Effect of Er:YAG Laser Parameters on Enamel: SEM Observations

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**Purpose:** To analyze in vitro the ablative and etching effect of the Er:YAG laser on the enamel of extracted teeth using scanning electron microscopy, comparing two different laser parameter settings.

**Materials and Methods:** Ten noncarious extracted human third molars were treated with an Er:YAG (2940 nm wavelength) set at different parameters. Changes in enamel were observed using scanning electron microscopy.

**Results:** SEM observation of dental hard tissue showed that excessive energy parameters did not give the same results in all the samples, because of the presence of induced alterations (microcracks, melting, flakes) resulting from the thermal effect.

**Conclusion:** This study confirms the possibility of performing ablation within defined limits, forming microcavities with a finely etched and rough surface that are well prepared for treatment with adhesive restorative materials. For best results, it is recommended to use lower levels of energy, emitted at a higher repetition rate.

**Keywords:** Er:YAG laser, laser etching, power density, fluence, focus, scanning electron microscopy.

*J Oral Laser Applications: 2007; 7: 27-35. Submitted for publication: 18.04.06; accepted for publication: 23.10.06.*

The possibility of substituting rotating instruments with the erbium laser in conservative dentistry has as its principle objective the performance of painless dentistry without anesthesia, uncomfortable vibrations, and noise. To reach this objective, it is advisable to use the lowest possible effective energy (mJ), successive pulses (μs) that are shorter in time than the refractory period of synaptic neural transmission, and frequencies (pps, Hz) of repetition of impulses that allow the tissue to cool, avoiding thermal damage and the consequent stimulation of pain.

This study aimed to analyze in vitro the ablative and etching effect of the Er:YAG laser on the enamel of extracted teeth using scanning electron microscopy. Two different Er:YAG lasers with the same delivery system (optical fiber) and the same declared pulse duration were used: these two lasers have different manufacturing philosophies with different parameters regarding pulse energy, applied fluence, pulse repetition rate, average power, application mode and spot size.

The parameters used were those recommended by the manufacturers, in order to critically evaluate their validity in relation to the most important and recent clinical and experimental studies.1-3

**MATERIALS AND METHODS**

**Choice and Conservation of Samples**

Ten healthy human extracted third molars were used. The teeth were cleaned and washed with a physiological saline solution in an ultrasonic bath and preserved separately in saline in sealed sterile containers at room temperature.
Lasers and Parameters Used

Two Er:YAG lasers (Key III, KaVo; Biberach, Germany; and DELight Hoya ConBio; Santa Clara, CA, USA) were used, each with a wavelength of 2940 nm (Tables 1 and 2).

The same operator applied a standard application time of 5 s with water spray using the parameters listed in Tables 3 and 4, according to the manufacturer’s recommendation. Pulse duration was not measured. Instead, the incident pulse energy was measured at the end of the delivery fiber using a power meter (Coherent PM30 Moletron Detector; Portland OR, USA). Laser 1 presented a loss of 18% of the energy pulse and laser 2 a 10% loss, both compared to the laser control panel display. As such, the energy applied was 82% and 90%, resp, of the reported energy.

The delivery tip was used in two modes, contact and noncontact. In contact mode, an operative distance of 1 to 1.5 mm (laser 2) was maintained and in noncontact mode (laser 1), a distance of 10 to 12 mm was maintained through the use of a spacer.

To study the effects on the enamel, the molars were treated on the vestibular side or the lingual side, subdividing each surface lengthwise into two symmetrical halves (mesial and distal). The demarcation line between the two halves represented a nontreated control area. The effects of the two instruments were therefore analyzed in parallel, working on the incisal part with parameters for etching (M) and on the cervical part with parameters for cutting (T) (Fig 1).
The mesial half of each tooth was treated with laser 1, the distal half with laser 2.

Classification of the Sample Groups

Each sample (A, B, C, D, E, F, G, H, I, L) treated with the two different lasers was subdivided into 2 groups (1, 2), with each group further subdivided into 2 subgroups, according to the parameters used (M, T) on the four quadrants.

SEM Evaluation

Following the laser treatment, the teeth were dehydrated in a progressive series of ethyl alcohol (25%, 50%, 75%, 90%, 100%) for 20 min per concentration, and then critical-point dried (Balzers, CPD 030; Balzers Union, Liechtenstein). Finally, the dehydrated samples were sputter coated with gold (Balzers Sputter Coater SCD 050, Balzers Union, Liechtenstein).

SEM Observation

The final phase of observation with the SEM (Philips 515; Eindhoven, The Netherlands) produced 94 images obtained with magnifications from 22X to 6500X, saved in TIF format on a personal computer.

RESULTS

The effects of the laser application on the enamel as observed with the SEM were as follows.

Group M – Etching

Samples treated with laser 1 (350 mJ, 10 Hz x 5 s in contact mode, water spray) viewed at low resolution (46.4X to 101X) a cratering effect, with uneven margins (micro-explosions) (Figs 2a and 2b), flakes, melting with lava-like concrescences on an irregular, yet homogeneous base.

At higher resolution (1620X to 6500X), the samples showed an effect similar to pronounced etching, both in depth and extension, with reduction of the high points of the enamel prismatic structure and a flatter surface. In addition, there was evidence of thermally induced effects with areas of vitrification and some fine cracking (Figs 2c and 2d).

Group T – Cutting

Samples treated with laser 1 (350 mJ, 10 Hz x 5 s, focus 10 mm, with co-axial water spray) showed at low resolution (101X to 406X) evidence of irregular cutting, non-homogeneous surfaces with ill-defined limits, irregular flakes and debris (Figs 4a and 4c) and areas of melting (Fig 4b). At higher resolution (1620X to 6500X), varying results were observed: in some samples there were irregular surfaces, vast areas of vitrification (Figs 4d and 4e) divided by some grooves and cracks, with the disappearance of normal prismatic pattern, probably due to thermal effects; in other samples, the appearance was similar to the etching already observed but with more marked thermal effects (Fig 4f), alternating with small areas of melting that were more defined.

Samples treated with laser 2 (250 mJ, 25 Hz x 5 s in contact mode with co-axial water spray) showed at low resolution results similar to laser 1 with the presence of more delineated craters and smaller flakes (Fig 5a). At higher resolution, the samples showed better maintenance of the prismatic pattern even though there was some evidence of grooving and more superficial melting (Figs 5b to 5d).

DISCUSSION

SEM analysis showed that the results obtained with laser 2 were in keeping with the most authoritative studies in the literature.1,3-7 The sites irradiated did not show any significant alterations. Areas of melting and cracking were only partially and rarely visible and phenomena of carbonization were not evident, confirming recent studies10,11 that validate the necessity of water to increase the efficacy of the ablative power and to reduce the structural changes caused by thermal effects.
Fig 2a  Laser 1: 46.4X image of enamel surface irradiated with 350 mJ/pulse, 3 pps. Sample D: uneven margins of single spot.

Fig 2b  Laser 1: 101X image of enamel surface irradiated with 350 mJ/pulse, 3 pps. Sample A: Crater with an irregular rough surface, flakes and areas of vitrification.

Fig 2c  Laser 1: 1620X image of enamel surface irradiated with 350 mJ/pulse, 3 pps. Sample D: etched-like aspect of the enamel prismatic structure with a flatter surface and evidence of cracks.

Fig 2d  Laser 1: 6500X image of enamel surface irradiated with 350 mJ/pulse, 3 pps. Sample D: etched-like aspect of the enamel surface with reduction of the high points of the enamel prismatic structure.
Fig 3a Laser 2: 101X image of enamel surface irradiated with 80 mJ/pulse, 10 pps. Sample A: crater with better defined margins.

Fig 3b Laser 2: 101X image of enamel surface irradiated with 80 mJ/pulse, 10 pps. Sample D: crater effect with rough, scaly surface; no flaking or melting.

Fig 3c Laser 2: 1620X image of enamel surface irradiated with 80 mJ/pulse, 10 pps. Sample E: etched-like aspect of the enamel prismatic structure, rarely, cracks are visible.

Fig 3d Laser 2: 1620X image of enamel surface irradiated with 80 mJ/pulse, 10 pps. Sample A: etched-like aspect of the enamel prismatic structure, no melting.

Fig 3e Laser 2: 6500X image of enamel surface irradiated with 80 mJ/pulse, 10 pps. Sample E: etched-like aspect of the enamel prismatic structure. No melting, no cracks.
Fig 4a  Laser 1: 101X image of enamel surface irradiated with 350 mJ/pulse, 10 pps. Sample A: uneven margins of single spot; irregular flakes, debris.

Fig 4b  Laser 1:101X image of enamel surface irradiated with 350 mJ/pulse, 10 pps. Sample E: areas of melting visible.

Fig 4c  Laser 1: 406X image of enamel surface irradiated with 350 mJ/pulse, 10 pps. Sample D: scaly, rough surface with typical shelves.

Fig 4d  Laser 1: 1620X image of enamel surface irradiated with 350 mJ/pulse, 10 pps. Sample D, A: irregular surfaces, vast areas of vitrification, presence of cracks, with the disappearance of the prismatic pattern, probably destroyed by thermal effects.
The SEM allowed closer examination of individual sites, thus freezing the effects of the energy of a single pulse. Through such examination the following observations were made:

- more defined ablation margins were obtained with laser 2 in contact mode.
- the qualitative and quantitative morphological differences on the surfaces irradiated by the two instruments were probably the result of thermal and photoacoustic effects, more evident with laser 1, using energy levels of 350 mJ/pulse.
- the greater crater depth, the nonhomogeneity of the surfaces with flakes and debris, areas of melting and cracks, the less defined limits of the single spots observed in the samples treated with laser 1 (350 mJ/pulse, 0.5 to 0.7 mm spot size, 10 to 12 mm focus) has prompted a critical revision of the parameters used, in accordance with recent literature.

Evaluation of various studies\(^2\text{-}^4,^6,^12,^13\) has indicated the validity of reducing the energy per pulse to obtain a more precise irradiation on the enamel, confirming that unwanted morphological effects on some samples observed with the SEM in this study are consistent with the use of parameters that are too high (> 350 mJ). Fluence values can be determined as a combination of pulsed energy (mJ) and spot size (focus).

The morphological quality of etched surfaces seemed to be more favorable with laser number 2, with applied power approximately 2.6 times less and with applied fluence approximately 3.2 times less than laser 1.

Furthermore, the higher frequency (Hz) used with laser 2 allows a working power twice as high as that of laser 1, but with an applied fluence 1.95 times less for cutting (laser 1: 3.5 W, fluence 178.4 J/cm\(^2\); laser 2: 6.25 W, fluence 88.46 J/cm\(^2\)) (Tables 3 and 4).

**CONCLUSION**

SEM analysis of the effects of the Er:YAG (2940 nm) laser on hard dental tissue confirm the possibility of performing ablation within defined limits and forming microcavities with finely etched and rough surfaces that are well prepared for treatment with adhesive restorative methods.

Energy parameters that were excessive did not produce uniform results on all the samples because of the presence of induced alterations (microcracks, melting, flakes, debris) resulting from the thermal effect. This validates the need to use lower pulse energy levels, coupled with higher repetition rates, to obtain efficient tissue ablation without unwanted collateral effects.
ACKNOWLEDGMENTS

We would like to thank both Prof. R. Graudini and Dr. M. Maggioni (University of Florence, Italy) for their support in producing the SAM images.

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