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Surface Topography of Enamel and Dentine from Primary Teeth Following Infra-red Nd-YAG Laser Irradiation: An In Vitro Study

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Abstract. Data on the effects of laser radiation on primary teeth are scarce. This study investigates the effects of exposing sound enamel, photo-initiated sound enamel, sound dentine and carious dentine of extracted primary teeth to a pulsed neodymium-yttrium aluminium garnet laser (Nd-YAG, wavelength 1.06 μm, pulse length 150μs). Each type of tissue was exposed to three fluences. Qualitative and quantitative assessments of the irradiated areas revealed that the most marked changes were produced in carious dentine, followed in ranking order by sound dentine, photo-initiated enamel and sound enamel. Evidence of thermal damage to the hard tissues peripheral to the fibre-optic tip, and considerable inter-sample variation were found. The experimental evidence obtained in this in vitro study does not support the clinical use of pulsed laser at 1.06 μm wavelength for cutting primary enamel and dentine.

INTRODUCTION

In dentistry, the use of lasers is growing as a result of the positive response from the patients and the increased variety of successful clinical applications. Although dental lasers are currently used in the treatment of oral soft tissues, various applications to dental hard tissues have been evaluated, such as ablation of dental hard tissues (1–4), increase of fluoride uptake by enamel (5–7), increased resistance to acid demineralization of enamel (8, 9), enamel etching (10), treatment of dentine sensitivity (11), root canal sterilization and fusion of apical plug (12, 13). Not all of them have proved to be successful.

The most common lasers which have been used in an attempt to remove hard dental tissues are CO_2 (carbon dioxide) (14, 15) and Nd-YAG (neodymium-yttrium aluminium garnet) lasers (16, 17), which operate in the far and in the near infra-red wavelength of the spectrum, respectively. More recently, Er-YAG (erbium-YAG) lasers, which operate in the mid infra-red, have been used with some success as a means of hard tissue removal (18). Both Er-YAG and CO_2 laser light are generally delivered down an articulated arm. This can be quite cumbersome.

Nd-YAG laser beams present the major advantage of being delivered through fibre-optic systems which provide much greater flexibility of access into the mouth. However, the depth of Nd-YAG laser penetration into the tissues is influenced by the optical properties of the enamel and dentine, and is less predictable than that observed with both CO_2 and Er-YAG laser radiation. Using these wavelengths, the radiation is absorbed within a short distance from the surface. Since the mode of tissue interaction with the laser beam of all infra-red lasers is photothermal, it is possible to induce thermal trauma when operating near the pulp (19). Moreover, alterations in the hard tissues surrounding the site of irradiation may be caused by the conversion of the absorbed laser energy to heat (20). Pulsing the beam will theoretically reduce the photothermal effects by allowing the surrounding tissues to cool between laser pulses. This is dependent on the thermal relaxation time of the irradiated tissue.

Nd-YAG laser radiation is not readily absorbed by dental tissues with nearly 75–85% of radiation being transmitted through dentine (21). As a means of enhancing the effects of Nd-YAG laser radiation, a photo-absorbing dye or photo-initiator may be used. Only very limited information exists on the effects of Nd-YAG radiation on the hard tissues of primary teeth (22, 23). The large majority of research studies are confined to the evaluation of the effects of lasers on permanent teeth. The observations from these investigations cannot be extrapolated to the hard tissues of primary teeth. In fact, the lower inorganic content and varying optical properties may have considerable influence on the mode of interaction of primary teeth with laser radiation.

The purpose of the present study is to determine whether pulsed Nd-YAG radiation can be used successfully to remove primary enamel and dentine.

MATERIALS AND METHODS

Sixty freshly extracted primary molars were assigned randomly to four groups of 15 samples divided by type of surface subjected to irradiation. These were:

Group A, sound enamel.
Group B, sound enamel pre-painted with India ink (Salis International, Hollywood, USA) as a photo-initiator.
Group C, sound dentine; surfaces were exposed by sectioning the teeth in a longitudinal plane mesiodistally using a band saw (Exact-Saw, Mederex, Bath, UK).
Group D, carious dentine surfaces exposed as in Group C.

After extraction, the specimens were cleaned in running tap water and stored in a 10% formal saline solution at 4 °C prior to use. Before laser treatment, each specimen was removed from the formal saline solution, blot dried to remove surface water and mounted on a motorized stage. The teeth remained damp throughout the experiment. An Nd-YAG laser (American Dental Laser, dLase 300, Sunrise Technology Inc., California, USA) was used, operating at wavelength of 1.06 μm and pulse duration 150 μs. The beam was passed down a 320 μm fibre-optic delivery system. Five samples from each group were exposed to one of the three laser variables presented in Table 1. Three different sites on each sample were exposed; each site was irradiated for 2 s. The laser handpiece was clamped and arranged so that the light beam was incident at right angles to the sample surface, and the fibre-optic tip made contact with the sample surface. The fibre-optic delivery wand was re-cleaved as necessary in order to remove accumulated debris.

Table 1. Laser variables

Pulse rate (pulses s^{-1})	Energy per pulse (mJ)	Total delivered energy (mJ) in 2 s
15	133	3990
20	180	7200
25	120	6000

Following irradiation, the specimens were allowed to air dry and then sputter coated with gold to a nominal thickness of 15 nm. They were then examined with a scanning electron microscope (Steroscan 90B, Cambridge Instruments, Barr Hill, UK) at 15 kV accelerating voltage.

A Reflex microscope (Reflex Measurements Ltd, Butleigh, Somerset, UK) was used to measure the cross-sectional area of irradiated sites.

RESULTS

The irradiation of all samples was accompanied by an explosive report. This was of greater intensity with higher fluencies and when dentine was being treated. While being irradiated, dentine produced a characteristic burning odour. Macroscopically, the treated dentine showed more marked changes than enamel.

SEM analysis

Group A: sound enamel [Fig. 1(a, b)]

Considerable intra-specimen variation was noted although specimens were subjected to the same energy levels. At the lowest delivered energy (3990 mJ), effects vary from surface roughening to microcrater formation; the latter being a more common feature. At higher energy levels (6000 and 7200 mJ), microcraters of varying depth were consistently produced.

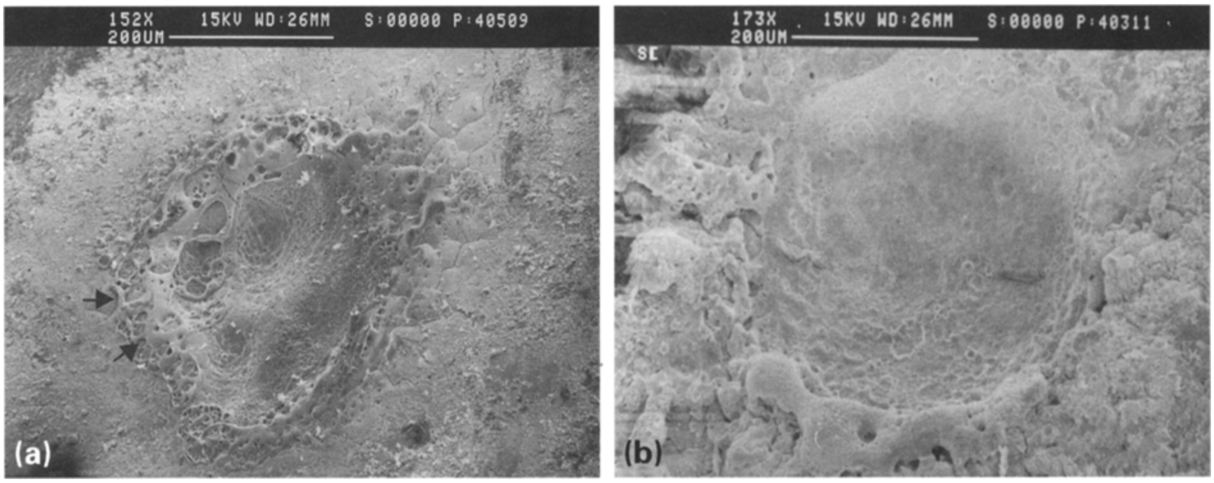

Fig. 1. (a) Scanning electron micrograph (SEM) of irradiated sound enamel showing shallow crater formation with ill-defined peripheral margins. Arrows show blisters of re-solidified material at the margin of the crater. Total delivered energy 3990 mJ; field of view 750 μm. (b) SEM of irradiated sound enamel showing deeper crater formation at the highest delivered energy. Deposits of debris in the area peripheral to the margin of the crater can also be observed. Total delivered energy 7200 mJ; field of view 667 μm.

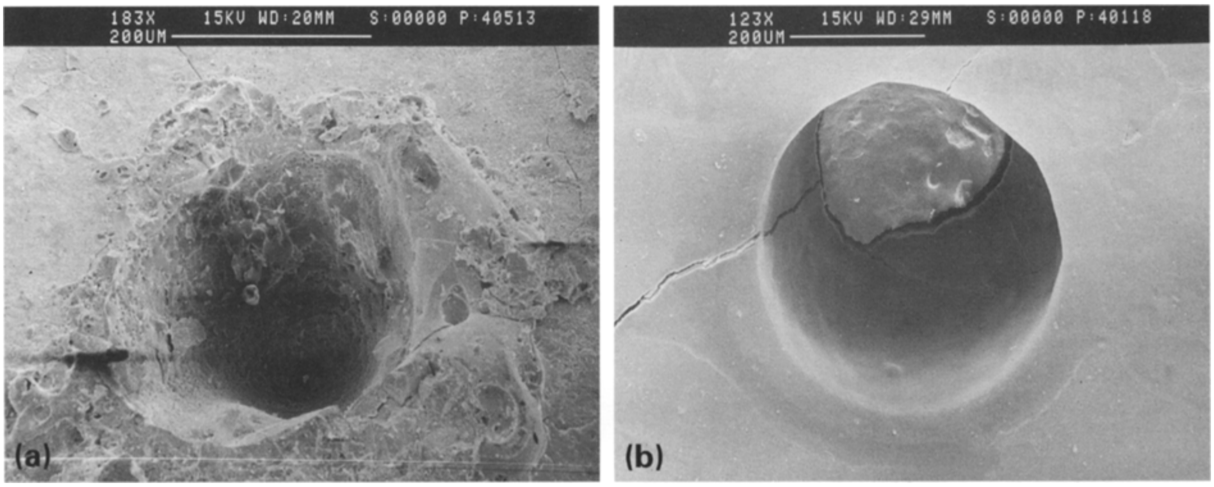

Fig. 2. (a) Scanning electron micrograph (SEM) of treated irradiated enamel showing deeper crater formation at the same delivered energy as Fig. 1(a). Total delivered energy 3990 mJ; field of view 625 μm. (b) SEM of treated irradiated enamel showing well-defined crater formation, no deposition of debris, amorphous structure of the walls and of the area surrounding the margin of the crater. Total delivered energy 7200 mJ; field of view 909 μm.

The margins of the microcraters were not well defined. Blistering was observed in all irradiated specimens. The area surrounding the irradiated sites exhibited deposition of debris.

Group B: enamel treated with photo-initiator [Fig. 2(a, b)]

In all cases, craters were formed on the surface of enamel treated with the initiator prior to exposure. The lesion appeared more defined and with sharper margins than those produced in untreated enamel. No apparent build-up or re-deposition of debris from the plume was present at the higher total delivered energies (6000 and 7200 mJ). High power magnification revealed that the floor of the crater had an amorphous surface. The enamel adjacent to the periphery of the lesions was also altered in appearance.

Group C: sound dentine [Fig. 3(a–c)]

Laser treatment of sound dentine surfaces resulted in more pronounced crater formation than on the enamel specimens at the same delivered energy levels. Raised and rolled edges to the lesion periphery were typically observed, which at higher magnification appeared to be re-solidified material. Deposits of debris from the plume were also evident at the periphery of the lesions. The lesion walls were characterized by the presence of coalesced bead-like amorphous material. The dentine tubules appeared to be partially obliterated. Some specimens irradiated with the highest total delivered energy (7200 mJ) also presented cracking of the wall of the craters [Fig. 3(b)].

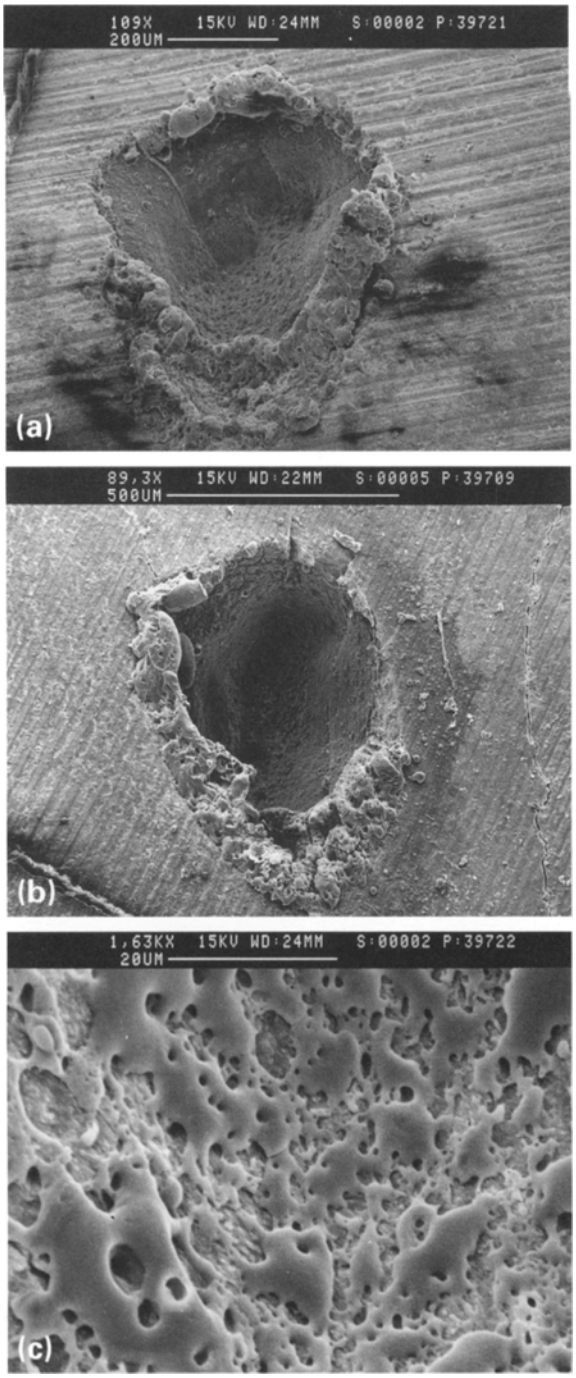

Fig. 3. (a) Scanning electron micrograph (SEM) of irradiated sound dentine showing formation of a crater with raised rolled edges. Total delivered energy 3990 mJ; field of view 1000 μm. (b) SEM of irradiated sound dentine showing a deeper crater formation at highest delivered energy. Raised rolled edges of lesion are evident. Total delivered energy 7200 mJ; field of view 1271 μm. (c) SEM of irradiated sound dentine showing the surface of the lesion floor. Dentine tubule openings appear to be partially obliterated by a coalesced amorphous material. Total delivered energy 7200 mJ; field of view 71 μm.

Group D: carious dentine [Fig. 4(a–c)]

Irradiated carious dentine exhibited the most extensive tissue change. Craters were obtained with disrupted anatomical form of the type observed in sound dentine, but without raised rolled edges. In some cases, a columnar structure was visible which appeared to be the original dentine tubule outline.

Quantitative analysis

The Reflex microscope measurements of the cross-sectional area of the irradiated sites are presented in Table 2. The average values of cross-sectional areas of the lesions increase with increasing delivered energy. Variations within, as well as between, specimens were observed.

DISCUSSION

The results from this study suggest that the absorption of Nd-YAG laser radiation was highest in carious dentine, followed by sound dentine, pre-treated sound enamel and untreated sound enamel. Generally, increasing energy densities produced progressively greater changes. This is in accord with previous work on permanent teeth (17). Often the same delivered energy produced a different degree of changes on the same type of tissue of different teeth and on different sites of the same tooth. This can be attributed to a site-to-site variability in the degree of translucency and degree of pigmentation. Enamel and dentine can vary greatly with regard to mineral content and pigmentation, and therefore are variably affected by exposure to Nd-YAG radiation. These variations in depth

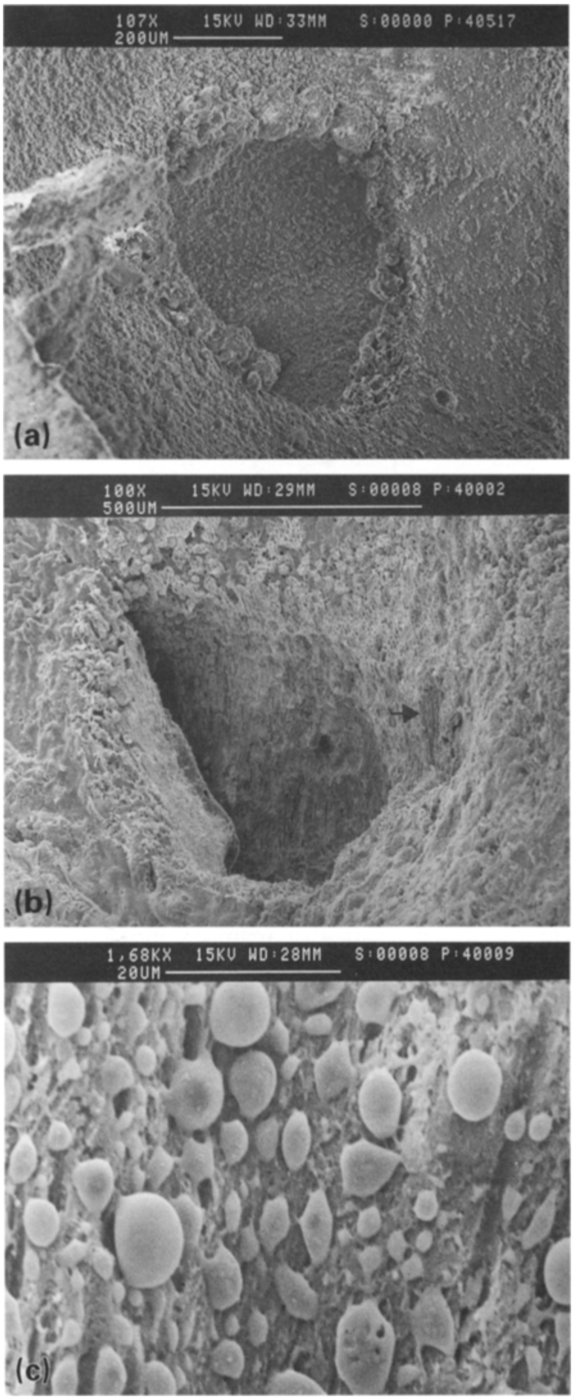

Fig. 4. (a) Scanning electron micrograph (SEM) of irradiated carious dentine showing crater formation. Total delivered energy 3990 mJ; field of view 1071 μm. (b) SEM of irradiated carious dentine a deeper crater formation at highest delivered energy. A columnar structure is visible (arrow) at the periphery of the lesion which appears to be the original dentine tubules. Total delivered energy 7200 mJ; field of view 1119 μm. (c) SEM of irradiated carious dentine. Higher magnification of (b). Bead-like amorphous material on the lesion walls can be observed. Total delivered energy 7200 mJ; field of view 71 μm.

and appearance of the lesions produced on dentine with Nd-YAG radiation at specific energy levels have been observed in previous studies (12, 17, 24).

Other factors that might have had an influence are the variations in beam profile and in actual energy that is being delivered. The collection of irradiation debris on the fibre-optic tip and the consequent need to cleave the tip between exposures could also influence the quality of contact with the tooth surface.

An example of the poor reproducibility of the cutting effects is the remarkably clean cut observed in Fig. 2(b), not found in any other example shown.

Untreated enamel is more translucent and less pigmented than other groups of tissues exposed in this study. A lower degree of energy absorption resulted in the formation of smaller craters, with cross-sectional areas closely approaching that of the laser beam delivery fibre. However, in some cases, a sufficient rise in temperature had occurred to produce blistering of the enamel, probably due to a combination of vaporization of water and melting of the enamel.

The use of the photo-initiator results in additional energy being absorbed, and greater ablation but also greater melting of enamel. This indicates that some of the absorbed energy that is converted to heat readily diffuses into the surrounding tissue. It was not possible to determine the lesion periphery clearly in all instances, and the area of tissue affected may be greater than was apparent.

The greater changes obtained by pre-painting the surfaces indicate that untreated enamel can transmit part of the energy which otherwise would be absorbed if a photo-initiator were to be applied. This is a particular problem with Nd-YAG laser radiation as its extinction rate (the distance necessary for the total attenuation of the beam) is very high (60 mm in water) (4).

In a previous study on the effects of Nd-YAG laser radiation on permanent teeth (17), higher energy densities were required to produce a degree of change similar to that obtained on untreated primary enamel in the present study. The well-known lower mineralization levels and higher opacity of primary enamel appears to contribute to the higher absorption of Nd-YAG laser radiation when compared to permanent enamel. The difference in changes observed between enamel and dentine is a

Table 2. Average cross-sectional area of lesions and relative range of measurements (mm^2)

Delivered energy (mJ)	Sound enamel	Photo-initiated sound enamel	Sound dentine	Carious dentine
3990	0.075 (0.068–0.090)	0.109 (0.096–0.121)	0.175 (0.090–0.211)	0.409 (0.234–0.450)
6000	0.084 (0.050–0.090)	0.121 (0.101–0.153)	0.211 (0.092–0.245)	0.456 (0.400–0.480)
7200	0.100 (0.090–0.120)	0.133 (0.116–0.160)	0.234 (0.102–0.250)	0.562 (0.490–0.584)

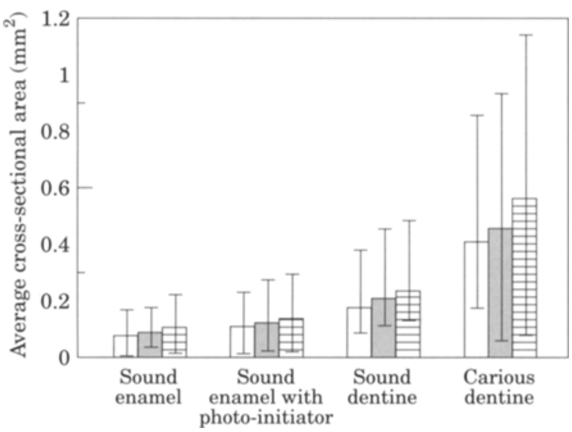

Fig. 5. Average cross-sectional area of lesions and relative range of measurements (bars). Open bars, 3990 mJ delivered energy; stippled bars; 6000 mJ delivered energy; hatched bars, 7200 mJ delivered energy.

direct consequence of their differences in optical properties and chemical composition. Nd-YAG laser radiation is more readily absorbed by dentine than by enamel as a result of its higher degree of pigmentation and lower translucency. The rate at which the tissue is removed is proportional to its inorganic content. The absorbed laser energy produces more destructive effects in dentine for the larger amounts of water and collagen it contains. The extent of the changes surrounding the exposed area of dentine is wider than the cross-sectional area of the fibre-optic delivery wand, suggesting that the effect of irradiation on dentine at the energies evaluated are not localized. Discolouration and demineralization also explain the greatest destruction and material removal observed in carious dentine. The absence of raised rolled edges characteristic of damaged sound dentine and the appearance of the normal dentine tubule structure in some cases, might suggest that carious dentine can absorb most of the delivered energy, thus preventing thermal damage to sound dentine. However, the reproducibility of such effects seems poor. Any effect of post-extraction changes on in vitro results are unknown and should be investigated. However, all samples were kept and tested in a hydrated state, which is probably the most relevant condition for the response of the tissues to laser irradiation.

The main advantage of the application of lasers to dental hard tissues is the ability to remove relatively smaller volumes of tissue in comparison with the traditional rotary cutting tools. This study confirms that Nd-YAG lasers can produce finite cavitation of sound or carious hard tissues of primary molars. However, at the energies evaluated, the effects produced were variable and relatively uncontrolled. It is apparent that the advantage of fibre-optic delivery of the Nd-YAG laser beam can be offset by its unpredictable effects.

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