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Effects of XeCl Excimer lasers and fluoride application on artificial caries-like lesions

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ABSTRACT

Previous studies have demonstrated modifications in tooth structure after laser irradiation. In this study the effects of a pulsed excimer laser emitting at 308 nm (XeCl) on enamel susceptibility to artificial caries-like lesions were investigated. Additional effects of fluoride (F) application were also studied and SEM examinations performed. Sixty-four extracted human molar teeth were coated with acid resistant varnish leaving 4 windows, then sectioned, leaving one window on each tooth quarter. The windows were treated in one of the following ways: untreated (control), or lased, or exposed to 4 min. APF(1.23% F) before lasing, or exposed to 4 min. APF (1.23% F) after lasing. Laser parameters were: frequency: 1, 25 Hz; pulse duration: 15 ns; fluence: 1, 5, 10, 30, 70, J/cm^2; spot size: 5.0 mm2. After lasing, microhardness profiles were obtained and SEM was performed. Caries resistance was generally increased at moderate fluences. F application combined with lasing enhanced caries resistance at some parameters. SEM showed effects ranging from minimal to localized effects to extended glazing. Pulsed excimer laser irradiation, especially combined with topical F application can inhibit development of artificial caries-like lesions.

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1. INTRODUCTION

Traditional caries-preventive measures provide a protective effect of approximately 50%, the specific figures depending on the exact techniques and evaluation methods utilized. Methods available to us include dietary measures, improved oral hygiene, systemic and topical applications of various fluorides and a wide range of varnishes and sealers. Disadvantages of these traditional methods include a need for continual patient motivation with regard to dietary and oral hygiene measures, and apprehensions about possible side effects of fluoride, especially when delivered systemically. A further disadvantage of fluoride applications is the finding that not all surfaces of the tooth are afforded equal protection by the application of fluoride. Topical fluorides require frequent reapplication. In children, the sealing of susceptible pits and fissures is often recommended; this technique has demonstrated a fair degree of success. However, loss of retention, leakage and decay beneath the sealer are all recognised as possible disadvantages of this technique.

Lasers were introduced to dental research over twenty five years ago and their use has been investigated in many areas of application including, for example, surgical laser treatment of oral malignancies and periodontal disease, dental caries detection and treatment, laser endodontics and optical storage of radiological material (1). In the field of caries prevention, several researchers have approached the issue of decay resistance using lasers. Thus in the early days Stern and Sognnaes (2) demonstrated that a glass-like fusion occurred in intact enamel when exposed to millisecond pulses from ruby lasers. Lobene et al (3) reported that CO2 laser irradiation of enamel caused a small amount of hydroxyapatite to be converted to a more insoluble calcium orthophosphate apatite. Yamamoto and Ooya (4) observed that enamel exposed to Nd:YAG lasers was more resistant to in vitro demineralization than non-irradiated enamel. Nelson et al (5) and Fox et al (6) reported similar effects using the CO2 laser. One of the disadvantages of using light in the IR range for caries prevention lies with the thermal effects accompanying this process: as a result, pulpal damage or structural defects in the form of cracks or fissures may result.

Excimer lasers constitute a class of electronically excited molecular gas lasers that emit high intensity, short duration pulses of ultraviolet light. They define a different regime of laser-tissue interaction because these UV photons are sufficiently high-energy to result in bond-breaking in organic molecules. This characteristic, in combination with the fact that excimer pulses are very short (in the order of 10-100 ns), gives rise to the observation that minimal thermal effects result from excimer laser irradiation (7). An additional benefit arises from the fact that organic tissue is a strong absorber of UV irradiation, assisting in control of the sphere of interaction (8,9).

Several authors have investigated use of excimer lasers for ablation of enamel (10-14). However, little is known about the susceptibility to caries of enamel after exposure to excimer laser irradiation.

The purpose of this investigation was to study the effects of pulsed XeCl laser irradiation (308 nm) and adjunct fluoride treatment on enamel susceptibility to artificial caries-like lesions using a fluence of 0.7 J/cm2, energy density values of 1,5,10,30,70 J/cm2 and frequencies of 1 and 25 Hz.

2. MATERIAL AND METHODS

Sixty four extracted human molar teeth with no obvious pathologies were coated with acid-resistant varnish leaving 4 windows, then sectioned vertically into quarters, leaving one window on each quarter. The quarters were treated as follows: untreated (control), or irradiated, or exposed to 4 min APF (1.23%F) before irradiation, or irradiated, then exposed to 4 min Acidulated Phosphate Fluoride (APF) (1.23%F). Laser parameters used were: frequency 1 or 25 Hz; pulse duration 15 ns; fluence 0.7 J/cm2; energy density 1,5,10,30,70 J/cm2; spot size 5.0 mm2. After treatment, the quarters were sectioned vertically through the center of the lesion, embedded in resin and polished. From one half microhardness profiles (at 25 - 200 micrometers depth) were obtained. Then both halves were subjected to a demineralizing process using pH 5.0, 0.04 mol/l lactic acid, 0.01 mmol/l MHDP for 14 days (as described by Nelson et al) (5). Microhardness profiles were obtained again from the same half. The other half of each specimen was then prepared for SEM by dehydration in a graded series of aqueous ethanol for 10 minutes at each concentration. These samples were mounted on stubs using colloidal silver liquid (Ted Pella, CA) and gold coated on a PAC-1 Pelco advanced coater 9500 (Ted Pella, CA). Micrographs of the enamel surface were taken on a Philips 515 SEM (Mohawk, N.J.).

3. RESULTS

In the SEM, a typical pattern of honeycomb-like destruction was visible in untreated enamel after demineralization.

Samples which had been irradiated prior to the induction of artificial caries-like lesions demonstrated some surface dissolution and destruction. The smallest amount of destruction was seen in the samples irradiated at 5-30 J/cm2. An appearance of localised pin-point-like damage was prevalent in contrast to the overall network of destruction seen in the untreated samples. After irradiation at higher energy densities, the enamel surface demonstrated a roughened, scaly appearance. At energy densities of 70 J/cm2, some samples also demonstrated a superficial network of interconnecting microcracks. At this energy density a few seemingly displaced enamel fragments or break-outs were visible on the enamel surface at high magnification; a few localized crater-like structures were also apparent.

Samples pretreated with APF before irradiation at energy densities below 30 J/cm2 showed some fairly small areas of surface breakdown, usually in the form of small pockets of destruction interconnected with superficial channels of dissolution. However, the flaking and breaking out of surface segments observed in the "irradiated only" samples was minimal in these specimens. Considerable sections of the treated surface seemed undamaged by the demineralization process, appearing smooth and intact even at high magnifications (x10000). Samples irradiated at 70J/cm2 demonstrated extensive, fine networks of superficial microcracks.

Enamel subjected to irradiation at energy densities between 5-30J/cm2 followed by fluoride application and demineralization appeared to a large extent smooth and undamaged in the SEM. Adjacent to intact zones, occasional very superficial lines of flaking were evident; at higher energy densities these became more pronounced and were infrequently associated with individual enamel break-out fragments. However, these fragments were smaller and far less frequent in their occurrence than was the case in the "irradiated only" samples.

After demineralization, untreated samples demonstrated a loss in surface hardness of 35-50%, with Knoop values rising towards the original enamel hardness at a depth of approx. 150 micrometers (Figs. 1-3).

The samples treated with irradiation only at moderate energy densities showed a decrease in surface hardness of approx. 20-45% after demineralization. At energy densities outside this range, a greater degree of softening was measured. At very high energy densities, tooth hardness appeared reduced as compared to lower exposure levels (Figs. 1-3).

In the teeth treated with APF prior to irradiation, microhardness events resembled those observed in the "irradiated only" group (Figs. 1-3).

The samples subjected to irradiation followed by APF demonstrated surface softening of 20-30% at energy densities of approximately 10 J/cm2. However, instead of the trough in hardness demonstrated by the other samples at depths of 25-75 micrometers, these specimens displayed a fairly direct, gradual return to full hardness at a depth of approximately 150 micrometers (Figs. 1-3).

Surfaces of samples irradiated at 1 Hz appeared rougher than those exposed at 25 Hz, all other parameters being equal.

In general, results in the "lased only" and the "APF + lase" group did not differ consistently and significantly (p >.05) from those

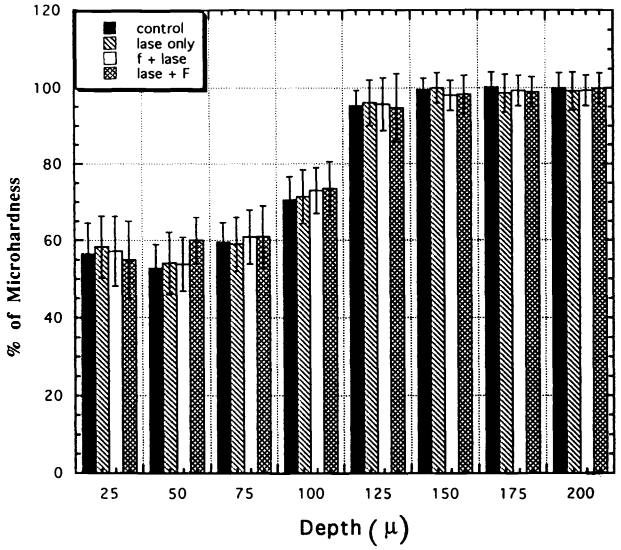

Fig. 1: Microhardness of enamel expressed as percentage of original microhardness in samples irradiated at an energy density of 1 J/cm2.

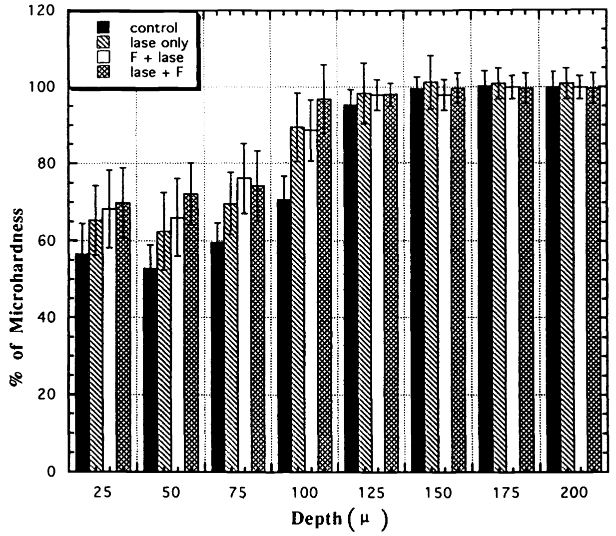

Fig. 2: Microhardness of enamel expressed as percentage of original microhardness in samples irradiated at an energy density of 10 J/cm2.

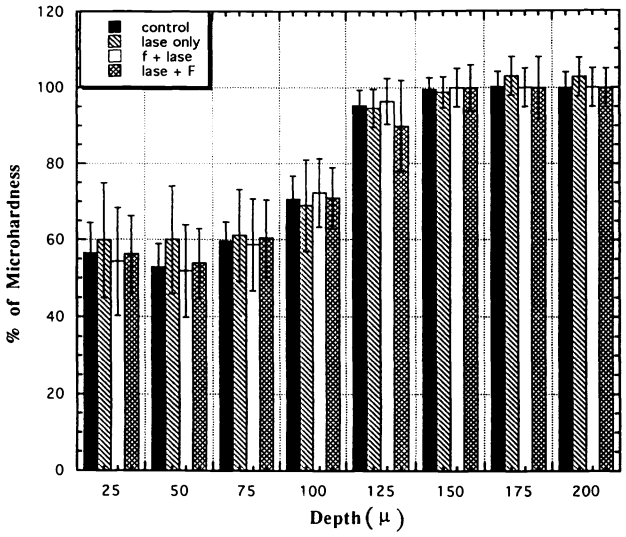

Fig. 3: Microhardness of enamel expressed as percentage of original microhardness in samples irradiated at an energy density of 30 J/cm2.

of the control group except at an energy density of 10 J/cm2 over the outermost 100 micrometers of the tooth specimen. Microhardness levels of samples which were lased at energy densities of approximately 10 J/cm2, then treated with APF remained significantly higher (p <.05) than in control samples over the outermost 100 micrometers of the tooth surface.

4. DISCUSSION

These preliminary results appear to indicate that exposure of enamel to laser irradiation at 308 nm at the parameters described does not increase enamel susceptibility to acid attack. Moreover, a protective effect against artificially induced caries-like decay , especially in conjunction with topical APF treatment, was observed at energy densities of approximately 10 J/cm2. Although microhardness measurements appear similar for the "lase + APF" and the "APF + lase" groups, SEM investigations demonstrate the maintenance after demineralization of a superior, more intact enamel structure when the sequence "lase + APF" is used. Morioka et al (15) reported similar results using the Nd:YAG laser, obtaining a better protective effect when irradiation was followed by fluoride application, than when the sequence was reversed. The reasons for this observation currently remain unclear; one explanation might be that the treated surface may permit less ion movement during demineralisation (16). Another consideration involves laser-induced compositional changes of enamel, which may inhibit dissolution (16). For example, it could be argued that the excimer laser may, by its action of selectively breaking organic bonds, preferentially be removing more acid-vulnerable components from the enamel structure, permitting their replacement by less susceptible constituents through subsequent fluoride application.

SEM observations reported in this study are in agreement with reports by other authors on the ultrastructural effects of XeCl laser irradiation on tooth enamel at sub-ablation threshold levels of exposure (17,18), where with increasing energy densities localized areas of break-out fragments and small fracture lines become visible. However, Liesenhoff et al (17,18) also reported areas of melting at fluences of approx. 1J/cm2. This phenomenon was not apparent in our study, perhaps due to the fact that we used lower fluences in our investigations.

The observation made in this study that sample surfaces appeared less rough after irradiation at 25 Hz than at 1 Hz is in accordance with reports by Neev et at al. (10, 12, 13) documenting reduced roughness possibly associated with thermal effects at higher irradiation frequencies.

Combined results of microhardness measurements and SEM infer that samples treated with APF after irradiation possess enhanced acid resistance. Furthermore, artificially-induced lesions penetrated the enamel to a lesser depth in these samples than in any of the other specimen groups. However, this effect could only be observed at energy densities of approximately 10 J/cm2. At higher and lower energy densities, a reduced protective effect was observed.

Thus, these preliminary investigations indicate that irradiation of enamel at 308 nm using fluences below 1J/cm2 and energy densities of approximately 10 J/cm2, especially in conjunction with APF application after lasing, appears to increase acid-resistance of the treated area of enamel. Further research is necessary to determine the optimal procedures and parameters and to identify more closely the processes involved.

5. ACKNOWLEDGMENT

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