Laser etching of enamel for direct bonding

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In recent years, there has been growing interest in the application of lasers for treating medical and dental maladies. Different laser systems have evolved in response to these varying needs. A laser system for dental applications should satisfy certain criteria. Portability of the unit is an obvious criterion when more than one operator uses the system or when the unit will be used at two or more sites within a given location. A light, low mass handpiece is necessary for ease of use and application of the laser beam to sites within the oral cavity. A controlled, well-focused beam is necessary to perform soft tissue surgery, enamel etching or other procedures without beam impingement on sensitive or damage-susceptible tissues. Clearly, for the purchase and use of a laser system to be viable, its application within the dental setting should be time- and cost-efficient. Finally, the system must be readily sterilized or incorporate the means whereby components that come into contact with the patient may be replaced or sterilized.

The first application of lasers in the dental field was reported in 1964,[1] when they were used to inhibit caries by increasing the resistance of enamel to demineralization.[1,2] Since then, attention has been focused on the treatment of soft and hard tissue lesions and desensitization of teeth.[3-12] Orthodontic applications of laser treatment were a natural outcome of the earlier studies of laser effects on enamel.

Laser treatment of dental hard tissues involves conversion of light energy to thermal energy to resect tissues. In particular, laser irradiation of dental enamel causes thermally-induced changes within the enamel to a depth of 10-20 µm depending on the type of laser and the energy applied to the enamel surface. Adjustment of the laser power output permits localized melting and ablation of the enamel surface, in effect etching it through a process of

Abstract

The application of laser irradiation to etch dental enamel in preparation for direct bonding of orthodontic appliances has been studied. Forty extracted human teeth were divided into four groups of 10 teeth. Within each group, five teeth were subjected to a 30 sec acid etch of the buccal enamel surface; the other five in each group were etched with a laser. Four power settings on the laser etching unit were used: 80mJ, 1W, 2W and 3W. After etching, brackets were adhered to the prepared buccal enamel surfaces with composite resin. Shear bond strength was tested 7 days later.

The findings showed that an acceptable shear bond strength, viz. ≥0.6kg/mm , could be achieved at laser power settings of 1 to 3W but not at the lowest setting (80 mJ). However, the mean shear bond strengths obtained with laser treatment of the enamel at 80mJ, 1W and 2W were lower ($p<0.01$ or 0.001) than that achieved with acid etching.

Key Words

Lasers • Etching • Direct bonding

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Table 1
Shear bond strengths (kg/mm) for different etch regimens

Power setting	Shear bond strength (kg/mm)	No. of failures
80mj	0.22±0.17*	5
1W, Level 2	0.71±0.28	2
2W, Level 6	0.77±0.17	1
3W, Level 10	1.28±0.24	0
Acid Etch	1.45±0.60	1
F value:	17.46	

*: Mean value and standard deviation

continuous vaporization and micro explosions due to vaporization of water trapped within the hydroxyapatite matrix. In general, more material is removed by the microexplosion of entrapped water than by direct vaporization of the hydroxyapatite crystals. However, the degree of surface roughening is dependent upon the system used and the wavelength of the laser. Studies with a CO_2 laser showed surface roughening at 9.32µm and surface glazing at 10.59µm. Researchers claimed that etching occurred at power levels low enough to avoid deleterious effects on the underlying dentin).[13] Other work on adhesion of composites to laser etched enamel found that the composite bond would fail without fracture of the enamel during shear bond strength testing, indicating the laser treatment did not make the enamel brittle.[8]

The present study was undertaken to evaluate the effectiveness of a commercial Nd:YAG laser in etching dental enamel for direct bonding of orthodontic appliances.

Materials and methods

This study used 40 freshly extracted, non-carious human maxillary and mandibular premolars and third molars. The teeth were stored continuously in distilled water at 10°C, with the water changed weekly to minimize bacterial growth. They were randomly assigned into four groups of 10 teeth. The roots were embedded in dental stone encased in plastic cylinders. The buccal enamel surfaces of the teeth were prophied, washed and dried prior to etching.

The buccal enamel surfaces of 20 teeth were etched chemically for 30 seconds with Ultra-Etch 40% H_3PO_4 gel (Ultradent Products, Inc., Salt Lake City, Utah) and then rinsed and dried. An Nd:YAG laser (American Dental Laser, Birmingham, Mich) was used to etch the buccal enamel of the remaining 20 teeth by irradiation for 12 seconds. Since there is little surface absorption of the Nd:YAG beam by enamel, it must be coated with a light-absorbing material such a black ink. Surfaces selected for laser etching were painted with a thin coat of initiator (Catman Water Colours, ivory black 331) with a nylon brush over an area of approximately 16mm , an area slightly greater than that of the bracket base. Four etching (power setting) regimens were used: 80 mJ at 10Hz, 1 watt at level 2 and 20Hz, 2 watts at level 6 and 20Hz and 3 watts at level 10 and 20Hz.

An Ormesh stainless steel bracket (Ormco Company, Glendora, Calif), selected to closely adapt to the teeth in the study, was bonded to each tooth with System 1 adhesive. The bonded specimens were stored at 100% humidity at room temperature for one week prior to bond strength testing.

The embedded specimens were secured in a vise-type jig attached to the base plate of a Unite-O-Matic FM 20 (United Calibration Corporation, Garden Grove, Calif). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned so that the leading edge contacted the enamel/adhesive interface before being brought into contact at a crosshead speed of 5mm/min. Shear bond strength was determined on all teeth in all groups one week after the orthodontic brackets were bonded. The shear bond strength data was subjected to a one-way ANOVA. Differences were identified by a post-hoc Tukey-Kramer test[14] using an *a priori* $\alpha = 0.05$.

Results

The summary mean shear bond strengths of the buccal enamel surfaces etched by laser irradiation and by phosphoric acid, along with their standard deviations, are given in Table 1. Since it has been suggested[15] that a minimum clinically acceptable bond strength for directly bonded orthodontic brackets is 0.60 kg/mm , specimens that did not achieve this shear bond strength were designated as bond failures. Accordingly, the shear bond strengths obtained on buccal surfaces etched with one of the four laser power settings and the number of specimens that did not achieve a bond strength of 0.6 kg/mm , i.e. bond "failures", are also listed in Table 1

Statistical analysis of the data indicates that there are significant differences ($p<0.01$) between the shear bond strengths obtained with laser irradiation and that found with acid etching of the enamel.

The bond strengths obtained at the lowest laser power setting were significantly lower ($p<0.05$ or 0.01) than those obtained at the three higher power settings. No statistically significant differences ($p>0.05$) were found in shear bonds strengths at the 1 watt and 2 watt settings. The shear bond strength obtained with surfaces etched at 3 watts, level 10 were greater than those obtained with any other power setting ($p<0.01$) but there was no difference ($p>0.05$) between these specimens and the acid etched specimens.

No specimens etched at 80 mJ achieved the clinically acceptable bond strength of 0.6kg/mm . All specimens etched at 3 watts, level 10 had bond strengths greater than this level, Table 2. The data showed, however, that a number of specimens etched at 1 watt and 2 watts did not achieve 0.6kg/mm , Table 1.

Table 2
Shear bond strengths (kg/mm^2)
for different laser power settings

80mj	1W Level 2	2W Level 6	3W Level 10
0.16	0.48	0.59	1.13
0.23	0.87	0.70	1.62
0.06	0.38	0.89	1.27
0.50	0.77	1.00	0.99
0.14	1.05	0.69	1.38
Mean±S.D.:			
0.22±0.17	0.71±0.28	0.77±0.17	1.28±0.24

Discussion

A shear bond strength of 0.60 kg/mm has been suggested as a minimum acceptable value for clinical use in direct bonding of orthodontic brackets[14]. Although bond strengths with laser etched enamel increased with the power and energy output from the laser unit, a finding consistent with previously reported work,[16,17] only surfaces etched at the higher power settings achieved this bond strength. Further, not all specimens achieved a bond strength of 0.6kg/mm , as shown in Table 1. The findings of this study suggest that bond strengths comparable to those found with acid etching occurred consistently only at a power output of 3W at 20 Hz.

A laser etch time of 12 seconds was adopted in this study. Pilot studies showed that a minimum irradiation time of 12 seconds was required to ablate all traces of the carbon-based initiator and this irradiation time was comparable to that required for acid etching of enamel. The minimum time required for acid etching is 15 seconds followed by a 15-30 second wash and then a 5-10 second desiccation of the etched surface, i.e. a total time expenditure of 30-55 seconds. If laser etching is completed within 12 seconds, enabling immediate placement of a bracket, there would be a savings of 15-40 seconds per tooth.

The manufacturers of the laser (American Dental Laser) suggest a power setting of 80 mJ at 10Hz for enamel etching but do not specify a time period for etching. The present findings clearly indicate that this power setting, applied for 12 seconds, is inadequate for conditioning enamel surfaces for direct bonding of orthodontic appliances. In fact, acceptable and consistent enamel conditions, i.e. etching to achieve an adequate shear bond strength, was found only at the maximum laser power output.

This study raises certain questions. Laser etching of enamel involves localized melting and ablation of the enamel surface with etching occurring through a process of continuous vaporization and micro-explosions due to vaporization of entrapped water within the hydroxyapatite matrix. It follows that there might be untoward thermal effects on the tooth pulp as result of this laser etching procedure.

Conclusions

If a shear bond strength of 0.60 kg/mm is taken as the minimum acceptable value for clinical use, the present findings indicate that laser etching must be performed at the maximum power output of the American Dental Nd:YAG laser to achieve consistent surface conditioning.

Laser etching may save some clinical time, but the savings are not great and may not justify the capital expenditure involved. However, the effect of laser irradiation on the substrate tooth, notably the effects on enamel morphology and physiological changes within the deeper structures, await clarification. Further work is in progress on thermal effects associated with enamel etching by laser irradiation.

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