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ER:YAG LASER ETCHING OF ENAMEL

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Abstract

This *in vitro* study compares the etching effects of acid treatment and Er:YAG laser radiation on the enamel of extracted permanent human molars. Oval cavities in the buccal surface were prepared in the conventional manner and then the edges of the cavities were irradiated by Er:YAG radiation. Laser energy was 105 mJ and 208 mJ and the repetition rate was 1 Hz. The radiation was focused by a CaF_2 lens and the sample was placed either in focus or in front of or behind the focal plane. To check the effect of the treatment, 10 samples were etched by phosphoric acid. A comparison of the samples showed that laser treatment also caused a desired roughness of the enamel. In the second part of the study, the cavities were filled with composite resin. Dye penetration in the cavity margin and the space between the composite restoration and enamel and dentin were similar.

Key words: Dentistry, laser therapy, Er:YAG laser, enamel, etching

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Introduction

In 1955 Buonocore (Buonocore, 1955) described phosphoric acid as a simple means for increasing the adhesion of acrylic filling materials to enamel surfaces. Since that time, several other types of etching solutions have been used (Gwinnett, 1963). For chemical etching the 37% phosphoric acid solution was the most effective, having produced the most consistent pattern of the enamel. Enamel etching has a direct influence on the retention of the composite materials in adhesive dentistry (Low and von Fraunhofer, 1976). The wet, saliva-contaminated surface prevents the etching of enamel and, therefore, the bond strength of the composite resin is significantly lower (Hormati *et al*., 1980). The attachment of the composite resin to the etched surface is achieved by applying a low viscosity liquid resin or an intermediate bonding agent, which flows into the micropores created by etching. The bond, then, is mechanical. The process depends on the viscosity of the free resin and intermediate composite resin (Jamjoum *et al*., 1995).

For etching it is possible to use phosphoric acid or other alternative methods such as air polishing, crystal growth, microretention with pressuring pumice and laser etching (Jamjoum *et al*., 1995). Enamel etch by the acid can be complicated by the removal of surface, variability of penetration depth, and strong washing and drying affecting the bond strength.

For that reason the dentist would like to find an alternative procedure for preparing the enamel. One of the effective methods may be to pretreat the enamel by laser radiation. According to the literature, various types of lasers were used, namely ruby laser (Vahl and Pfefferkorn, 1967), CO_2 laser (Ferreira *et al*., 1989), Nd:YAG laser (Myers, 1990) and Er:YAG laser (Lukač *et al*., 1993, Schilke and Geurtsen, 1994). The aim of this *in vitro* study was to evaluate the roughness structure of the edge of the prepared cavity, the etching having been performed by Er:YAG laser and by phosphoric acid. By Er:YAG laser etching we would like to obtain the optimal structure of the surface related to laser energy and position of laser irradiation focus.

Materials and Methods

Laser equipment and experiment preparation

For the experiment, a special Er:YAG laser drilling machine was designed. The system has a laser head with an articulated arm, water cooler, and power supply with automatic control. The power supply consists of a controller and a high voltage charging unit. The controller allows the operator to check the laser energy generation, and the high voltage charging unit supplies voltage to the laser head where the laser radiation is generated. The water cooler is a self-contained system providing water to the pumping cavity. The control system includes a microprocessor to ensure that all parts of the system are working properly. The laser head consists of an Er:YAG crystal with a diameter of 4 mm and length of 100 mm placed along with an LMI 1620 (LMI, Santa Clara, CA) xenon flash-lamp into the pumping cavity. Special design of the resonator enables the generation of the output energy up to 700 mJ in a free-running, long-pulse mode regime. The length of the generated pulses was 200 μsec. By the articulated arm the radiation was incited on the investigated place and focused by the CaF_2 lens (f = 55 mm) on the samples tested. Along with the articulated arm the water and air were, focused on the same place.

During our experiments cooling of the samples was achieved by fine water mist (water - 50 ml/min) and air flow (2 atm pressure). The delivery system for this case was the same as in the classical high-speed drilling machine (two channels, i.e., one for the water, one for the air).

Preparation of the teeth

For this study, 41 extracted noncarious permanent human molars were used. They were kept in 10% formalin, then cleaned and rinsed with water and stored in distilled water (at room temperature). Prior to the experiments, the teeth were wiped clean with cellulose wool and allowed to dry in the air.

In the buccal surface of each tooth an oval cavity was prepared with steel burs (round ISO 014, Maillefer, Ballaigues, Switzerland; cylinder square ISO 012, Maillefer) in the classical handpiece. The cavity diameters were 3 x by diamond drill (Maillefer 66) at an angle of 45°.

The edges of the cavities were irradiated by two energies, namely 105 mJ (21 teeth) for one set of samples and 208 mJ (10 teeth) for another set. For each energy the edge of each cavity was irradiated by 20 pulses, aimed next to each other. Each experimental arrangement was repeated three times, i.e., in focus, 5 mm in front of the focus, and 5 mm behind the focus.

Following the manufacturer's directions, the enamel surface at the cavity edge in the 10 check (control) samples was etched for 60 sec with 35% phosphoric acid (Esticid Gel; Heraeus-Kulzer, Wehrheim, Germany).

Ten teeth after irradiation energy of 105 mJ and 10 teeth from the control group were filled with composite resin filling (Charisma, Heraeus-Kulzer). After etching, cleaning and conditioning of dentin with Denthesive (Heraeus-Kulzer) cleaner (40 sec) was performed. Dentin bonding with Denthesive A + B mixture was applied to the dentin surface and base lining (15 sec). The cavity was sealed with Adhesive bond which was placed on the enamel and dentin surface and polymerized with a Translux (Heraeus-Kulzer) light unit (20 sec). Then the composite restoration was built up and cured with the Translux and finished with discs/silicone polishers.

The teeth were immersed in 0.5% basic fuchsin (24 hours). Before immersion, teeth were painted with nail varnish (except for a 3 mm window around the cavity) to prevent dye penetration through the pulp cavity).

Transverse sections through the composite restoration were prepared (from 2 to 4 from each sample).

Analytical Methods

The enamel surface was analyzed in the scanning electron microscope (SEM) in the following manner: The tested specimens were fixed onto a specimen holder and then dehydrated and sputter-coated with gold. A JEOL scanning electron microscope (JEOL Superprobe 733; Tokyo, Japan) was employed to observe the diameter and type of the surface produced by laser radiation and phosphoric acid. The effect of both processes was studied at magnifications of 40 x, 100 x and 1100 x.

The sections were viewed using a stereomicroscope (Nikon SMZ 2T; Nikon, Tokyo, Japan) (magnification 10 x) which was connected with a charge-coupled device (CCD) camera (Mitsubishi, Tokyo, Japan). A computer software system (Sigma Scan and Sigma Scan Pro, San Rafael, CA) was used to analyze dye penetration. Significant differences between the experimental and control groups were calculated by Student's t-test at a probability P = 0.05.

Results

Due to the preferential loss of material from the prism core, the classical acid-etched surface had a honeycomb appearance. The border of acid etching in the enamel is fuzzy (Fig. 1).

The structure of the enamel exposed by the laser differs and depends on the energy and position of the focus. The energy of 208 mJ produced a drilling effect, and therefore it is possible to observe crater formation in the enamel (Fig. 2). The position of the focus (behind the focus, the spot was larger and the energy lower) did not effect crater formation. An irregular loss of enamel was also seen.

The energy of 105 mJ can prepare a well-defined roughness of enamel in focus and an irregular undulation

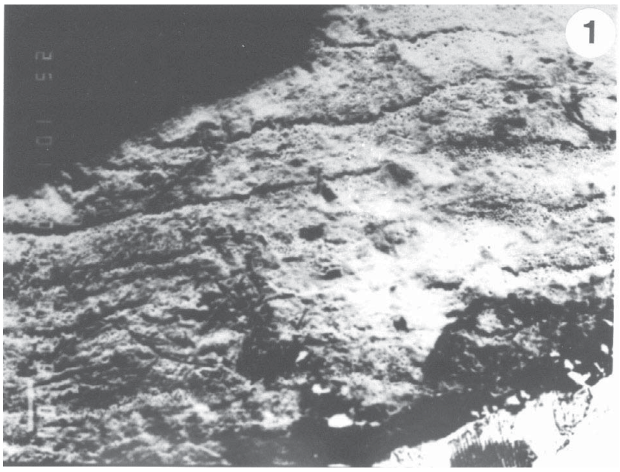

Figure 1. Honeycomb appearance of enamel after acid etching. Picture width 89 µm.

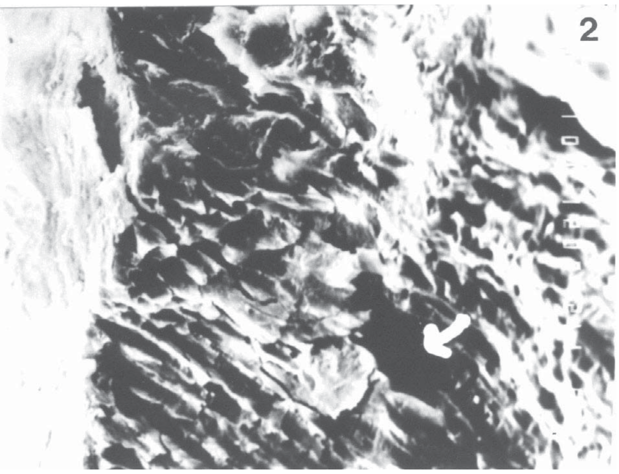

Figure 2. Irregular loss of enamel after irradiation with Er:YAG laser energy of 208 mJ, repetition rate 1 Hz, in focus. Picture width 89 µm.

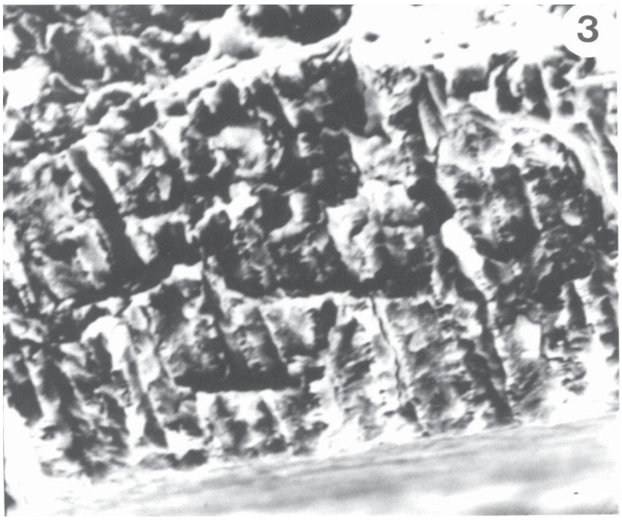

Figure 3. Straight lines of indentation around the edge of the cavity after irradiation with Er:YAG laser energy of 105 mJ, repetition rate 1 Hz, in focus. Picture width 790 µm.

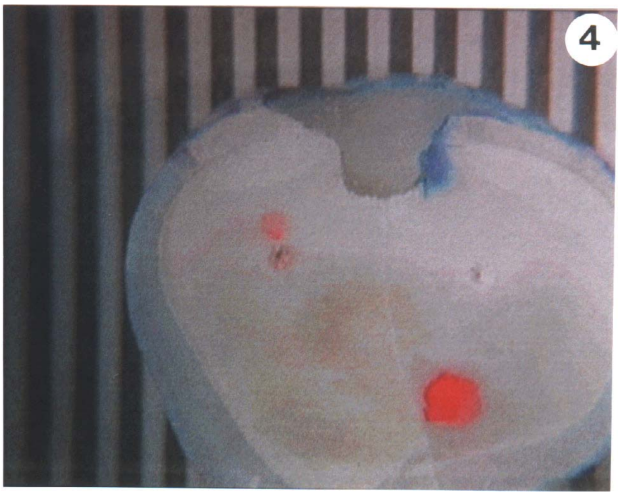

Figure 4. Penetration of dye into enamel and dentin after laser etching. Picture width 9 mm.

of the surface. The indentations lay in straight lines around the cavity edge (Fig. 3). In front of the focus where the energy is higher than behind it, no crater formation was found (the maximum energy having been in focus). Behind the focus, (larger spot, lower energy) the enamel structure was smoother, with less prominent indentations.

The frequency of dye penetration was similar - 20.8% by laser etching and 25.0% (Table 1). When dye penetration was observed, the dye penetrated in only one side of the composite resin restoration (Fig. 4). The space in enamel and dentin measured about tenth micrometers (Figs. 5 and 6).

Discussion

This study compared the etching effect in enamel by both acid and the Er:YAG laser. Laser-etching is possible by using Nd:YAG, CO_2 and Er:YAG lasers. The surface changes seen in the Nd:YAG laser-etched enamel are non-uniform and they result in a rough porous surface. Pitting was evident on the surface, but this effect was superficial and shallow, and as such it would limit the length of the resin tags formed in the enamel surface (Jamjoum *et al.*, 1995). The acid and the Nd:YAG laser energy penetrated the enamel to the same depth i.e., from 20 µm to 40 µm, and

Table 1: Dye penetration after laser and acid etching

	laser etching	SE	acid etching	SE
circumference of cavity (mm)	27.11	1.35	24.84	0.72
area of cavity (mm)	38.45	3.56	29.67	1.96
dye penetration (mm)	1.67	0.94	1.83	0.55
frequency of dye penetration (%)	20.8		25.0	

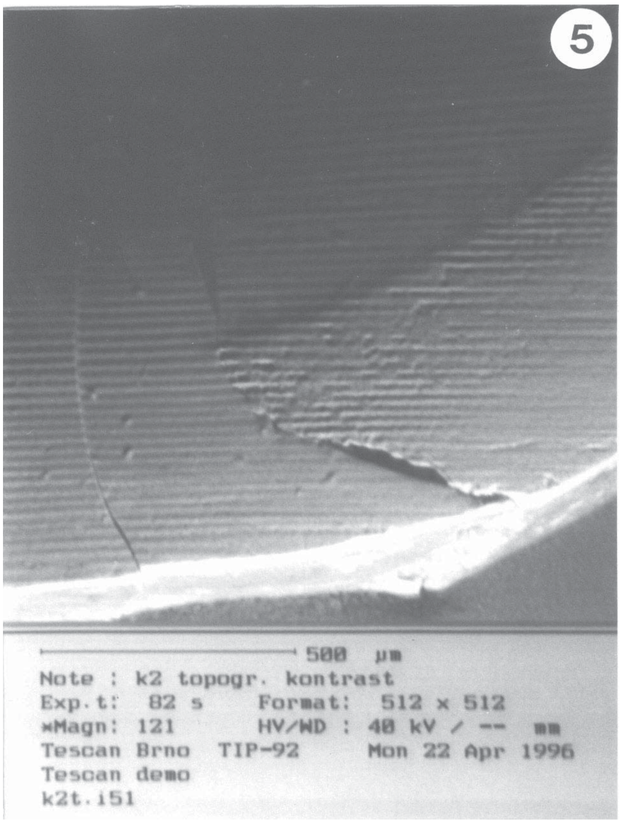

Figure 5. Space between composite resin and enamel after laser etching in SEM. Picture width 1.2 mm.

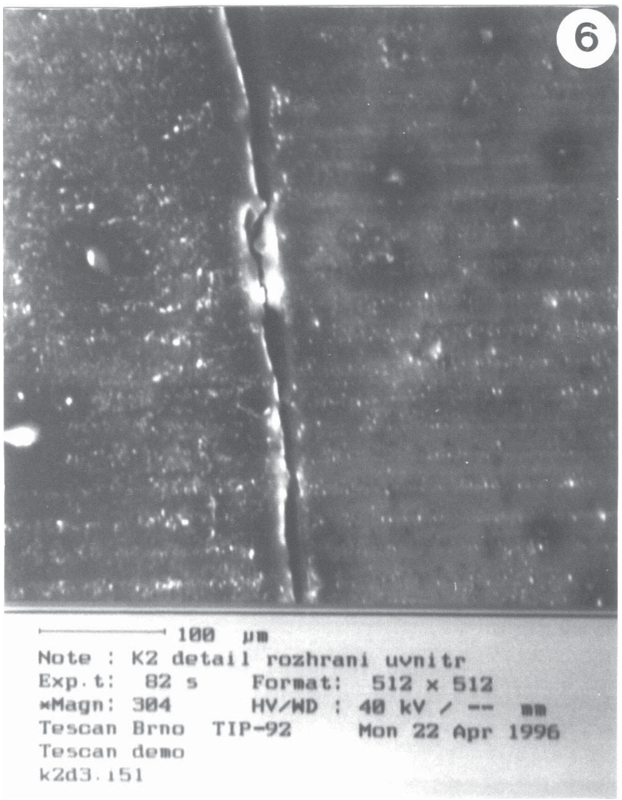

Figure 6. Space between composite resin and dentin after laser etching in SEM. Picture width 470 µm.

the morphological changes of these two techniques were very similar (Myers, 1990). Acid etching has a typical honeycomb appearance due to the preferential loss of material from the prisma core (Hormati *et al.*, 1980). Ferriera *et al.*, (1989) found that CO_2 and Nd:YAG irradiation was responsible for reduced enamel porosity.

Generally it can be said that hard dental substances can be removed by pulsed Er:YAG laser radiation. The effect depends on the type of hard dental tissues, i.e., enamel and dentin (Hibst and Keller, 1989). The difference depends on water content (enamel 25%, dentin 13.5%) and inorganic compounds (enamel 96%, dentin 69%) (Hibst and Keller, 1989). For the 2.94 µm Er:YAG laser, the absorption of laser radiation is about twice as high in dentin as compared with enamel (Hibst and Keller, 1989).

For that reason we must separate the influence of the laser radiation on the enamel and on the dentin. This process would have a direct effect on the bonding of the composite bond to dentin. The treatment in dentin with a dental handpiece produces well-defined rows between the handpiece/translator steps, thus creating a series of hills and valleys. A smear layer with some flaky debris was evident. Some debris appeared to be removed following the primer stage but no dentin tubules were evident. The surface was completely masked by adhesive coating (Visuri *et al.*, 1995). The laser-treated teeth showed dramatic differences: the radiation produced a less ordered pattern of hills and valleys (Schilke and Geurtsen, 1994). The peritubular dentin may have been removed in the process. It can be said that compared to the handpiece (Visuri *et al*., 1995), laser preparation yields stronger bonds to composite resin.

The increase of seal materials adhesion to cavity walls in enamel and dentin formed by Er:YAG radiation was also observed by Altshuler *et al*. (1994).

From our study it can be said that there is no significant difference between laser and acid etching. Dye penetration into the space between composite resin and enamel and dentin was similar. It is interesting that penetration of dye was observed in only one side of the composite restoration, which may be connected with composite resin contraction.

A positive effect of Er:YAG laser radiation on the retention of composite resin to laser-conditioned enamel was observed. This effect was proved for bovine enamel but not for human enamel (Roth *et al*., 1994). This difference can depend on the type of the material used (Haller *et al*., 1993). We confirmed that laser and acid etching have the same effect on the bond of composite resin to enamel and dentin.

Energy exceeding 100 mJ can destroy the enamel. In our study crater formation was observed. With low energy it is possible to etch the tooth surface without removing the enamel; the border is well-defined, the roughness is clearly visible. The position of the focus has only a small influence on the structure of etched enamel. In practice during Er:YAG laser etching the dentist does not have the ability to easily maintain a precise and consistent distance from the tooth. Er:YAG laser etching can apparently replace acid etching with similar effect on enamel and without the negative influence of phosphoric acid.

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Discussion with Reviewer

T.D. Myers: Why were the specific energy levels of 105 and 208 mJ chosen for this study?

Authors: With every use of the dental laser system we measure the laser energy. It is not possible to set this energy

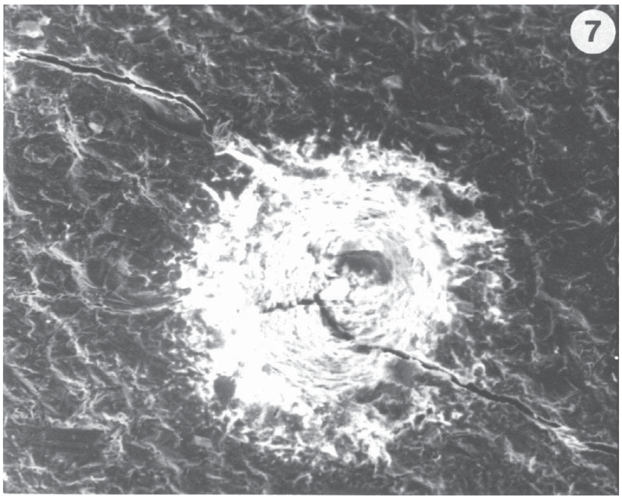

Figure 7: Structure of enamel surface after application of 1 pulse (Energy 96 mJ, repetition rate 1 Hz, in focus. Picture width 0.9 mm.

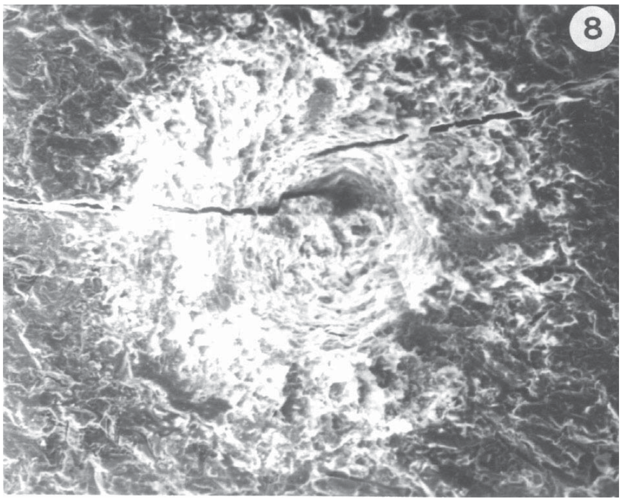

Figure 8. Loss of enamel after application of 1 pulse (Energy 193 mJ, repetition rate 1 Hz, in focus. Picture width 0.9 mm.

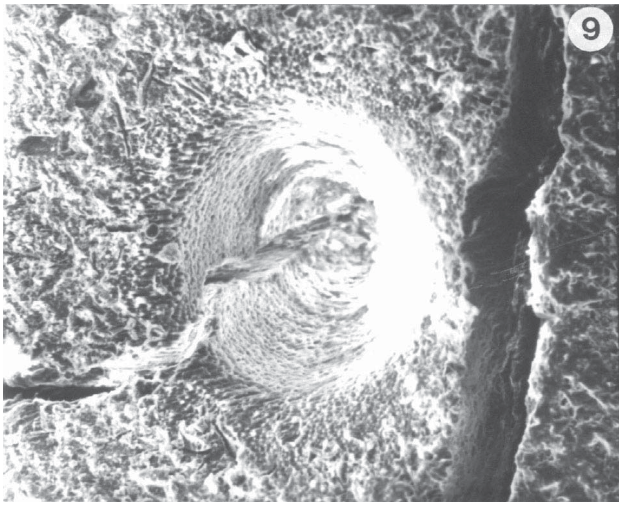

Figure 9. Structure of dentin surface after application of 1 pulse (Energy 96 mJ, repetition rate 1 Hz, in focus. Picture width 0.9 mm.

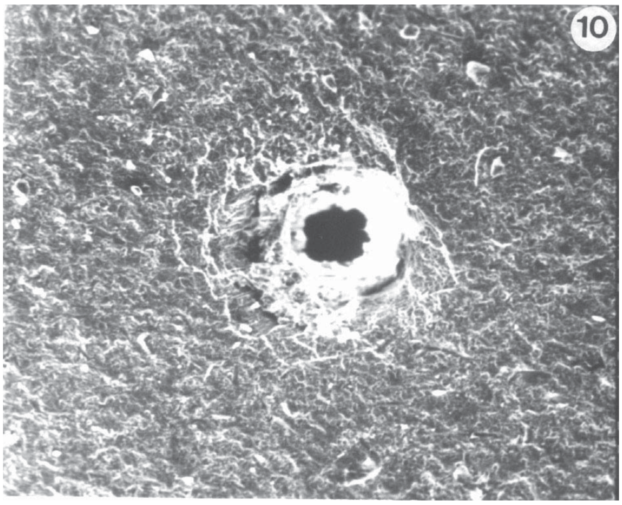

Figure 10. Loss of dentin after application of 1 pulse (Energy 96 mJ, repetition rate 1 Hz, in focus. Picture width 0.9 mm.

precisely to 100 or 200 mJ. For that reason we added the real measured information to the text. As you see in our additional scanning micrographs (Figs. 7 and 8), crater formation started at about 200 mJ of energy; it did not matter whether the energy was 190 or 210 mJ.

T.D. Myers: How practical is the experimental delivery system for oral use?
Authors: We use a special light optical ending. The shape is similar to classical drilling systems with water and air spray.

T.D. Myers: Please comment on the time efficiency of laser vs. acid etching.
Authors: The time for laser etching is shorter (200 ms pulse width, 2 pulses per second). For this study we used 20 pulses (10 sec). For acid etching we followed the manufacturer's directions (60 sec).

T.D. Myers: Please comment on the determination of optimum energies and treatment surface area for optimum bond strength of restorative materials.
Authors: The optimum energy is about 100 mJ for enamel. The optimal way is to treat not only enamel but also dentin

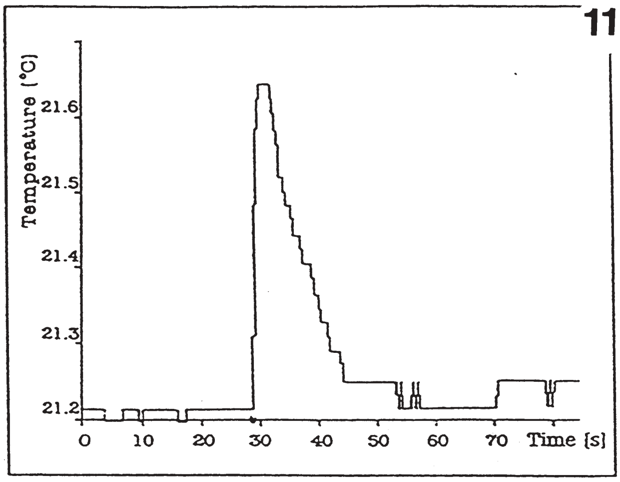

Figure 11. Temperature response to a single pulse in a spray cooled sample (Energy 200 mJ, repetition rate 1 Hz, in focus).

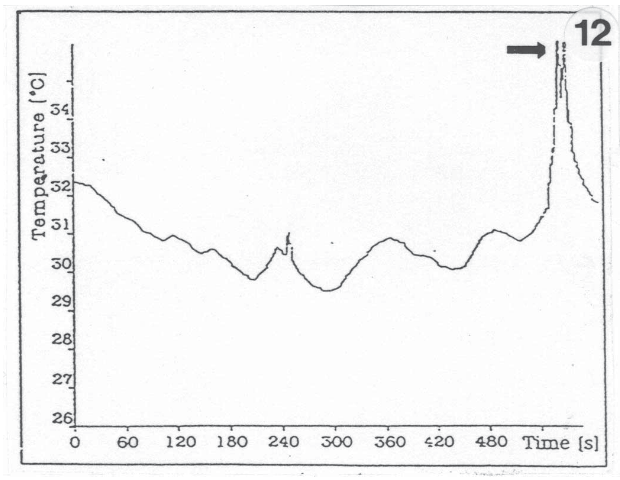

Figure 12. Long-term preparation of enamel and dentin (arrow - pulp perforation).

(the laser energy could be lower for dentin, see Figs. 9 and 10).

T.D. Myers: Are there any possible contraindications or detrimental clinical effects of laser etching?
Authors: Laser ablation is directly connected with visual control of the process. For that reason it is not possible to use this system in places where this visual control is not possible.

T.D. Myers: The authors conducted dye penetration tests as part of their *in vitro* study. Some individuals suggest it may be more clinically relevant to conduct shear bonding strength tests rather than dye penetration tests. Please comment.
Authors: We agree that shear bond strength test is a good check of the adhesion of restorative material. However, we think that the test could be better used not only for etching of enamel but also for enamel and dentin (influence of smear layer on restorative material). For the shear bond strength test it would be necessary to prepare a flat surface and we could not influence the real shape of the cavity preparation through enamel etching only.

T.D. Myers: What Hertz rate of Er:YAG laser irradiation was used in this study?
Authors: We used a repetition rate of 1 Hz.

T.D. Myers: For clinical relevance, what are the possible thermal effects on the pulp due to the Er:YAG laser irradiation used in this study?
Authors: The temperature rise with this Er:YAG drilling system is local without temperature transmission to the pulp. To be safe, the system must be directly connected with a water spray. Fig. 11 shows the temperature response to a single pulse at higher energy (200 mJ). Fig. 12 shows that the long term thermal rise was about 2°C up to the pulp opening.