Experimental Studies of the Applications of the Holmium Laser in Dentistry

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ABSTRACT

The purpose of this study is to evaluate the possibility of using a pulsed Ho:YLF laser for endodontic surgery access, preparation of cavities, etching of dental enamel, and treatment of dental caries. Specimens were irradiated with a prototype of pulsed Ho:YLF laser (2,065 μm). Laser energies in the range of 120–750 mJ per pulse were used. The study of morphological changes on enamel and dentine was conducted on light and scanning electron microscopes. Perforation of approximately 4 mm depth with homogeneous and smooth aspect of its wall surfaces was obtained. There was no carbonization. Irradiation with low energy results in melted and recrystalized surface with small and shallow pits. In accordance with our results the Ho:YLF laser produces surfaces that are white in appearance in contrast to the Nd:YAG modified enamel and dentine surfaces, that were darkened. These are indications that the holmium laser may be useful for dentistry in the future.

INTRODUCTION

Since 1964 when Stern and Sognnaes reported the first application of lasers in dentistry,[1] various lasers have been studied and applied for both soft and hard tissue applications.[2] Lasers used for soft tissue surgery became an effective treatment option, reducing bleeding and patient pain during and after the laser surgery.[3–5]

To exert an effect upon biological tissue, the laser light has to be absorbed. If the light is scattered it will be absorbed by a larger volume of tissue and its effects will be more diffuse. If it is reflected from the tissue or transmitted through it, no effect will occur. Absorption of the light depends on the specific properties of each tissue, its chromophores, and its percentage of water. The effects produced by the light absorption is related to the laser's characteristics such as energy density, pulse duration, and the interaction time of the light in the tissue. These effects can be photomechanical, photochemical, and thermal, and a result of biostimulation.

Figure 1 shows the water absorption spectrum. The weak absorption of water at the 1.06-μm neodymium line allows the laser light to penetrate deeper in the biological tissue, causing damage of 1 mm or more. This can be useful for cauterizing highly vascularized tissue, but requires extra healing time.[6] The stronger absorption of water at 2 μm light produces superficially damaged zones (only the outer layers of tissue are affected) making the holmium laser an excellent choice for precision surgeries on cartilage and similar hard tissue. Although water absorbs much more light at 3 and 10 μm, silica fibers cannot carry those wavelengths. The 2-μm laser light does not harm the eye and can be delivered by commercial silica fibers.

For these reasons the rare earth solid state holmium laser emission of wavelengths around 2 μm can be useful for treating dental hard tissue. Holmium ion can dope different hosts, like YAG, YLF, and YSGG. Ho:YLF laser emitting $\lambda = 2{,}065$ μm is nearer to the water absorption peak than the Ho:YAG laser at 2.1 μm.

Several laser systems have been investigated for hard tissue applications, including the Nd:YAG ($\lambda = 1.06$ μm), CO_2 ($\lambda = 10.6$ μm), Ho:YAG ($\lambda = 2.1$ μm), Er:YAG ($\lambda = 2.94$ μm), and Er:YSGG ($\lambda = 2.078$ μm).[7–10]

According to White et al.[11,12] the energy threshold for modifications of dentine surface is 67 mJ when using a Ho:YAG laser with a pulsewidth of 150 μsec. This study concluded that

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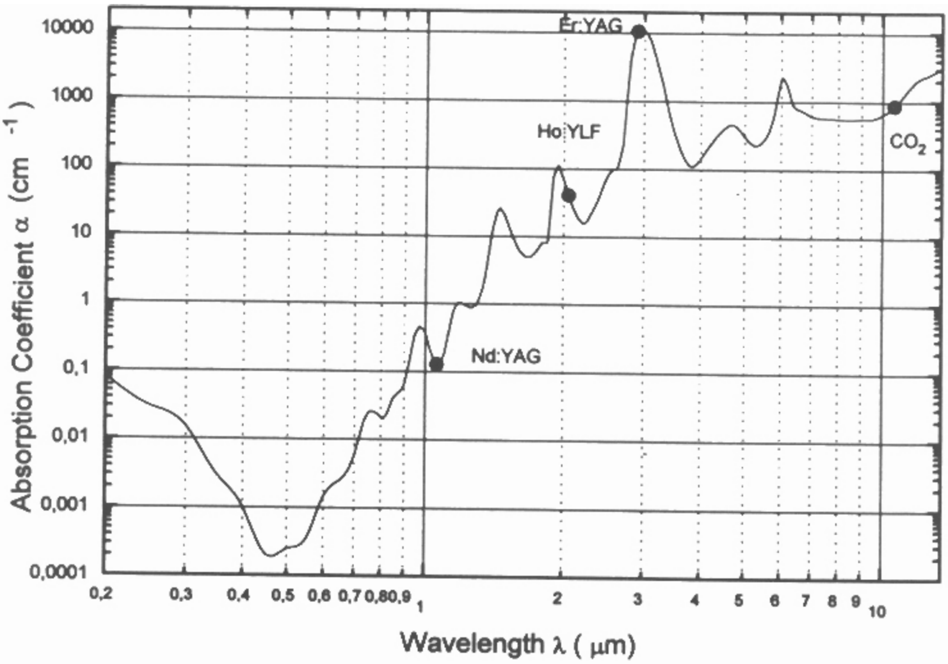

FIG. 1. Absorption spectrum of water.

the laser shows promise for surface modification of dentine. Goodis *et al.*[13] concluded that Nd:YAG and Ho:YAG lasers are helpful in removing smear layer and may aid in reducing microorganisms in root canal spaces. According to a study by Lippas *et al.*[14] teeth irradiated by Ho:YAG laser resulted in cavitated and roughened enamel surfaces with minimal charring.

The purpose of this *in vitro* study was to evaluate the possibility of using a pulsed Ho:YLF laser for preparation of cavities, removal of debris from pits and fissures and etching of dental enamel.

MATERIALS AND METHODS

A prototype of a flashlamp pumped erbium:thulium:holmium:LiYF$_4$ (Er:Tm:Ho:LiYF$_4$) (Ho:YLF) laser was developed for biomedical applications at the Division of Optoelectronic Materials, Energy and Nuclear Research Institute (IPEN). This laser emits single pulses with a pulsewidth of 300 μsec (FWHM) at $\lambda = 2{,}065$ μm. To obtain the beam profile with a gaussian distribution an iris was placed inside the resonator, in front of the back mirror. The energy was measured by a Scientech Energy and Power Meter model 373. Laser energies in the range of 120–750 mJ per pulse were used. The laser beam was delivered perpendicularly on to the teeth through an optical glass biconvex lense at focal distances of 40, 100, or 200 mm.

Four extracted human teeth (dried) and three freshly extracted teeth were used in this study. After extraction the latter were kept in a saline solution. All teeth were cleaned in an acetone solution with ultrasound before laser irradiation and investigated on a light microscope, Zeiss model POH II (40×), before and after irradiation. The lesions' diameters were determined by micrometry.

To investigate the possibility of using a holmium laser to prepare cavities, specimens 1 and 2 (fresh) were irradiated with 750 mJ/pulse and 30 pulses in each position, through a lens of $f = 40$ mm.

To understand the effectiveness of the laser for enamel etching, the teeth were irradiated in a large area of the vestibular face. Specimen 3 (fresh) was irradiated with 400 mJ/pulse, 1 pulse per position, through a lens of $f = 40$ mm; specimen 4 (fresh) was irradiated with 500 mJ/pulse, 1 pulse per position, through a lens of $f = 20$ mm; and specimen 5 was irradiated with 600 mJ/pulse, 2 pulses per position, through a lens of $f = 40$ mm.

To investigate the possibility of cleaning pits and fissures, specimen 6 was irradiated with 600 mJ/pulse, 2 pulses per position, through a lens of $f = 40$ mm, and specimen 7 was irradiated with 120 mJ/pulse, 2 pulses per position, through a lens of $f = 100$ mm.

Table 1 summarizes the Ho:YLF irradiation.

Samples were dehydrated in alcohol solutions of increasing concentrations (70–100%), dried by the Hitachi Critical Point Dryer HCP2, and sputtered with platinum. They were analyzed and photographed using a scanning electron microscope (Jeol-JSM T220A).

RESULTS

Observation of the irradiated occlusal surface of specimens 1 and 2 with 2400 J/cm^2/pulse, 30 pulses per position, was performed using a light microscope. A white and round shaped cavity border was formed (Fig. 2). There was no carbonization. To reveal the cavity in the dentine the specimen was cut longitudinally. Figure 3A shows the homogeneous and smooth aspect of the perforation wall surfaces of approximately 4 mm

TABLE 1. IRRADIATION CONDITIONS OF HO:YLF LASER IN TEETH

Specimen	*Energy per pulse (mJ)*	*Pulses per position*	*Focal length (mm)*	*Energy density (J/cm²/pulse)*
1	750	30	40	2400
2 (fresh)	750	30	40	2400
3 (fresh)	400	1	100	1800
4 (fresh)	500	1	200	2800
5	600	20	40	850
6	600	2	40	1900
7	120	2	100	1500

depth, with no carbonization. The irradiated crown of this molar tooth was horizontally cut at the distance of 4 mm from the occlusal surface. The cut surface was than analyzed using a light microscope. Figure 3B shows the results obtained in a transversal section; round holes of smooth shape can be seen in the carious and sound dentine. There were no carbonized areas around the hole and no crack zones, which is an important and interesting observation.

On the same specimen (3), several cavities were prepared on the enamel surface with holmium irradiation (Fig. 4). The surfaces were observed using a scanning electron microscope (SEM). As a result, the specimens lased under low energy irradiation (1800 J/cm²/pulse) show pits which look like a lion's mane, in which the central portion was melted and recrystallized. In some points, in which melted and recrystallized zones were not found, exposed enamel rods and prisms can be seen (Fig. 4B).

In specimen 4, which was irradiated using a higher energy density (2800 J/cm²/pulse), cavities of about 150 μm in diameter were observed (Fig. 5). The cavity border does not reveal a sharp and evaporated surface. Some of these cavities are filled with melted enamel substance in the center, which was caused by laser instability—the space energy distribution was not uniform (see d in Fig. 5A). In the magnified Figure 5B, the evaporated enamel surface can be observed and numerous pits on the irradiated enamel surface can be seen. But in some points, on the cavity wall, the irregular and rough upheaval belts were observed.

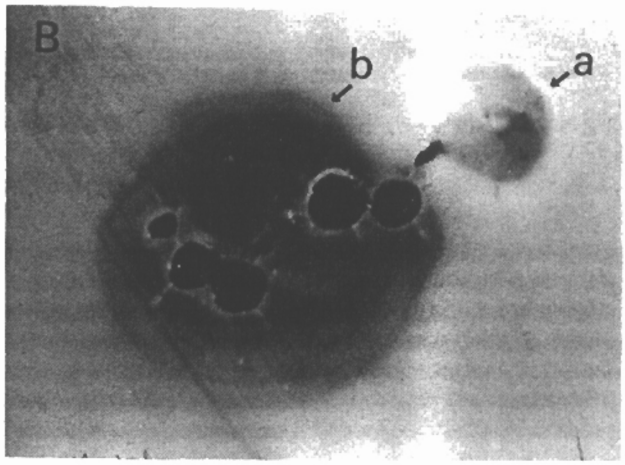

FIG. 3. (A) A longitudinally splitted molar showing the depth of perforations. Notice the light aspect of the perforation walls with no carbonization (2, 2400 J/cm²/pulse, 30 pulses/position, 60×). (B) Transverse cut of a molar at 3 mm distance from the occlusal surface. Notice the difference between the effect of irradiation on healthy (a) and carious (b) tissue.

FIG. 2. Perforations on the occlusal face of a freshly extracted molar irradiated by Ho:YLF (1, 2800 J/cm²/pulse, 30 pulses/position, 20×).

In some points of specimen 4, deep cavities of smooth and melted surfaces with numerous pits were visible instead of irregular and rough upheaval belts. Thus, in these cavities a smooth wall was obtained (Fig. 5C). In the highly magnified Figure 5D, a melted and recrystallized surface with small and shallow pits can be observed.

Specimen 5, irradiated with 850 J/cm²/pulse, 20 pulses/position, shows a deep hole (Fig. 6). Its cavity border of the lased enamel presented the same characteristics as the acid-etched enamel. However at higher magnification a considerable difference between the acid-etched and lased etched enamel structure (Fig. 6B) is apparent.

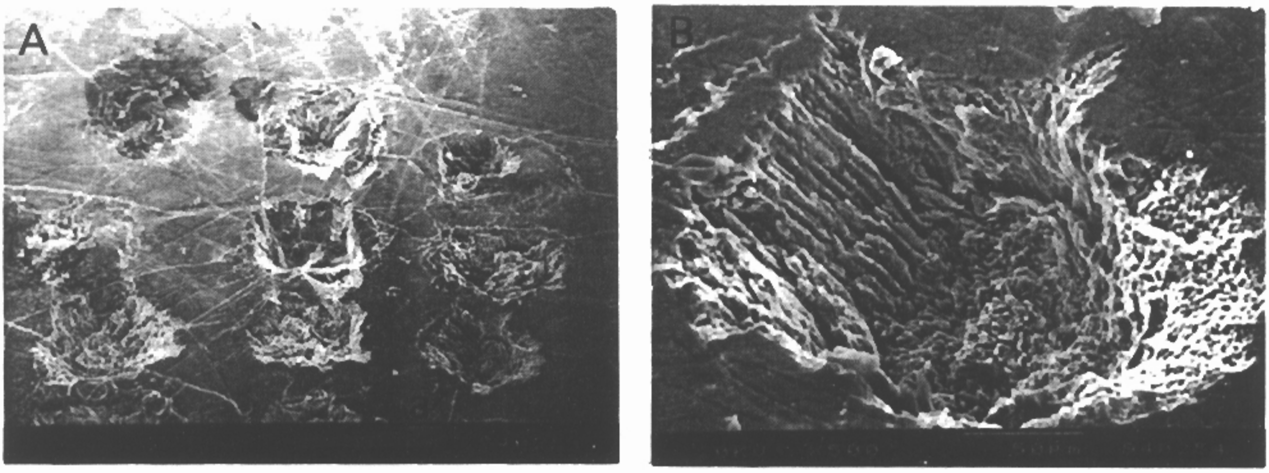

FIG. 4. (A) Vestibular surface of a freshly extracted molar (4, 1800 J/cm²/pulse). (B) Highly magnified cavity (a) in (A). Notice the resemblance to a lion's mane.

When there is a difference of enamel thickness in the buccal and occlusal surfaces, different results are obtained using the same parameters. Furthermore, there is a difference between irradiation of freshly extracted and dried teeth (mainly because of their different hydration, Figs. 6 and 7).

Dried tooth 6 was irradiated in the pits and fissures areas with 1900 J/cm²/pulse, 2 pulses in each position. Following irradiation deep cavities were formed. Figure 7 shows cavities' borders with melted and recrystallized banks. Although the cavities are very deep there are some melted substances inside them. In the highly magnified figure a smooth cavity wall with some melted particles can be observed (Fig. 7B). In 7, which was irradiated with 1500 J/cm²/pulse, 2 pulses in each position, a very smooth surface with a melted enamel substance like cementum

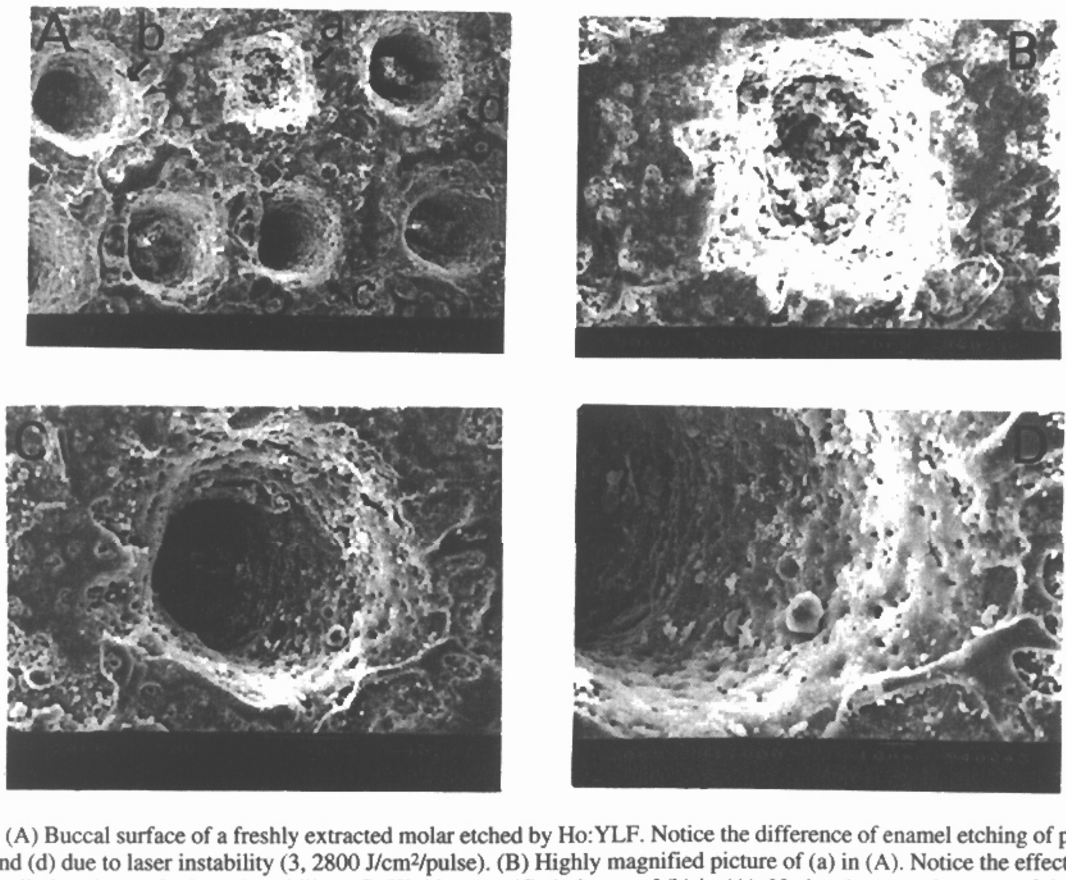

FIG. 5. (A) Buccal surface of a freshly extracted molar etched by Ho:YLF. Notice the difference of enamel etching of points (a), (b), (c), and (d) due to laser instability (3, 2800 J/cm²/pulse). (B) Highly magnified picture of (a) in (A). Notice the effect of lower energy irradiation due to the laser instability. (C) Highly magnified picture of (b) in (A). Notice the smooth aspect of the surface. (D) Highly magnified picture of (c).

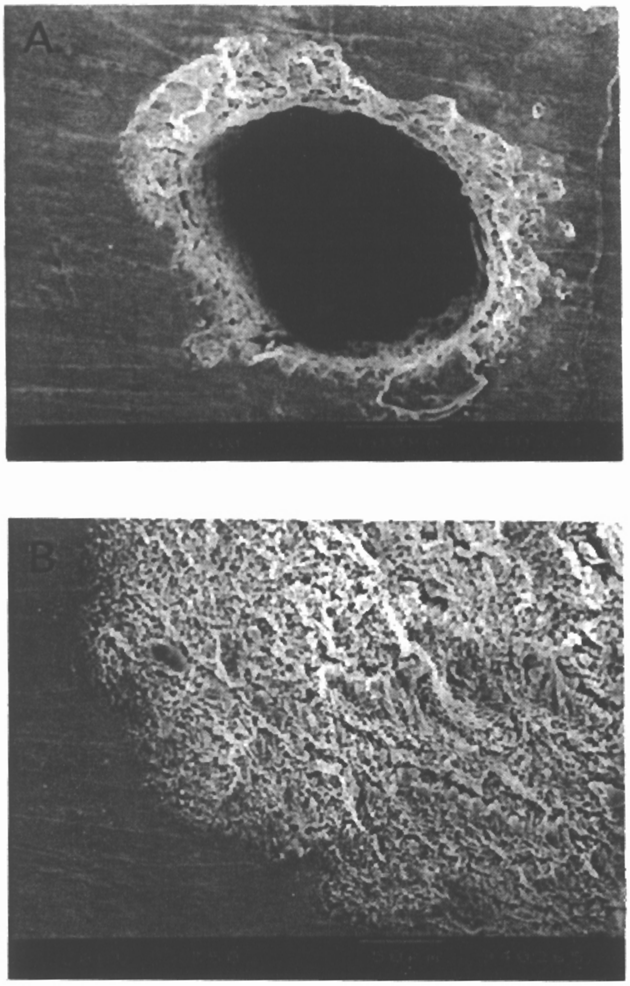

FIG. 6. (A) Vestibular surface of a incisor tooth. Notice the cavity border with similar characteristics as the acid-etched enamel (5, 850 J/cm²/pulse, 20 pulses). (B) Highly magnified picture of (A). The exposed dentinary tubules characteristics of acid-etched enamel are not seen in the laser-etched enamel.

can be seen (Fig. 8). Irradiating pits and fissures show the efficiency of the holmium laser.

DISCUSSION

The study of morphological changes after Ho:YLF laser irradiation on enamel surface was reported by Matsumoto *et al.*,[15] Goodis *et al.*,[13] Lippas *et al.*,[14] and White *et al.*[16]

Ertl and Müller[17] found that only lasers emitting in spectral areas with a high absorption coefficient of dental hard tissue (excimer, erbium, and TEA CO_2) with pulsewidth of 100–350 μsec have good ablation efficiency and can be used for cavity preparation.

Despite most authors' conclusions, Frentzen and Koort[18] found that the ablation of mineralized tissues using Ho:YAG, Tm:YAG, and Er:YAG lasers was not very efficient.

Under the condition of 78 J/cm²/sec (with spot size of 0.8 mm) Matsumoto *et al.*[15] carried out experiments with Ho:YAG and reported results in accordance with those presented in this work. However, they did not report morphological changes under low energy irradiation. The present work reveals the results of low energy irradiation to be pits that resemble a lion's mane (Fig. 4B). According to these results, bonding effects between enamel and composite (Fig. 5A) may become more effective. Furthermore, White *et al.*[16] reported that using laser irradiation of 67 mJ/pulse, with energy density of 83 J/cm² and 100 μsec, rough and irregular irradiated enamel surface with lots of small pits can be observed. In the present experiment the same results can be obtained with 100 mJ/pulse on dried enamel surface.

After laser irradiation, a morphological modification of dentine surface was observed, which may be a result of denaturation of the collagen matrix followed by chemical changes in the inorganic matrix of dentine.[16]

Finally, Ho:YLF laser produces surfaces that are white in appearance in contrast to the Nd:YAG modified dentine surfaces that are darkened. This may indicate an improvement in the combustion of collagen without carbonization by the holmium laser.

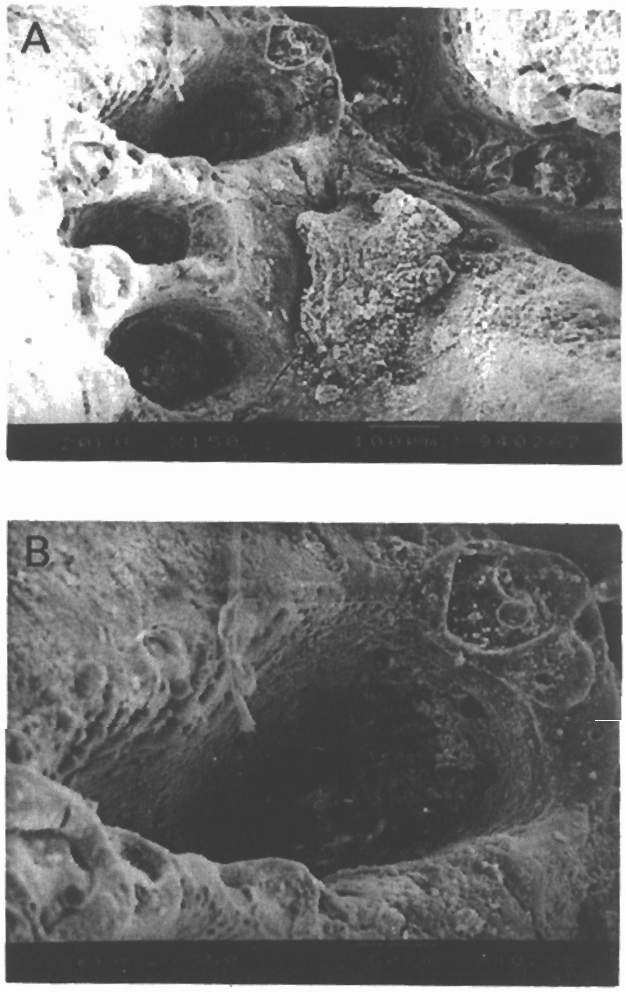

FIG. 7. (A) Pits and fissures areas irradiated with 1900 J/cm²/pulse, 2 pulses/position. Deep cavities were formed (6). (B) Highly magnified picture of (a) in (A). Notice melted substances inside the cavity.

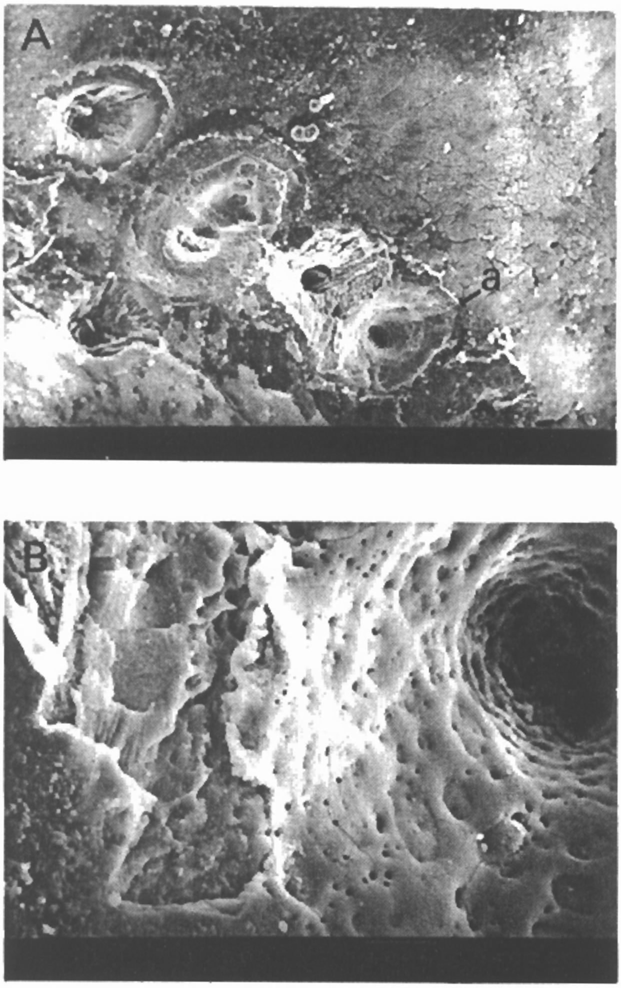

FIG. 8. (A) Pits and fissures area irradiated with low energy (7, 1500 J/cm²/pulse, 2 pulses/position). (B) Highly magnified picture of (a) in (A), showing smooth and melted enamel surface with small pits distributed like dentinal canals.

CONCLUSION

Using 4 dried and 3 fresh human extracted teeth the morphological research under Ho:YLF irradiation was conducted using a light microscope and a scanning electron microscope. Depending on the laser energy density, the laser enamel surface revealed slightly different morphological aspects. When the teeth are irradiated with relatively high energy densities (2800 J/cm²/pulse), the surfaces show a deep hole and the cavity wall is melted and recrystallized. In some cases, melted substances attached to the perforation wall can be seen. These melted substances may seal or close open tubules, that can reduce sensitivity and pain as well as increasing resistance to caries. On the other hand, under low energy density irradiation (1800 J/cm²/pulse) the results were very interesting, and shallow cavities that resemble a lion's mane can be observed. These results are obviously very different from those of CO_2 and Nd:YAG lasers.

As a result of our experiments, we conclude that irradiating pits and fissures by holmium laser can be useful for prevention. It causes the vaporization of organic substances and enamel etching and may promote better sealant bonding. Perforations of approximately 4 mm depth with homogeneous and smooth aspects of its wall surfaces presenting no carbonization were obtained with the holmium laser. These results suggest that the holmium laser may be useful for endodontic access and cavity preparation.

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