The influence of laser-textured dentinal surface on bond strength

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\textbf{A B S T R A C T}

Objective. To assess the influence of laser-textured surfaces on the adhesion of composite to dentin after being rotary prepared.

Methods. Thirty healthy teeth were kept in 0.1% thymol solution prior to being ground down to dentin to create a $4 \times 4$ mm\textsuperscript{2} flat surface. Teeth were divided into 3 groups ($n=10$). Groups 1 and 2 utilized the prototype Erbium doped, Yttrium–Aluminum–Garnet Er:YAG laser by Dental Photonics, Inc. A single pulse was delivered to each spot to create an equally spaced square $4 \times 4$ mm\textsuperscript{2} matrix of micro craters. All craters had 100 $\mu$m diameter/45 $\mu$m depth; two different spacing patterns were prepared in Groups 1 and 2. In Group 1, distance between crater centers was 50 $\mu$m; Group 2 had 100 $\mu$m. In Group 3 (control), 10 samples were prepared without laser texturing. G-bond (GC America) was applied to testing area of all samples in all groups according to manufacturer’s instructions. Bonding resin was applied and shear-bond strength tests were employed using an Instron machine to measure adhesive strength.

Results. One-way analysis of variance (ANOVA) was used to compare the 3 groups. Pair wise t-tests implementing the Bonferroni correction for multiple comparisons found a statistically significant difference between Group 3 and Group 2 ($p=0.019$) but no statistically significant difference between Group 3 and Group 1 ($p=0.263$) or Group 1 and Group 2 ($p=0.743$).

Significance. The bond strengths between bonded composite to laser-textured dentinal surfaces with larger spacing patterns are greater than that of non-textured surfaces.

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1. Introduction

Modern dentistry has been concerned with reducing patients’ risk of caries, preserving tooth structure, and noninvasive conservative techniques such as composite restorative material. However, the benefit of this treatment relies upon the ability of the restorative material to promote an appropriate sealing and remain completely intact and bonded to the surface, thus increase the longevity of the restoration.
Air turbine drills for preparations of surfaces has been the most used method. It is less expensive and smaller in and can be used with ease. However, it presents disadvantages like the unpleasant noise and vibration in the dental structure, which can generate pain and tension in the patients as well as cause contamination of the clinical atmosphere [1]. Alternative methods for preparing dental surfaces, such as laser [2], that emits light through a process of optical amplification based on the stimulated emission of photon, have been developed and their effect on bond strength to tooth structure has been a research interest.

The application of laser beam on dental hard tissue was investigated by Goldman et al. [3] shortly after its discovery by Maiman [2]. Improvements in laser technology have led to a great number of applications in the field of dentistry such as periodontal soft tissue surgery [4], gingivectomy [5], crown lengthening procedure [6], gingival retraction [7], frenectomy [8], treatment of aphthous ulcers [9], tooth whitening [10], endodontic procedures [11,12], caries detection [13,14], caries removal and controlled bleeding post dental operative surgery [15–18].

The carbon dioxide (CO2) laser was the first dental laser approved by the FDA and has been successfully used in soft tissue surgeries [19]. The Neodymium–Yttrium–Aluminum–Garnet (Nd:YAG) laser uses a fiber optic delivery system that penetrates wet tissue more easily than the CO2 laser. There has been interest in using the Nd:YAG laser on mineralized tissue to possibly enhance the bond strength of composite to dentin [20], but the Nd:YAG laser is still not approved for hard tissue applications.

Erbium doped, Yttrium–Aluminum–Garnet (Er:YAG) laser is a system that can be used for both soft and hard tissue procedures but most of its applications has focused on hard tissue [21,22]. Er:YAG laser is a system which was approved by the FDA for removal of caries, preparations of cavities, and modification of enamel and dentin [23].

It has been shown that preparation of tooth using Er:YAG did not significantly increase the temperature compared to a rotary handpiece [24,25] and the thermal effects are negligible [26]. In addition, it was demonstrated that the Er:YAG laser produces smaller thermal effects in comparison to other laser system during tooth preparation [27,28].

Unlike enamel, dentin contains a higher percentage of water and organic material like collagen and is heterogeneous tissue [29]. Composite bonding to dentinal surfaces poses a greater challenge than enamel due to its complexity. Therefore, dentinal substrate is less receptive to adhesive treatments. Mechanical theories state that adhesives interlock micromechanically with irregularities of the surface of the adhered [29].

The reported bond strengths of composite to (Er:YAG) laser textured surfaces vary in the literature. For example, Visuri et al. [30] reported that shear bond strength of composite to dentin prepared with an Er:YAG laser was significantly higher. In contrast, Sakakibara et al. [23], Van Meerbeek et al. [31], and Cardoso et al. [32] showed that the bond strength to laser-irradiated dentin decreased. In addition, Armengol et al. [33], Sattabanasuk et al. [34] and Kataumi et al. [35] found no difference between laser-irradiated and non-irradiated teeth. In most of these past studies of bonding to Er:YAG lased surface, the surface of dentin was uniformly irradiated. In other studies, spatial patterning of dentin surfaces was postulated to influence the magnitude of the bond strength to composite. For example, as shown by Gardner et al. [36], dentin surfaces irradiated with varying spatial overlap of adjacent laser pulses produced different bond strengths to composite. However, in this study, the shear bond strength of the non-irradiated dentin control group was always higher than those of irradiated ones. Therefore, producing a laser-textured dentin surface with appropriate spatial pattern that yields high shear bond strength to composite poses a greater challenge. To this end, the aim of this study is to assess the influence of the laser textured surface, prior to the adhesion of composite to dentin after preparation with diamond disk.

We hypothesize that texturing the surface of the rotary prepared dentin using spatial patterns with Er: YAG laser would significantly affect the shear bond strength of resin composite to dentin.

2. Materials and methods

2.1. Teeth collection

Thirty human molar teeth were collected and kept in 0.1% thymol solution for no more than six months prior to specimen preparation. The teeth were free of visible caries and other surface defects. The buccal surface of each tooth was ground down with bur part number 806 with a diamond head ADO-22 (“NPOOO Systema” company, Minsk, Belarus) to create a flat uniform layer of peripheral dentin of 4 × 4 mm² surface. Teeth were randomly divided into 3 groups (n = 10).

Teeth in Groups 1 and 2 were micro-textured to create craters with diameter of 100 μm and depth of 45 μm. This was done using the laser device which is explained below. However, two different spacing patterns were prepared in Groups 1 and 2. In Group 1, distance between crater centers was 50 μm. For Group 2 this was 100 μm. In Group 3 (control), ten samples were prepared without laser texturing.

2.2. Laser device

The Er:YAG laser apparatus (prototype laser by Dental Photonics, Inc.) emits radiation at a wavelength of 2940 nm, with an output energy in the range 30–350 mJ/pulse, repetition rate of 1 Hz, and pulse mode of 100 μs duration. Energy output was monitored using a power meter (Field Master and detector LM-P10i; Coherent Company, OH). Laser irradiation was performed perpendicular to the dentin surface to create cone shaped craters. The flat 4 × 4 mm² dentin surface was placed in a focal plane of 38 mm lens. A single pulse with 1.2 mJ energy was delivered to each spot and then the sample was laterally moved to the next spot to create an equally spaced 4 × 4 mm² matrix of laser micro craters.
2.3. Bond strength measurements

The teeth were then embedded in acrylic in similar size and shape molds with prepared buccal dentin surfaces extending 1-mm above the level of the acrylic.

G-Bond (GC America) was applied to testing area of all samples in all groups according to manufacturer’s instructions. The surface of the prepared area was gently dried by blowing air with air syringe. G-Bond was applied and left undisturbed for 10 s and then was thoroughly dried under maximum air pressure for 5 s. It was cured with a halogen light for 10 s.

An approximately 3-mm long composite rod (Tetric-EvoCeram, A1 shade) was bonded to all dentin specimens using a jig (Ultradent) with an inner diameter of 2.38 mm. The mold was secured to the specimen, and then two 1.5-mm increments of composite were polymerized separately with halogen light for 40 s each. The jig was removed and specimens were stored in water at 37 °C for 24 h. After this period, shear-bond strength tests were employed using Universal Testing Machine (Instron 4201) to measure adhesive strength in megapascals (MPa) with crosshead speed of 5 mm/min.

The force to failure was recorded for each specimen. The mean shear bond strength in MPa was determined for each group. Fractured specimens were observed with a stereomicroscope (Olympus) at 20x magnification for determination of failure modes, such as cases of cohesive, and mixed with adhesive.

Data were subjected to a one-way analysis of variance (ANOVA) to compare the effects of preparation type among the three groups. All statistical analyses were performed at \( p < 0.05 \).

2.4. Scanning electron micrographs

For electrospun silk mats, the materials were sputter-coated with gold/palladium using a Polaron SC502 Sputter Coater (Fison Instruments, UK). Specimens were then examined using an ISI-DS-130 SEM (Avon, CT) at 15 kV. Images of representative samples were obtained once prior to bonding and once after shear-bond strength test.

3. Results

All craters had a diameter of 100 \( \mu \text{m} \) and depth of 45 \( \mu \text{m} \). Two different spacing patterns were prepared in Groups 1 and 2. In Group 1, distance between crater centers was 50 \( \mu \text{m} \) (Fig. 1A–C). For Group 2 this was 100 \( \mu \text{m} \) (Fig. 1D–F). In Group 3 (control), 10 samples were prepared without laser texturing. The teeth were then embedded in acrylic in similar size and shape molds with prepared buccal dentin surfaces extending 1-mm above the level of the acrylic.

The stereomicroscopic images of laser treated dentin surfaces are shown in Fig. 1B and E. The crater separation was not discernable on the Group 1 surfaces. In contrast, at a separation of 100 \( \mu \text{m} \) the craters formed a very distinct pattern on the surfaces of Group 2 teeth.

Scanning electron microscopy of rotary prepared dentin revealed the presence of laser-created holes without a modification of the global topology of the dentin (Fig. 2). No tubule orifice and smear plugs could be detected. The regularity of the laser etched surface is confirmed as the distance of the holes can be precisely measured (50 and 100 \( \mu \text{m} \), respectively Fig. 2A,
B and C, D). The depth of the holes can be estimated from the pictures at no more than half of the diameter or between 10 and 20 μm. The overall surface shows an irregular surface with large areas of flaking and scaling.

After measuring and analyzing the shear-bond strength, the following mean and standard deviation was obtained (Fig. 3); Group 1 = 20.7 ± 6.6 MPa; Group 2 = 24.5 ± 9.6 MPa; Group 3 = 14.9 ± 4.4 MPa.

As mentioned before, one-way analysis of variance (ANOVA) was used to compare the 3 groups. p-Value of 0.022 suggests that means are not equal across groups. Pair wise t-tests implementing the Bonferroni correction for multiple comparisons found a statistically significant difference between Group 3 and Group 2 (p = 0.019). This result shows significant improvements when craters are at the distance of 100 μm. However, there was no statistically significant difference between Group 3 and Group 1 (p = 0.263) or Group 1 and Group 2 (p = 0.743). Therefore, placing the craters at the distance of 50 μm from each other did not yield a significant bonding strength.

After the application of the bonding resin and its detachment to measure the shear-bond strength, the scanning electron microscopy revealed a good conservation of the structure when the craters are separated by 100 μm (Fig. 4). While the craters separated by 50 μm can hardly be detected (Fig. 4A and B), the surface left after the bonding is severely affected, presenting an important flaking as well as microfissuring beyond normal resin penetration depth. By contrast the surface of the 100 μm separated craters (Fig. 4C and D) is very similar to the one observed before the resin. The laser-created topology seems unchanged and the surface flaking is restricted to the craters area. In our experiment, the sur-
Fig. 4 – Scanning electron microscopic images of Dentin laser prepared after the measurement of the shear bond strength. The preservation of the structure is less visible when the laser creates spacing patterns with a distance of $50 \mu m$ (A and B – Group 1) than a distance of $100 \mu m$ between the crater centers (C and D – Group 2). (•) Indicates crater center.

face seems unaffected by the application of the resin and its removal.

4. Discussion

Many of the previous investigations compare the bond strength of composite to laser-irradiated dentin and that of acid-etched dentin by itself or together with rotary headpiece preparation. Some of these studies, like those of Ceballos et al. [37], Kameyama et al. [38], Martinez-Insua et al. [39], and Aoki et al. [40] demonstrate that bond strengths are significantly weaker when tooth surfaces are prepared with the Er:YAG laser. In contrast, Keller and Hibst [41], Visuri et al. [30], and Stiesch-Scholz and Hanning [42] postulated that the lased dentin surface possessed an advantage because of an apparent enlarged surface area for adhesion based on the scaly and flaky surface appearance following Er:YAG irradiation.

Aoki et al. [40] describes this scaly surface appearance of laser ablated dentin, along with the cuff-like appearance of peritubular dentin. The unusual appearance of laser-irradiated dentin can be explained by understanding the process of laser ablation. Li et al. [43] explained that the Er:YAG laser thermomechanically ablates hard tissues by causing micro-explosions within inorganic structures in teeth. Initially, the Er:YAG laser vaporizes water and other hydrated organic components until internal pressure causes the destructive explosion of the inorganic component before the melting point is reached. Aoki et al. [40] determined that intertubular dentin was selectively ablated more than peritubular dentin, leaving a cuff of more highly mineralized dentin around dentin tubule orifices. The higher water content of intertubular dentin compared to peritubular dentin can explain this.

This may contribute to an increase in the adhesive area. Patent tubules and the absence of a smear layer are additional factors that may enhance bonding to laser-treated dentin [30,40,44]. Adhesion to laser-treated dentin would be explained by the mechanical retention provided by resin tag formation and the infiltration of adhesive resin into the micro-irregularities in lased, mineralized dentin.

However, Ceballos et al. [37] proposed that the ablation of dentin fused collagen fibrils together resulting in a lack of interfibrillar space, restricting resin diffusion into the sub-surface intertubular dentin. The lack of resin penetration in laser-ablated dentin is the most likely explanation for lower bond strengths. Data from such studies substantiate the observation that laser ablated dentin results in significantly lower shear bond strength compared with rotary prepared, acid-etched dentin.

In the current study, however, the surface of the dentin was initially prepared using a rotary mechanical instrument.
This reduced the proposed effects on laser on the reduction of interfibrillar space. On the other hand, creating a crater pattern using laser increased the surface area of the preparation in a conservative way.

The results show significant improvements with Group 2, when craters are farther from each other. The data suggests that the use of laser texturing and adhesive combined results in stronger bonds. This is likely due to improved micromechanical retention in Group 2 samples where the underlying dentin structure was not as undermined as those in Group 1 due to farther distances between adjacent craters. It is important to note that the variation in the texture design or the way the laser is applied did change the strength of the bond when compared to control. For example, in another study [36], when the crater in dentin was created with a diameter of 300 µm with a distance of 100 µm, the bond strength was weaker than the non-irradiated control. However, in the same study, as the distance between craters increased from 50 µm to 100 µm, the bond strength of surface to composite increased. This is in agreement with our findings but it is important to note the craters created in this study had a diameter of 100 µm. These facts indicate that any laser patterning by itself may not result in stronger bonds and therefore, selection of the proper texture pattern of the laser or the properties of laser itself may improve the bond strength. Further studies must be done to determine the most efficient laser-textured patterns.

Finally, given the results of this study and considering that Er:YAG laser presents the advantage of being more comfortable for the patient [45] and shortens chair-time [22], it also is important to take into account its impact on patient care given the relatively high prices of laser equipment and whether, in longer terms, higher bond strengths and further development of laser technology manufacturing could justify the higher costs.

5. Conclusion

When using the bonding agent in this study, the bond strengths of composite to laser-textured dentinal surfaces are greater compared to those of non-textured surfaces when the centers of laser generated craters are placed 100 µm apart compared to those when they are only 50 µm apart. Furthermore, the physical characteristics of the laser texturing can significantly improve the bond strengths.

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REFERENCES


