulp exposure occurs, Biodentine[™] has been used to restore teeth following pulpotomy, i.e., where the contents of

the pulp chamber are removed and a biocompatible material placed over the radicular pulp tissue. In such a situation, adequate stability and retention of the coronal restoration are critical to the long-term success of the pulp treatment. Similar requirements apply to Biodentine[™] repair of perforations.^[17]

Therefore, our study examined whether treating dentine with the Er: YAG laser would change the adhesion of Biodentine[™] and GC Fuji IX[®] to dentine.

MATERIALS AND METHODS

Twenty sound permanent premolar teeth were cleaned from debris and remnants of tissue using periodontal curettes and polished with a slurry of pumice and water. The teeth were stored in a 10% buffered formalin solution before the experiment under license from the Human Tissue Act, 2004 in the UK. The teeth were sectioned transversely to provide 40 dentine sections. The sections were individually embedded in stone and polished with silicon carbide paper of #2100-grit (Buehler Ltd, Lake Bluff, IL, USA) to remove any remnant of stone on the surface and to get a perfectly flat surface. The polishing was done under continuous water cooling to avoid surface desiccation. The specimens were then randomly divided into four groups with 10 samples in each group.

- Group 1: No treatment of the dentine surface and the restorative material was GC Fuji IX[®]
- Group 2: The moist dentine surface was irradiated with a noncontact Er: YAG laser for 30 s, and GC Fuji IX[®] was used as the restorative material
- Group 3: No laser treatment of the dentine surface, and the restorative material was Biodentine[™]
- Group 4: Noncontact Er: YAG laser radiation was used to treat the moist dentine surface for 30 s, and Biodentine[™] was used as the restorative material.

Bisected silicon molds (3 mm diameter and 2 mm height) were positioned over the dentine samples and filled with GC Fuji IX[®] or Biodentine[™], which were mixed as specified by each manufacturer. Details regarding the tested restorative materials are described in Table 1. All of the samples were stored in distilled water in an incubator at 37°C for 7 days to ensure full setting of the restorative materials and to ensure that the tooth and restorative materials remained fully hydrated.

Laser treatment

The Er: YAG laser was operated at 15 Hz and 100 mJ, with an energy density of 8.42J/cm². It was used to

treat the dentine surface before the application of the restorative material. The dentine surface was continuously irrigated with water delivered across the dentine surface using a syringe with a low water flow rate. This ensured a sufficiently continuous thin water film over the dentine surface. Each dentine slab was irradiated over its entire surface.

Shear bond strength test

At the end of the storage period, the samples were mounted in the Zwick universal testing machine (Roell Z020, Zwick GmbH and Co. KG, Germany) by their metallic molds. The specimens were positioned in such a way that the stainless steel chisel of the universal testing machine was oriented perpendicularly between the tested material and tooth surface. The chisel was utilized to apply a load at a cross head speed of 0.5 mm/min in a compression mode until debonding occurred.

The maximum fracture load in Newtons was recorded and values of SBS were calculated in Mega Pascal (MPa) according to the following equation:

$$\text{Shear bond strength} = \text{Fractured load (N)} / \text{Surface area (mm}^2\text{)}$$

The surface area (A) was calculated from the following equation:

$$A = \pi r^2$$

Whereas π is 3.14 and r is the radius of each specimen that equals 1.5 mm. Therefore, the surface area (A) was 7.06 mm².

Thus, the following equation was used to convert the SBS into MPa:

$$\text{MPa} = \text{Fractured force (N)} / 7.06$$

Table 1: Tested restorative materials		
Material	Manufacture	Composition & Form
Fuji IX GC	GC Corporation, Tokyo, Japan	Conventional glass ionomer in form of powder and liquid. Powder: Aluminofluorosilicate glass. Liquid: Polyacrylic acid, polybasic carboxylic acid, water
Biodentine	Septodont, Saint Maur des Fosses, France	Powder: Solid: Ca ₃ SiO ₅ (> 80%), CaCO ₃ , ZrO ₂ Liquid: Water, CaCl ₂ , partially modified polycarboxylate

Analysis of fracture by a light microscope and scanning electron microscope

All the specimens were analyzed using a stereomicroscope at a magnification of ×40 to assess the mode of failure after the bond strength test. A representative sample from each group was further investigated under the scanning electron microscope (FEI Quanta 200 ESEM).

Mode of failure

The failure was considered (i) cohesive if it occurred in the substrate or material (a visible thin coating or bulk amounts of restorative material remained on the dentine surface), (ii) adhesive when it occurred between the material and dentine, and (iii) mixed or combined if some material remained on the dentine surface.

Statistical analysis

Mean and standard deviations (SDs) were calculated, and the data were analysed by two-way analysis of variance (ANOVA), and the significance between control and lased groups within the same material was determined by the independent sample *t*-test. A Pearson Chi-squared test was applied to find the correlation between the SBS and type of failure using Statistical Package of Social Science SPSS Version 20 version 23 (IBM Corp., Armonk, US).

RESULTS

Shear bond strength

Figure 1 and Table 2 summarizes the mean values, SD, and statistical analysis of SBS for each of the experimental groups.

Two-way ANOVA showed a significant effect of the Er: YAG laser radiation and restorative material on SBS

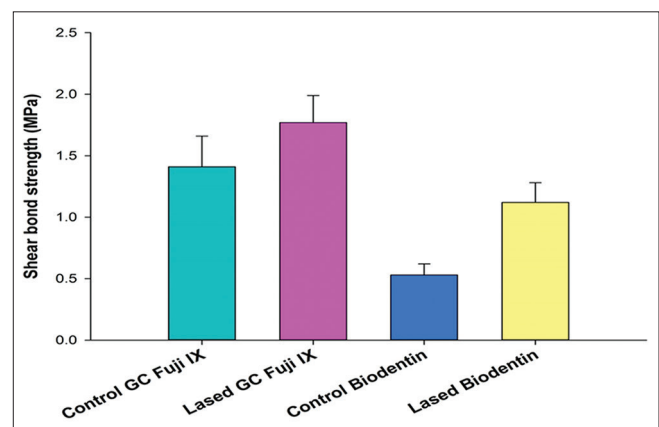


Figure 1: A bar chart illustrating the mean (M) and standard deviation of shear bond strength megapascal for each group

to dentine with $P = 0.00001$ and 0.0001 , respectively. There was a significant difference in the SBS of laser treatment in the glass ionomer cement (GIC) group (mean = 1.77MPa) compared to no laser treatment (mean = 1.41MPa) (t -test = 3.311, $P = 0.004$). The SBS of the lased Biodentine™ group (mean = 1.12MPa) was also significantly different from the nonlased Biodentine™ (mean = 0.53MPa) (t -test = 9.660, $P = 0.00001$).

Mode of failure

The percentages of failure mode in all groups are presented in Table 3. The observation of fractured samples under the stereomicroscope microscopy showed that almost all fractures were adhesive in both GC Fuji IX® and Biodentine™ groups. The Pearson Chi-square test indicated no relation between SBS value and mode of failure ($P = 0.467$). Furthermore, there was no difference in the type of failure between the groups. Images of different failure modes under the light microscope and scanning electron microscope are presented in Figures 2-5.

DISCUSSION

In our experiments, laser pretreatment of dentine surfaces increased the bond strength significantly for both GC Fuji IX® and Biodentine™. Er: YAG laser treatment yielded a dentinal surface without a smear layer and with micro irregularities leading to a high surface wettability and producing tag formation.^[18,19] This could explain the high SBS obtained in the lased groups. The greater SBS with GC Fuji IX® than Biodentine™ might be due to differences in the mechanism of adhesion of the materials to dentine. The adhesion of GIC to dentine

is mainly chemical through the ionic bonding with hydroxyapatite,^[20] whereas the Biodentine™ bonds micromechanically to dentine.^[4] Our experiments show that maintaining a smear layer is not essential for effective SBS of Biodentine™. We propose that changes in the organic and mineral content of the dentine surface produced by the laser radiation might be favorable to improve molecular interactions and increase the SBS. Supporting evidence comes from Kobayashi *et al.*,^[19] who concluded that a high Ca/P ratio of laser irradiated dentinal surfaces could be one reason for increased bond strength.

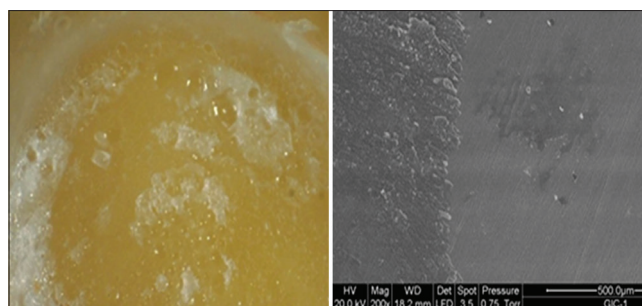


Figure 2: Stereomicroscope and scanning electron microscopy images of dentine side of the debonded specimen (GC Fuji IX) showing mixed mode of failure (some remnants of glass ionomer attached to dentine surface)

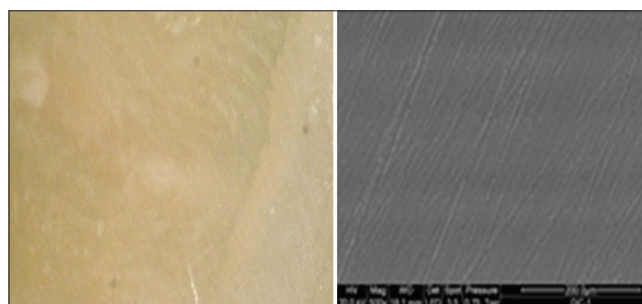


Figure 3: Stereomicroscope and scanning electron microscopy images of dentine side of debonded specimen (GC Fuji IX) showing the adhesive mode of failure (complete detachment of glass ionomer from dentine surface)

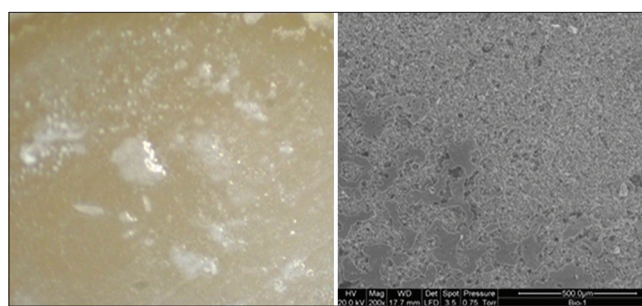


Figure 4: Stereomicroscope and scanning electron microscopy images of dentine side of debonded specimen (Biodentine) showing mixed mode of failure (some remnants of Biodentine attached to dentine surface)

Table 2 : Mean and standard deviation of shear bond strength (MPa) of all groups

Groups	Mean±SD
Control GC Fuji IX®	1.41±0.25
Lased GC Fuji IX®	1.77±0.22
Control Biodentine™	0.53±0.09
Lased Biodentine™	1.12±0.16

Table 3: Mode of failure of tested material

Group	Subgroup	Mode of Fracture		
		Adhesive	Cohesive	Mixed
GC Fuji IX®	No laser	(8) 80%	(1) 10%	(1) 10%
	Laser treatment	(3) 30%	(3) 30%	(4) 40%
Biodentine™	No laser	(7) 70%	—	(3) 30%
	Laser treatment	(5) 50%	(3) 30%	(2) 20%

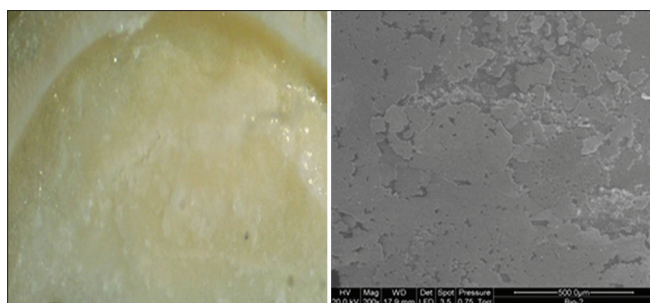


Figure 5: Stereomicroscope and scanning electron microscopy images of dentine side of debonded specimen (Biodentine) showing cohesive mode of failure (complete attachment of Biodentine to dentine)

In the literature, there are wide variations in the bond strength values produced by laser pretreatment. For instance, Kobayashi *et al.*^[19] used different powers of Nd: YAG laser radiation to investigate the effect of laser pretreatment on the SBS of glass ionomer to dentine. They found that at a power of 3W a significant increase in the bond strength to dentine was seen, while a laser power of 1 and 2W increased the bond strength but without statistical significance. In contrast, de Souza-Gabriel *et al.*^[21] stated that the Er: YAG laser treatment of both enamel and dentine adversely influenced the SBS of resin-modified glass ionomer to dental substrates; however, this conflicts with other results.^[18,22] Variations in the value of SBS for control GC Fuji IX[®] and Biodentine[™] in comparison with previous studies were reported. The justification for this is mainly the different methodologies applied in each study. For instance, El Wakeel, *et al.*^[23] reported that the mean μ SBS of Fuji IX[®] was 4.82 MPa compared to the mean SBS of 1.77MPa in this study. The difference might be attributed to the low-surface area used in the El Wakeel, *et al.* study (0.9 mm in diameter and 0.7 mm in height) compared to the area (3 mm \times 3 mm) in our study, as aforementioned, the SBS is calculated according to the following equation:

Shear bond strength = Fractured load (N)/Surface area (mm²)

The timeframe through which the SBS is evaluated is a significant consideration.^[24] The storage period of this study was 7 days whereas that of El Wakeel *et al.*'s study^[23] was 24 h where setting may have been incomplete. Following 24 h of storage, the glass ionomer maturation may be incomplete resulting in a low value of bond strength.^[25] This was confirmed by Choudhari,^[26] who stated that the initial adhesion between glass ionomer, and tooth is based on hydrogen bonding that matures and evolves to a stronger chemical bond over time. Nevertheless, the

results of the present study regarding Biodentine[™] are in the same range as that of some other studies.^[27]

The adhesive mode of failure was predominately observed among all the tested groups, with a few samples exhibiting a mixed and cohesive failure pattern. Similar results have been reported with previous studies.^[19,28,29] However, some studies reported cohesive failure as the main mode of fracture.^[27,30,31] The presence of a mixed failure could be attributed to various factors such as the low wear resistance of glass ionomer, the formation of a matrix layer, and the chemical bonding of GIC to the tooth.^[30] The high incidence of adhesive failure indicates that a more uniform distribution of stress existed along the bonded assembly.^[32,33] In the present study, no direct relationship between the value of bond strength and the mode of failure was observed. However, direct comparison of the present data of SBS with values of previous studies might only be possible if the materials were tested utilizing the same conditions.^[34]

It is important to state that the water storage media of specimens throughout the experiment may affect the validity of the results. *In vivo* the dentinal tubules are mainly occupied with fluid and odontoblastic processes, thus the utilization of water as a means of storage may have changed the dentine permeability leading to possible differences between *in vivo* and *in vitro* findings.^[35] A lack of dentine vitality in *in vitro* experiments might limit the possibility of extrapolating these data to *in vivo* conditions.^[30] Moreover, the test of bond strength was not done immediately after the initial setting, whereas in the real clinical situation, the restored teeth are exposed to masticatory load immediately. It is assumed that other variations between the groups such as due to storage of the specimens were accounted for since all the teeth of all groups were treated in the same way except for the experimental manipulation.

CONCLUSION

It can be concluded that lasing the dentine with an Er: YAG laser improved the mean SBS of both GC Fuji IX[®] and Biodentine[™]. In the case of Biodentine, this was approximately doubled following the laser treatment. Er: YAG laser irradiation produced surface properties that enhanced the adhesion of restorative materials to dentine. However, GC Fuji IX[®] has a stronger bond strength to dentine than Biodentine[™] due to chemical and mechanical interactions between dentine and GC Fuji IX.

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Conflicts of interest

There are no conflicts of interest.

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