Shear Bond Strength of Resin Composite to Rotary and Er:YAG Laser-Prepared Enamel

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ABSTRACT

Objective: *The aim of this study was to compare enamel shear bond strength to resin composite following preparation with a carbide bur, fine diamond bur, or erbium doped, yttrium–aluminium–garnet (Er:YAG) laser.*

Materials & Methods: *Forty-eight human anterior teeth, randomly assigned to each preparation group, were studied. Each tooth was mounted in self-curing acrylic resin with the desirable flat facial surface exposed and was randomly assigned to 3 groups according to surface preparation: Er:YAG laser irradiation, carbide bur, or fine-grit diamond bur. A polypropylene cylinder was fixed to the prepared surface, which was demarcated for the area to be bonded with the single bonding system. Restorative composite was then incrementallyinserted into the tubing lumens. The teeth were shear tested to failure at a crosshead speed of 1.0mm/minute. One-way ANOVA and the Tukey test were used for analysis.*

Results: *The mean bond strength values were as follows: fine diamond bur, 23.88MPa; carbide bur, 13.28 MPa; and Er:YAG laser, 12.61 MPa.*

Conclusions: *Different enamel preparation methods affect the shear bond strength between enamel and resin composite.*

KEYWORDS

Shear bond strength, Enamel, Diamond bur, Carbide bur, Er:YAG laser, Resin composite.

INTRODUCTION

Goldman *et al.*[1] first investigated the application of laser beams on dental hard tissues. Initially, clinicians were concerned about possible adverse pulpal responses,[2] but subsequent investigations demonstrated that lasers cause little thermal damage,[3,4] especially if used with water sprays.[5] In addition, lasers have demonstrated some analgesic effects, which could increase patient acceptance of certain procedures.[6] Advancements in laser technology have led to their use in multiple dental applications.

The first dental lasers cleared by the United States Food and Drug Administration (FDA) were used exclusively for soft tissue procedures and included the carbon dioxide (CO2) laser, neodymium–yttrium-aluminium-garnet (Nd:YAG) laser, argon laser, and the semiconductor diode laser.

There has been interest in using the Nd:YAG laser on mineralized tissue, possibly to enhance the bond strength of composite to dentin,[7] but this laser is not approved for hard tissue applications.[8] Other approved systems include the erbium, chromium: yttrium-scallium-gallium-garnet (Er,Cr:YSGG) laser and the erbium-doped: yttrium-aluminum-garnet (Er:YAG) laser. These systems can be used for soft tissue procedures, but most of the interest in erbium lasers has been focused on their effectiveness in hard tissue applications such as caries removal, endodontic cleaning, and shaping of the root canal system.[9] The Er:YAG laser, originally developed by Zharikov *et al.*[10] in 1975, was approved by the FDA in 1997 for caries removal, forming cavity preparations, and modifying dentin and enamel prior to etching.[11]

As opposed to hard tissue removal by classical mechanical burs, the erbium laser's removal of hard dental tissue is enabled by contact-free, optically induced, micro-explosions within the tissue. The use oferbium laser technologyinstead ofrotary instruments offers several advantages, such as reduced pain, and decreased noise and vibrations during cavity preparation. The erbium laser is also partially selective in caries removal because of its higher absorption in the more humid carious tissue, in comparison with that in the surrounding healthy tissue.[12] An important additional potential advantage of the erbium laser cavity preparation is that the erbium laser is capable of creating a surface without a smear layer—similar to acid-etched surfaces—that should be favourable for bonding procedures.[13,14] Laser energy enables localized melting and ablation of the enamel surface. It imparts etching through a process of continuous vaporization and micro-explosions, which occur due to the vaporization of the water trapped within the hydroxyapatite matrix.[15] Irradiation of the enamel by laser energy may be beneficial because it inhibits enamel demineralization and, thereby, caries formation.[16]

Initial reports on bond strengths to Er:YAG-irradiated tooth substrates presented confusing and even contradictory results. The purpose of this study was to evaluate enamel bond strength to resin-based composite following high-speed rotary handpiece preparation or Er:YAG laser preparation with a multi-step, total-etch adhesive system.

MATERIALS & METHODS

Teeth collection

Forty-eight caries-free human incisors were used for the bonding tests. The teeth were washed under running water immediately after extraction and stored in 0.02% thymol solution until the time of the experiment. They were rinsed in running distilled water and the facial surfaces were examined under a stereomicroscopeto ensure they were free of surface cracks, decalcification, or any sign of previous grinding. Thereafter, each tooth was mounted in self-curing acrylic resin, exposing only the desirable facial surface. After that, the bonding area was demarcated to outline the flattest area.

Teeth grouping & preparation

The specimens were then randomly assigned to 3 groups (of 16 specimens each) according to the type of enamel surface preparation:

- Group1: The demarcated area was irradiated with an Er:YAG (*DEKA Smart 2950D PLUS*) laser, which was delivered to a handpiece connected to a contact probe. The diameter of the straight-type contact tip was 0.6mm, the laser at 250mJ/pulse and a frequency of 6 Hz administered from a distance of 1mm.
- Group 2: A carbide bur (*SS White FG-556; Lakewood, New Jersey, USA*) was applied on the enamel surface using a high-speed handpiece with water coolant to create 0.5mm deep grooves on the surface and to flatten the enamel surface in between grooves.
- Group 3: A tapered round-end fine-grit diamond bur (*DIATECH Diamond FG-368; Altstatten, Switzerland*) was applied on the enamel surface by using the same high-speed handpiece with water coolant. This procedure created 0.5mm-deep grooves on the surface, after which the area between grooves was flattened with the same bur.

Each bur was replaced by a new one after preparation of 4 specimens, to avoid the problems associated with bur wear. All specimens were numbered for ease in data recording, and the demarcated area for all specimens was treated with the same adhesive system (*DMPltd System*). This was a total-etch system applied under controlled environmental conditions (20°C, 30% relative humidity) by a single operator, following the bonding protocol: the surface was treated with 37% phosphoric acid for 15s, rinsed off with distilled water, and dried using an air water syringe for 5s. The bonding agent (single bonding) was applied on the dried enamel surface followed by light irradiation for 40s with a light-curing device (*Flashite 1401 Discus Dental, Inc., Culver City, CA, USA*). Hollow polypropylene cylinders (5mm diameter and 4mm height) were placed on the treated surfaces. Restorative composite (*Clearfil APX Shade A3, Kuraray Medical; Osaka, Japan*) was carefully inserted into the tubing lumens in 2 increments built each of 2mm thickness and was light cured individually for 60s according to the manufacturer's instructions. The specimens were then stored in water at 37°C for 24h. After removal from water, the polypropylene cylinder around the composite was removed by gently cutting the tube into 2 hemi-cylinders using a feather-edge blade. This procedure was done under a stereomicroscope and special caution was taken to avoid applying any stress to the bonded composite cylinders.

Shear bond test

Each specimen was attached to the testing apparatus and tested in shear mode with a knife-edge testing apparatus in a universal testing machine (*Instron; High Wycombe, UK*). The force was applied at a crosshead speed of 1.0mm/min until failure occurred. The maximum load at the time of failure was recorded. Shear bond strength (SBS) was calculated as the ratio of fracture load and bonding area expressed in MPa. Data were analysed using analysis of variance (ANOVA) and Tukey test.

The types of failure were observed at 2.5× magnification under stereomicroscopy (*HMV-2; Shimadzu, Tokyo, Japan*) and categorized as adhesive, cohesive, or mixed.

RESULTS

The mean SBS values of resin composite with 3 different enamel surface preparations are shown in MPa in **Table 1**. The results showed that teeth prepared using a fine diamond bur had the strongest SBS (23.88 MPa), and the teeth prepared using Er:YAG laser had the weakest SBS (12.61 MPa). The teeth prepared by the carbide bur had values in between the other two groups (13.28 MPa), but were much closer to the Er:YAG laser. Thus, the fine diamond group showedsignificantly higher retention than the other groups.

(Table 1) *Shear Bond strength in MPa (means ± standard deviations) of resin composite to different enamel surface preparation*		
Surface treatment groups	**Mean**	**Standard deviation**
Laser group	12.6114	5.19141
Carbide bur group	13.2801	4.05284
Diamond bur group	23.8852	8.44455

ANOVA test revealed statistically significant differences among the 3 enamel surface preparations. To analyse which preparation methods were significant when related to each other, the post-hoc Tukey test was used.

According to the results of the Tukey test, shown in **Table 2**, there was a highly significant difference between Er:YAG laser and the fine diamond groups at *p*0.05, and the difference was in favour of the fine diamond bur. We also observeda highly significant difference between the fine diamond and the carbide bur groups at *p*0.05, which was in favour of the fine diamond bur group, but there was no significant difference between theEr:YAG laser and the carbide bur groups at $p>0.05$.

(Table 2) *Statistical analysis of data using Tukey test*		
Comparing between groups	**Mean differences**	***P* value**
Carbide bur versus laser	13.2801 vs. 12.6114	0.950
Carbide bur versus diamond bur	13.2801 vs. 23.8852	0.000*
Laser versus diamond bur	12.6114 vs. 23.8852	0.000*

The types of failure observed at 2.5× magnification under stereomicroscopy were mostly evaluated as adhesive failure, within the interface with the tooth's surface, in the fine diamond group, but were mostly cohesive for the Er:YAG laser. For the carbide bur group, both adhesive and cohesive failureswere observed within the enamel.

DISCUSSION

In our study, the highest SBS was obtained withthe fine diamond bur, and it was significantly higher than the SBS of composite bonded to carbide bur- or Er:YAG laser-prepared enamel.

Cavity preparation with dental burs can easily produce micro-fractures in the enamel, and the degree of the damage induced during cavity preparation can be influenced by diamond grit size and type of the burs. Cavity preparation with minimal mechanical damage at the cavo-surface margins may be important factors for preventing enamel cracks at the site of resin composite restoration.[17-19] Enamel cracking is initiated by the damage occurring during preparation with burs and is likely to be furthered by the contraction of the polymerizing resin composite;[20] therefore, selecting a bur for cavity preparations is an important factor in improving the cavo-surface margin integrity.[21]

However, it has been proposed that roughening the enamel surface using a regular diamond (coarse) or carbide bur was effective when bonding to resin, because a roughened surface increases the area available for adhesion. Thus, at least theoretically, it improves mechanical retention.[22] However, Nishimura *et al.* reported a great number of smeared enamel fragments on the surface prepared with the coarse diamond bur, and a great number of enamel micro-fractures were observed for the carbide bur. Indeed, the presence of microscopic enamel fragments and cracks seems to be closely relatable to gap formation Therefore, because the bond strength of the resin and adhesive system used with composite restoration has been improved dramatically, it might be unnecessary to create a rough surface with a coarse diamond or carbide bur.[23] Thus, it may be that using the fine diamond bur in this study might be associated with minimal mechanical damage, and in combination witha strong bonding system, which was the etch and rinse form in this case, it may yield the highest bond strength.

The initial reports of bond strengths to Er:YAG-irradiated tooth substrates in the literature were confusing and even contradictory. These discrepancies may be attributed to inter-study differences in the testing methods and conditions, such as bur type, substrate, the composite-adhesive used, laser types, laser power outputs, application distances, and other variable factors. Therefore, it is difficult to make direct comparisons with other studies. There are serious doubts about the ideal energy density to obtain a suitable micro-retentive pattern for adhesion procedures. Some clinicians have preferred to prepare the bonding surface by utilizing lower energy settings. De Sousa *et al.*[24] used the setting 80mJ/2 Hz, whereas Egura *et al.*[25] used 100mJ/4 Hz, and De Munck *et al.*[26] used 80mJ/10 Hz, while Gurgan *et al.* used 120mJ/10 Hz for better efficiency, minimal number of induced changes, and favourable surface characteristics. Yet another study was performed in which sufficient attention was paid to the decisive role of the Er:YAG pulse duration and pulse energy by using a novel quantum-square-pulse mode (QSP), in which a 2-step laser procedure is effectively optimized to just a single step.[27]

This study evaluated treatment with a beam of Er:YAG laser delivered to a handpiece connected to a contact probe. The diameter of the straight-type contact tip was 0.6mm, and 250mJ/pulse and 6Hz frequency administered from 1mm and followed by application of acid etch yielded lower SBS than rotary preparation, which is in agreement with the results obtained by Martinez *et al.*[28] and William & John.[29] This is may be explained by the extensive fissuring and subsurface cracking that occurs with the Er:YAG laser on enamel surfaces because one of the problems of the Er:YAG laser radiation is that it may deleteriously alter the surface of the tooth substrate, causing cracks to propagate into the teeth. The presence of micro-cracks in the bonding interface may leave flaws that will diminish the bond strength of resin composite to the tooth.[30] In addition, William and John[29] documented that the laser-irradiated enamel surface produced surface fissuring and a union or blending of the distinctive etch pattern normally seen in acid-etched enamel. This blending effect likely prevented the penetration of resin into the enamel, resulting in lower enamel SBS values. It appears that the thermo-mechanical effects of laser irradiation extend into the subsurface in both dentin and enamel, compromising the integrity of the tooth-restoration bonded interface and decreasing the resulting SBS.

This study revealed fracture patterns of composite rods bonded to laser-ablated enamel specimens with cohesive enamel failures, suggesting that the Er:YAG laser produces subsurface fissuring that penetrates beyond the resin when dentin and enamel specimens are acid-etched. Although the Er:YAG laser has been touted as a promising technology, the need for more research is clear. Further studies must examine the effects of Er:YAG irradiation and the structural changes in teeth that result before Er:YAG laser use can be established as a reliable operative technique in dentistry. With regard to the bond strength to enamel with the Er:YAG laser and the constant development of the field of restorative dentistry, studies are always necessary to consolidate new concepts.

CONCLUSION

Within the limits of this study, we conclude the following:

1. Enamel preparation with a diamond bur yielded significantly higher SBS than carbide and Er:YAG laser preparation.
2. Er:YAG laser preparation using a power setting of 250mJ/pulse and a frequency of 6Hz presented the lowest SBS.
3. Improvements in laser technology and the increased interest in their potential for hard tissue application warrant further investigations of Er:YAG laser-prepared teeth and adhesion with resin-based composites.

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