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Influence of Nd:YAG Laser Irradiation on an Adhesive Restorative Procedure

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Clinical Relevance

Statistical analysis of the results obtained in this study shows that Nd:YAG laser irradiation on the adhesive system has a significant influence on bond strength to dentin. Bond strength is improved by better adhesive penetration when low energy is applied; whereas, high energy densities have a deleterious effect on the procedure.

SUMMARY

Hard tissue modification by means of laser irradiation is becoming popular in dentistry, since it promotes assorted responses between the tooth and the restorative material. Some studies on the bond strength of adhesive systems to Nd:YAG irradiated teeth have shown distinctive behaviors when irradiation was applied before or after the adhesive agent. This study evaluated the microtensile bond strength of a commercial adhesive system to dentin irradiated with Nd:YAG laser after adhesive application but prior to polymerization. The experiment was conducted *in vitro*, using freshly extracted human teeth as samples. For the microtensile test, the teeth were separated into 4 different groups according to the energy density of laser irradiation: 0, 5, 10 and 50 J/cm². The data was analyzed with analysis of variance (ANOVA) and LSD tests, and the results indicated that the group that was irradiated with 5 J/cm² had significantly higher bond strength values. Adhesive penetration on the etched dentin was observed by scanning electron microscopy, where the images showed better adhesive penetration on dentinal tubules after dentin irradiation with 5J/cm². Based on the results of this study, it is possible to conclude that irradiation of dentin with the Nd:YAG laser at low energy densities after application of the adhesive but prior to polymerization might be positive for the adhesive restorative process.

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INTRODUCTION

The use of laser technology in dentistry has been widely studied because of its potential use in several applications, such as oral surgery, periodontics, endodontics, prevention, dentistics and prosthetics. Recent studies also suggest that lasers could be used as an alternative or complementary method for the modification of dental surfaces.[1-6]

In terms of dental hard tissues, these modifications have a direct impact on properties such as permeability, microhardness and resistance to acid attack. As a consequence, this promotes diverse responses between the tooth and the restorative material. Hence, characterization of the bond strength of these materials with laser treated dental tissues is of great importance.

With the advent of adhesive dentistry, several advances have been made in the prevention of oral diseases, the conservation of sound dental tissue and in the practice of aesthetical procedures. For these reasons, the adhesive technique has been studied extensively in past decades.

Adhesion to enamel is a procedure that was established in 1955, when Buonocore[7] proposed acid etching of this tissue. After etching, a micromechanical union between the tooth and resin is obtained due to resinous tags that protrude inside the conditioned enamel surface. Dentin, however, is less favorable to such a union when compared to enamel. There are several aspects that are related to this difficulty, such as the high organic content of the dentin, variations in its intrinsic composition, the existence of fluids and odontoblastic processes in the dentinal tubules, the inherent surface humidity and existence of a smear layer.[8-10] The presence of a smear layer hinders a direct interaction of the adhesive with the tissue such that pre-treatment of the dentin surface is necessary to achieve effective adhesion.

Several studies have shown that dentin irradiation with the Nd:YAG laser before the adhesive procedure results in a reduction in bond strength with the resin composite.[2,11-13] This effect is credited with obliteration of the dentinal tubules due to the melting and resolidification of the irradiated dentin. These observations are related to absorption of laser radiation by hard dental tissues, which is dependent on the optical properties of the target tissue and on the characteristics of the laser, such as its wavelength, the emission mode (continuous or pulsed) and energy density. In the spectral region of the red and near infrared (600 nm–1.5 μm) of electromagnetic radiation, the tissues have a transmission window in order that the absorption of Neodimium lasers (1064 nm) by water and hydroxyapatite is low. Even though the energy is only partially absorbed by dentin, the laser is still able to heat the tissue to the point of carbonization (600-800°C), at which time the organic and inorganic materials can melt and vaporize, leading to micro-explosions and ejection of the molten mineral phase, which subsequently re-solidifies at the surface.[1] For this reason, this laser is not indicated for cutting hard tissues. To this purpose, the Er:YAG laser is utilized, because its wavelength of 2940 nm is highly absorbed by water and hydroxyapatite, allowing for removal of the enamel and dentin.

However, when Nd:YAG laser irradiation is applied over the adhesive and prior to polymerization, some positive results might occur.[2-4] Even with the good results that were reported, few studies have used this technique. Therefore, to date, few energy densities and adhesive materials have been evaluated in this way.

In order to extend the applications of Nd:YAG laser, which already have many uses in areas such as oral surgery, periodontology and endodontology, and, thus, increase the advantages of a possible investment in such equipment, research on the benefits of irradiation are of interest to dental professionals.

In view of these observations, this study evaluated the microtensile bond strength of a dental adhesive to dentin when the dentin is irradiated with a Nd:YAG laser after adhesive application but prior to polymerization. The tested hypothesis is that the adhesive, being transparent to the Nd:YAG laser wavelength, will not suffer vaporization, while the dentin irradiated with low energy densities will experience heating (below its melting point), allowing for better flow of the adhesive to its interior.

METHODS AND MATERIALS

Twelve sound human molars were used in this study. In order to hinder bacterial growth, the molars where cleaned and stored in a Thymol 0.1% solution.

All the teeth were transversely sectioned and abraded to remove the occlusal enamel, until it reached a plane surface at a medium depth. To standardize the surface and promote the formation of a smear layer, all samples were ground with 220, 360 and 600 mesh abrasive sheets.

For the adhesive procedure, the surfaces were acid etched with a 35% phosphoric acid (3M Dental Products, St Paul, MN, USA) for 15 seconds. The dentin was then washed, the excess water removed and 2 layers of a 1-bottle adhesive (Single Bond/3M Dental Products, St Paul, MN, USA) was applied, followed by a 5-second gentle air stream. Before adhesive photopolymerization, half of each tooth was irradiated with a series of laser pulses from a Nd:YAG laser (Quanta-Ray GCR-11 Spectra-Physics, Mountain View, CA, USA). The teeth were separated into 3 groups according to the total amount of energy density deposited at the tooth surface. The non-irradiated halves were used as the control, constituting the fourth group (Table 1).

The laser used in this work produces 200 µs light pulses at a 10 Hz repetition frequency with a wavelength of 1,064 µm. The laser beam was concentrated, using a special conical mirror, resulting in a focal spot of constant light intensity about 3-mm in diameter. The teeth were irradiated by scanning the focal spot across the surface by tilting the focusing mirror. The total amount of energy deposited at the tooth surface was controlled by limiting the number of laser pulses.

Table 1: *Group Distribution According to the Laser Irradiation Parameters*

Group	Number of Teeth	Treatment	Energy (mJ/pulse)	Laser Energy Density at the Surface (J/cm²)
L0	12	Acid + Adhesive (Control)	0	0
L5	4	Acid + Adhesive + Laser	100	5
L10	4	Acid + Adhesive + Laser	100	10
L50	4	Acid + Adhesive + Laser	100	50

Table 2: *Adhesive Composition*

Material	Composition
Single Bond	HEMA, ethanol, water, Bis-GMA, dimethacrylates, amines, polyalkenoic acid copolymer.

Data obtained from the manufacturer. (3M Dental Products)

Table 3: *Resin Composite Composition*

Material	Matrix	Filler	Filler Volume (%)	Filler Average Size (µm)
Filtek: Z250	Bis-GMA, Bis-EMA, UDMA	Zircon and Silica	60	0.6

Data obtained from the manufacturer. (3M Dental Products)

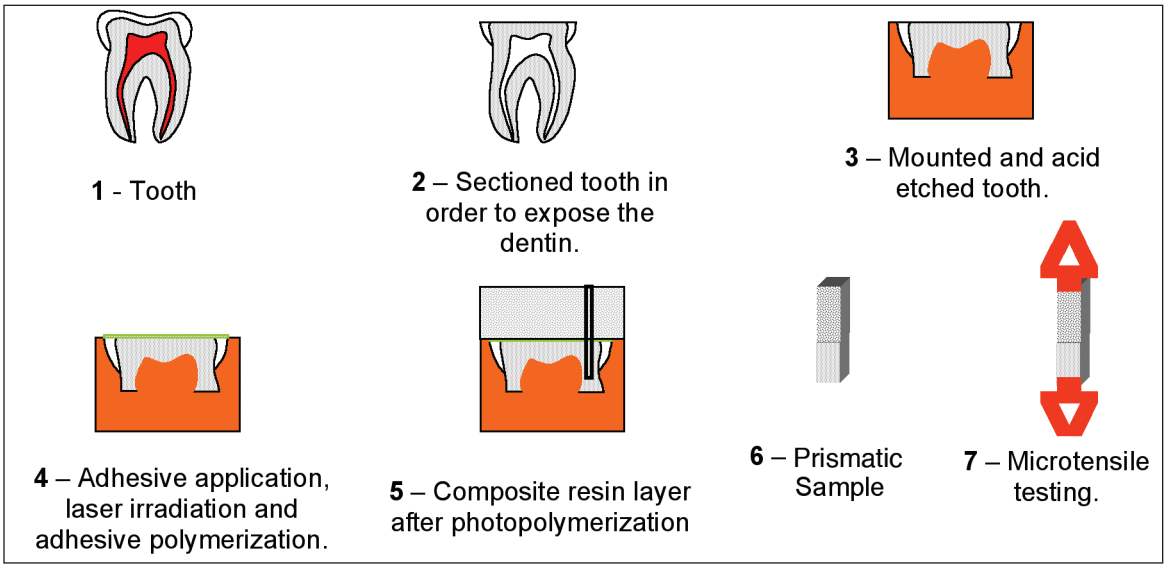

Figure 1. *Sample preparation.*

After laser irradiation, the adhesive was photopolymerized for 20 seconds with a Visiolux 2 apparatus (3M Dental Products, St Paul, MN, USA). The resin composite Filtek Z-250 (3M Dental Products) was then applied to the dental surface in increments in order to build up a resin block approximately 5-mm high above the teeth. Tables 2 and 3 detail the composition of the resin composite and adhesive system. The samples were then stored for 24 hours in distilled water at 37°C.

The restored teeth were then sliced with a diamond wheel saw (South Bay Technology, San Clemente, CA, USA) using a low speed precision machine (Isomet 1000, Buhler, Duesseldorf, Germany). As a result, prismatic samples approximately 10-mm high were obtained, where one half had dentin and the other half the resin composite (Figure 1).

For microtensile testing, a cyanoacrylate adhesive (Superbonder, Loctite, Brazil) was used to glue the samples to a microtensile device (Bencor Mult-T, Danville Engineering, San Ramon, CA, USA). The samples were then tested in a universal testing machine Instron 4444 (Instron, Canton, MA, USA) with a constant crosshead speed of 0.5 mm/minute. Prior to the test, the cross section of each sample was measured with a digital micrometer next to the adhesive interface, where diverse values between 0.6 and 1.0 mm² were obtained.

The measured bonding strengths for each energy density were analyzed with 1-way analysis of variance (ANOVA) and least significant difference analysis (LSD). In order to evaluate the statistical significance of the comparisons, a *p*-value of 0.05 was used.

Some of the samples were also used to investigate adhesive penetration in the dentinal tubules (resinous tags). For these analyses, the organic and inorganic dental substrates were dissolved in alternate immersions of sodium hypochlorite and hydrochloric acid; they were then taken to a scanning electron microscope (Phillips XL-30, Eindhoven, The Netherlands).

RESULTS

The results obtained with ANOVA showed that there were significant differences among the groups. To identify which samples were different from the others, the post hoc LSD test was used. The mean values and standard deviations obtained with the microtensile tests for each energy density are presented in Table 4.

The results demonstrate that the L5 group, which showed a mean value of 56.88 MPa, had the highest microtensile values, with statistical significance in relation to the other groups. The L50 group, however, had the lowest mean value of 30.42 MPa, with a significant difference among the others, while the L0 and L10 groups had equivalent results (48.14 MPa and 48.81 MPa, respectively).

Microscopic analysis of the fracture topography showed that all the samples broke at the interfacial region, whereas, the fracture propagated along the 3 different layers (dentin, adhesive and composite) (Figures 2 and 3).

SEM micrographs of the bonded interface showed that adhesive agent infiltration in the dentinal tubules was deeper in teeth where a laser energy density of 5 J/cm^2 was used compared to the group where no irradiation was made (Figures 4 and 5).

DISCUSSION

The use of Nd:YAG laser before the adhesive restorative process is not recommended, given the fact that this type of irradiation leads to tissue depleted in dentinal tubules with its partial or total occlusion,[2,14] making adhesive infiltration and micromechanic retention more difficult.

If the tooth is filled using an adhesive technique, this fact seems to make use of this laser for caries removal also not feasible.

However, the use of an Nd:YAG laser after adhesive application, as has already been proposed by some researchers[2-4] seems a more appealing way to achieve higher bonding strengths.

In this study, the results showed statistically significant differences in bond strength according to the energy density of the laser. When an energy density of 5J/cm^2 was applied to the adhesive, the results were better than that of all the other groups. With 10J/cm^2, the results were equivalent to those achieved with the group where no irradiation was applied. With an even higher energy density (50J/cm^2), bond strength was significantly lower than that of all the other groups. This suggests that low energy densities seem to be more

Table 4: *Mean Values Obtained for the Microtensile Testing after ANOVA and LSD Analysis*

Group	Mean (MPa)	Standard Deviation (MPa)
L0	48.14	17.06
L5	**56.88**	15.43
L10	48.81	16.68
L50	**30.42**	10.53

The bold values indicate significant differences.

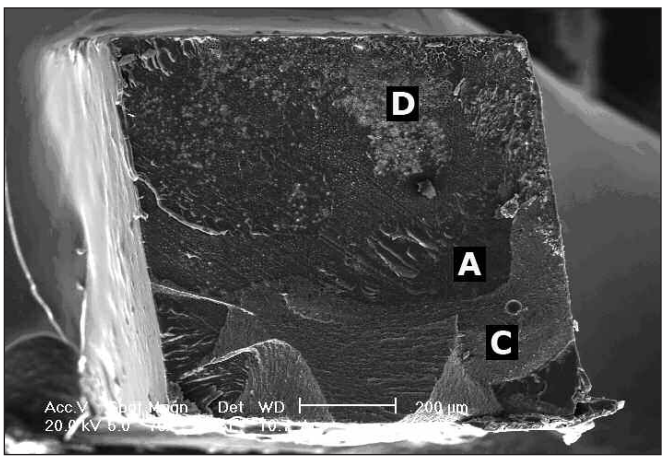

Figure 2. *Fracture surface of an L0 sample showing the fracture propagation along the dentin (D) adhesive (A) and composite (C).*

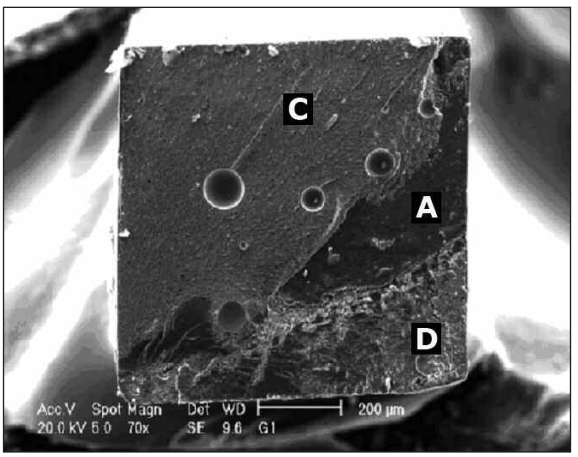

Figure 3. *Fracture surface of an L5 sample, showing the fracture propagation along the dentin (D), adhesive (A) and composite (C).*

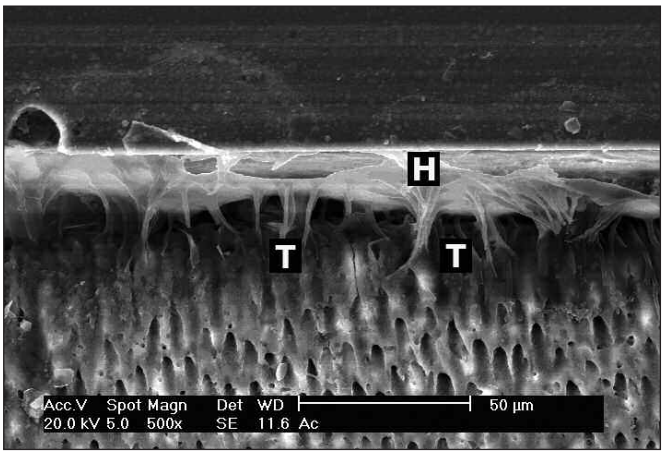

Figure 4. *Hybrid layer (H) and resinous tags (T) on a phosphoric acid treated tooth (L0 group). 500x.*

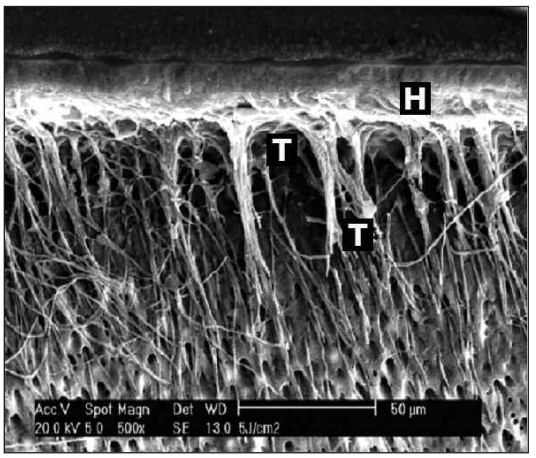

Figure 5. *Hybrid layer (H) and resinous tags (T) on a laser irradiated (5 J/cm²) tooth. 500x. Observe that the adhesive penetration was better when the laser was used.*

adequate in order to promote a strong bond between the tooth and the restorative system. With a comparatively high energy density, such as 50J/cm², the tooth surface is probably overheated, resulting in degradation of both the tooth and the adhesive agent.

Regarding the bond strength test, some interesting aspects shall be discussed, once it is widely accepted and recommended in the dental scientific community. In this work, microtensile testing was the authors' choice. Disparity in the results, however, was reasonably high.

Inspection of the fracture after testing can provide some information about the way and mechanisms that might be involved in the fracture process, for example, which is the weaker region, how the fracture propagates and, most important, which are the possible causes for the disparity that was noticed in the results.

According to the fracture mechanism, the greatest area of stress concentration will be the area where crack formation is initiated, and it propagates until specimen failure occurs. In this study, the fracture was always initiated at the interface of the resin composite with dentin.

Based on Figures 2 and 3, the regions where the fracture occurred can be clearly seen: composite (C), adhesive (A) and dentin (D). This fact, however, does not mean that these regions have the same strength, but that a small misalignment probably occurred when positioning the sample in the microtensile device and, in turn, the treated surface was not perpendicular to the loading axis. Any slight misalignment could result in fracture propagation among the 3 layers.

Also, the dentin, itself, owing to its heterogeneity, might influence bond strength. Structure quality of the exposed dentin is strongly influenced by the type of tooth and its age, as well as by the size and quantity of open tubules. As a result of this heterogeneity in dentin structure, distinctive behaviors after the acid treatment and adhesive procedures can be seen.[15-16]

With respect to adhesive penetration, the SEM images showed that there were fewer resinous tags in the sample where no irradiation was applied (Figure 4) when compared with the sample that was irradiated with an energy density of 5J/cm² (Figure 5). With laser treatment, the tags were more numerous; whereas, one can also see lateral projections. This improved adhesive infiltration probably led to better bonding strength. According to Swift, Perdigão and Heymann[17] and Perdigão,[18] the existence of resinous tags inside the tubules is of low importance if they are not properly hybridized with the lateral walls. Therefore, laser irradiation over the adhesive at low energy densities seems to contribute to better, more intimate interaction of the adhesive with the dentinal tubules.

Another situation that must be considered is that the use of strong acids to remove the smear layer and surface demineralization might result in an incomplete diffusion of resin monomers in the whole cavity of demineralized dentin, thus leading to an unprotected, exposed collagen zone. These exposed collagen fibers would be subject to hydrolysis and nanoleakage and could act as a region of stress concentration.[19-20] However, based on the quality of adhesive penetration seen in the micrographs of the samples irradiated at 5J/cm² (Figure 5), it seems that such areas were not created during laser treatment.

In addition to the influence on bonding strength, other effects of laser irradiation on dentin are also beneficial. Some effects include the enhancement of microhardness and demineralization resistance[21-22] and the decrease of dentinal permeability,[14,23] diminishing bacterial access to pulp and, thus, protecting the teeth from pulp inflammations, post-operative sensitivity and recurrent caries.

CONCLUSIONS

Dentin irradiation with the Nd:YAG laser after Single Bond (3M) adhesive application but prior to polymerization might influence microtensile bond strength in several ways, depending on the total energy density of the irradiation. According to the results obtained in this study, low energy densities (on the order of 5J/cm^2) induce heating of the dentin (below its melting point), allowing for better adhesive penetration, which, in turn, results in higher bonding strengths. On the other hand, if the energy applied is too elevated (50 J/cm^2), bond strength is reduced.

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