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The Effects of Laser Radiation on Exposed Dentine Surfaces in the Treatment of Dentine Sensitivity. An *In Vitro* Study

Research Article

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Abstract

Aim: This *in vitro* pilot study was undertaken to investigate the effects of Neodymium: Yttrium Aluminium Garnet (Nd:YAG), Erbium: Yttrium Aluminium Garnet (Er:YAG) and Helium Neon (HeNe) laser radiation on dentine surfaces in extracted human teeth.

Material and Methods: Instrumented root surfaces and etched and unetched dentine discs were irradiated with a Nd:YAG laser operating at 3.5, 3.75 or 4W or an Er:YAG laser operating at 60, 80, 100mJ or with a HeNe laser. **Results**: The Nd:YAG laser produced melting and resolidification of dentine on all surfaces while the Er:YAG laser produced craters with closed tubules in root surfaces, but open tubules in dentine discs. The HeNe laser produced no apparent surface alteration. Both lased and unlased control surfaces were compared using Scanning Electron Microscopy (SEM).

Conclusions: Irradiation with the Nd:YAG and Er:YAG lasers caused significant disruption of the dentine surfaces on both root surfaces and also on dentine discs. Nd:YAG radiation produced irregular melting and resolidification of the dentine surface with some occlusion of open dentine tubules. Er:YAG radiation caused ablation of dentine and produced craters with open tubules in the dentine discs, but closed tubules on most root surfaces. Irradiation using a HeNe laser produced no noticeable surface effect.

Keywords: Dentine Sensitivity; Er:YAG & Nd:YAG Laser; Scanning Electron Microscopy

Introduction

Dentine sensitivity (DS) or Dentine Hypersensitivity (DH) may be defined as a transient pain arising from exposed dentine typically in response to chemical, thermal, tactile or osmotic stimuli which cannot be explained by any other dental defect or pathology [1]. The mechanism of pain generation is uncertain, but current opinion and evidence [2,3] favours the Hydrodynamic Theory. Available treatment options aim to occlude the dentine tubules either by altering tubular contents or by surface deposition. Previously it has been proposed that lasers may be used to achieve this, as they have the potential for fusing the dentine surface into a glazed impermeable layer [4]. The effects of laser radiation on tissues are determined by the interaction of photons of light energy with the atoms or molecules that make up the target tissue. These interactions are complex and not fully understood [5] and they depend on a range of variables including wavelength, energy, and duration of the radiation together with the specific absorption, clinical structure, and density of the target tissue. The laser-induced effects on biologic tissues have been examined [6] and are categorised as follows: l- Photo-thermal 2- Photochemical 3- Non-Linear processes (Photo-ablation). There is also considerable variation in the effects of laser radiation on the dental hard tissues. Carbon dioxide (CO_2) laser light at a wavelength of 106μm is readily absorbed by hard and soft tissues whereas Nd:YAG laser light at a wavelength of 1.06μm is poorly absorbed by enamel. In dentine, the absorption of Nd:YAG laser radiation is determined by colour [7] with the darker dentine absorbing more radiation. Commercial dental laser systems have been available for some time and manufacturers are recommending their use for applications ranging from enamel surface modification to cavity preparation. One proposed application for laser irradiation is for the relief of DS although, there is equivocal information in the published literature on the use of lasers for the treatment of DS. For example, Pashley *et al.* [8], conducted an *in vitro* study on the effect of CO_2 laser radiation on dentine permeability and noted that lased surfaces exhibited greater permeability than unlased surfaces unless irradiated at the highest energy levels. Stabholz *et al.* [9], studied dentine surfaces following irradiation with a Nd:YAG laser and noted melting and solidification of dentine to give a material that resembled glazed interconnected droplets. Wakabayashi & Matsumoto [10] and Gerschman *et al.* [11], studied the effect of irradiation with a gallium aluminium arsenide (GaAlAs) laser in placebo-controlled trials and found that it was effective in the treatment of dentine sensitivity. However, Manton *et al.* [12], compared the use of the Nd:YAG laser with the GaAlAs laser and found that treatment with the Nd:YAG laser produced a significant reduction in dentine sensitivity whereas the GaAlAs laser had no apparent effect.

The aim of this *in vitro* study therefore was to determine the effects of laser radiation on exposed surfaces using a commercially available laser unit operating at two infrared wavelengths, 2.94μm and 1.064μm.

Materials and Methods

The laser used for this study was the Fotona Twinlight Dental Laser (Fotona d.d Ljubljana, Slovenia). This produces beams using Yttrium Aluminium Garnet (YAG) crystals doped with either Neodymium (Nd) or Erbium (Er) and a visible aiming light using a Helium Neon (HeNe) laser. The Nd:YAG laser radiation [1.064um] was delivered via a fibre optic cable to a contact handpiece and the Er:YAG beam [2.94pm] via a system of articulated mirrors to a non-contact handpiece. The specifications of the laser are shown in Table 1.

Table 1: Specifications of the Fotona Twinlight Dental Laser

	Wavelength (μm)	Frequency (Hz)	Power (W)	Mode
Nd:YAG	1.064	10-100	0.5-8	Pulsed
Er:YAG	2.94	02-Oct	0.12-5	Pulsed
HeNe	0.67		0.001	Continuous

Following ethical approval, extracted human teeth from the Dental Hospital were stored under water and used at the earliest opportunity. Teeth were either sectioned to provide dentine discs from the mid-coronal area or they were left intact (Figure 1). On each un-sectioned tooth, one of two areas was isolated:

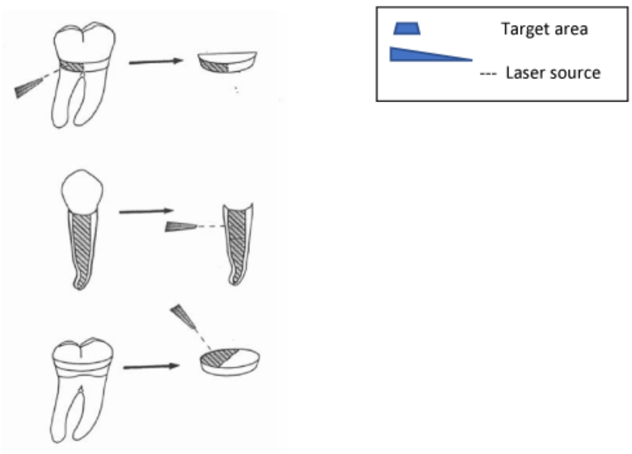

Figure 1: Schematic representation of the methods of irradiating the root surface and the dentine disc

- A band on the root surface in the bucco-cervical region (Table 2).
- A band of dentine running the length of the root.

The bucco-cervical samples were divided into target and control groups following surface

Table 2: Root surface preparation

NUMBER	GROUP	PREPARATION
6	A	Control group, root surface left un-instrumented
6	B	Instrumented for 30s using an ultrasonic scaler (TP 10 tip)
6	C	Instrumented using a Columbia 4L/4R curette. 30 strokes in vertical direction from root apex to crown
6	D	Instrumented for 30s using an ultrasonic scaler (TP 10 tip), then etched for 1min with 35% orthophosphoric acid and washed for 1min with water

Table 3: Power (Energy) levels used in the study

	Nd:YAG	Er:YAG
Power	3.5W, 3.75W, 4W	60mJ, 80mJ, 100mJ
Frequency	80Hz	2Hz
Duration	25s	10s

preparation and some were etched with citric acid. Targets were irradiated with the two treatment lasers at the radiation levels and durations shown in Table 3. The levels of radiation used [3.75 W for Nd:YAG and 80mJ per pulse for Er:YAG] were those recommended by the manufacturer for the treatment of dentine sensitivity. Also selected for investigation were 3.5 and 4 W [Nd:YAG] and 60 and 100mJ per pulse Er:YAG, these being the power/energy density above and below those recommended by the manufacturer. Target areas were also irradiated using the HeNe laser alone.

The tip of the fibre optic cable of the Nd:YAG laser was held in contact with the target while the Er:YAG laser handpiece was held at the focus point of the beam, l cm from the target. This was achieved by ensuring that the HeNe aiming lights were in focus on the tooth surface. Following irradiation, the samples were desiccated and then sputter coated with gold prior to viewing in a scanning electron microscope (Stereoscan 90B, Cambridge Instruments UK).

Results

Overall

Treatment with the Er:YAG laser was accompanied by a percussive sound each time an energy pulse was discharged. In contrast, treatment with the Nd:YAG laser produced a buzzing sound that increased in intensity as the dentine started to char. This may be attributable to the higher pulse repetition rate used with this laser. Although the specimens were kept moist during treatment by periodic irrigation with distilled water, use of the Nd:YAG laser produced charring of the dentine surface. The Er:YAG laser operated under a fine water spray and produced no evidence of surface charring. It was relatively simple to keep the fibre optic cable in contact with the tooth surface when using the Nd:YAG laser, but it was much more difficult to maintain the beam of the Er:YAG in focus as it traversed the surface.

The recommended method of treatment with both lasers, moving the handpiece across the surface of the target with horizontal and vertical strokes, failed to produce an even coverage of the target and resulted in some areas being irradiated twice. Other areas were not irradiated at all.

Microscopic examination

The Nd:YAG and Er:YAG laser radiation produced characteristic effects irrespective of the target or energy level used. The HeNe laser radiation produced no apparent surface effect on any of the specimens.

Irradiation with the Er:YAG laser produced craters with a circular outline, crater depth varying with the energy level used. The walls of the crater had a "terraced" like appearance (Figure 2) and the overlying dentine appeared to have been removed to expose the underlying layers deposited during incremental formation. A single

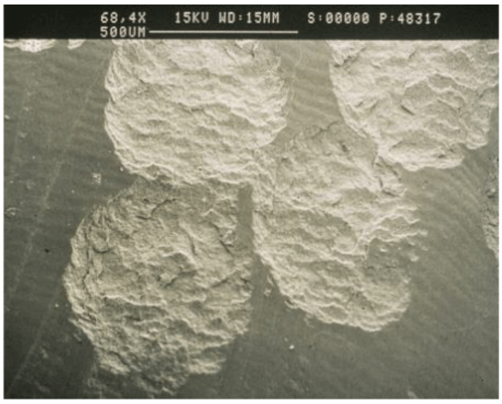

Figure 2: Electron micrograph of a hand instrumented root surface treated with an Er:YAG laser at 60mJ. The specimen shows craters with well-defined perimeters with the banding running horizontally across the electron micrograph which is indicative of the incremental lines within the dentine. Total delivered energy 1200mJ (Field of view 1716μm)

laser pulse would produce this effect. Only a small area of dentine was irradiated on each specimen however, it was not possible to expose the whole area evenly using the recommended method and the area was at times exposed to several pulses.

Multiple impacts on a single target area of untreated root dentine produced craters with an irregular surface and greater disruption occurred as the energy density per pulse was increased. There was no evidence of melting or of re-solidified dentine debris on either the target root surfaces or dentine discs. Er:YAG laser radiation produced craters with partly occluded dentine tubules on the root surfaces while on dentine discs it produced craters with open tubules (Figure 2-4) The presence or absence of a smear layer appeared to have no influence on the surface effect produced by the laser.

Treatment with the Nd:YAG laser produced a much more variable surface. On both root surfaces and dentine discs certain regions of the target tissue seemed more susceptible to the effects of the radiation producing cratering and troughing. The craters had an irregular outline and there was evidence of melting and re-solidification or partial melting of material at all exposure parameters. At high magnification the melted surface looked like a network of glazed interconnected globules of material (Figure 5). Open tubules were evident on the walls of craters produced on both dentine discs and root surfaces, but melted material appeared to produce some tubule occlusion. Multiple impacts of Nd:YAG laser

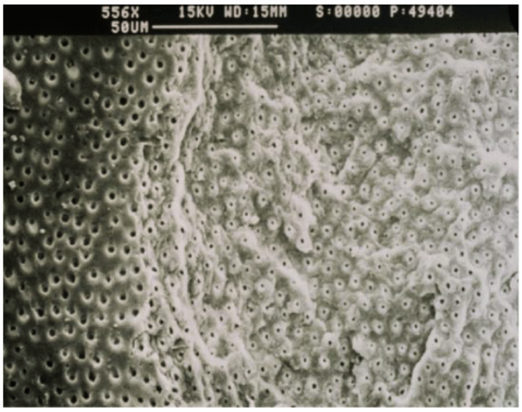

Figure 3: Electron micrograph of an etched 1mm dentine disc treated with an Er:YAG laser operating at 60mJ. The view shows the edge of a crater with unlased dentine on the left. There appears to be no evidence of melted dentine and the dentinal tubules are open in the crater wall. Total delivered energy 1200mJ. (field of view 175µm).

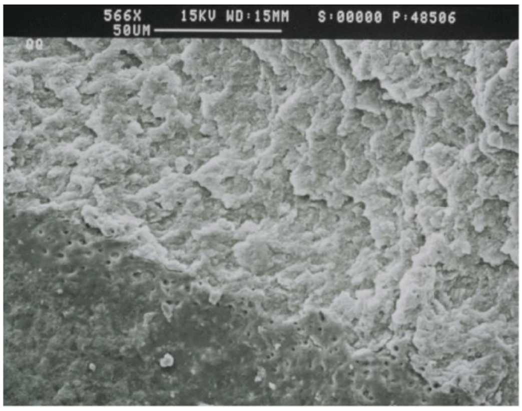

Figure 4: Electron micrograph of an ultrasonically instrumented and etched root surface treated with an Er:YAG laser operating at 80mJ. Unlased dentine is seen on the lower left. There appears to be open tubules around the rim, but no open tubules are visible in the wall of the crater. Total energy delivered 1600mJ (Field of view 201µm)

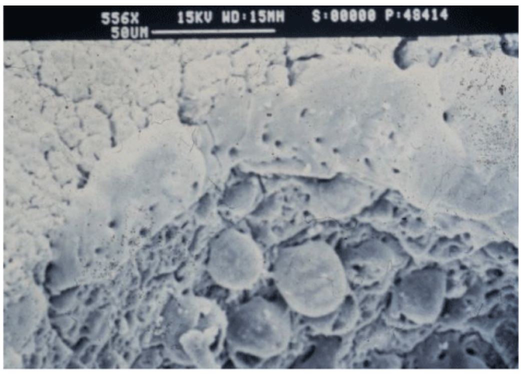

Figure 5: Electron micrograph of a root surface treated with a Nd:YAG laser operating at 3.75W. The micrographs show the junction between the root surface and the crater with both melted and solidified material visible around the rim. The untreated root surface is visible in the top left-hand corner (Field of View 208µm)

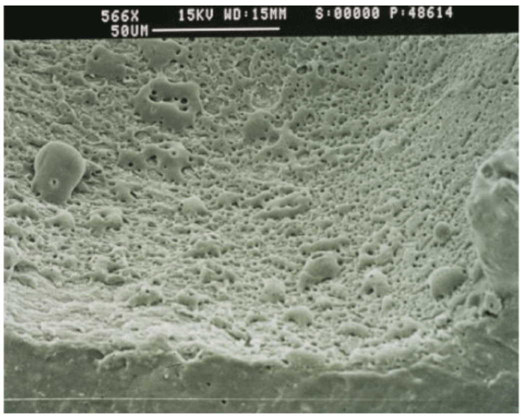

Figure 6: Electron micrograph of part of the rim of a crater formed by several impacts from a number of pulses of Nd:YAG radiation. Melting and solidification of the crater can be observed which has resulted in a partly glazed surface with inter-connecting beads of amorphous material. This appears to cover the whole surface (Field of View 193µm)

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radiation on a single target area produced craters with well-defined perimeters. The walls were covered with melted and re-solidified material (Figure 6). Voids were present in the larger globules of melted material.

Discussion

Most studies related to the interaction between laser radiation and tooth tissue have been laboratory based and have investigated structural and thermal changes. Previous reports on the clinical application of lasers are usually from uncontrolled trials and many of the claimed benefits are unsubstantiated [13]. However, several systematic reviews have indicated that most desensitising agents including laser irradiation were more effective than placebo although again the results from the included studies in these reviews are conflicting due to the heterogeneity of the included studies [14-16].

One of the potential laser applications would be to change the surface of the dentine which has been reported to occur when the tooth tissue is exposed to laser radiation. This may benefit the treatment of dentine sensitivity since occlusion of the orifices to the dentine tubules appears to be one treatment option. However, the laser beam has a very small footprint and the treatment of a large area in an even and uniform manner is unpredictable. In this study the method of traversing the dentine surface followed the manufacturer's recommendations for laser irradiation clinically. Both horizontal and vertical strokes were proposed to provide an even coverage however this was not possible. The area irradiated is a function of the speed at which the handpiece is moved across the target and the target area. The manufacturers provided optimum values for pulse frequency, pulse duration, time of irradiation and laser beam dimensions but do not relate these to the speed of movement of the handpiece or the size of the target area.

The small diameter of the fibre optic [0.32mm] used with the Nd:YAG laser and the small diameter of the beam [50.45mm] of the Er:YAG laser would require many traverses of the target to irradiate the whole surface. Similarly, it is almost impossible to ensure that there were no multiple irradiation(s) of certain areas.

While *in vitro* experiments on root surfaces are not truly representative of the clinical conditions the root surfaces and the dentine discs used were comparable with previous studies. These give a relatively similar result to clinical findings. The target areas were isolated on the bucco-cervical region on the roots of extracted teeth or the cut surfaces of dentine discs. These areas were selected as the cervical region is a common site of dentine sensitivity [17-19] and dentine discs provide a standard model for dentine permeability and perfusion experiments. The emission wavelength of the Nd:YAG laser is not well absorbed by water or hydroxyapatite and the radiation can therefore penetrate deeply into the hard tissue. This is a particular problem where the colour of the dentine is light. The action of the Nd:YAG is photo-thermal. In dentine when the temperature reaches above 300°C charring and pyrolysis begins. This leads to discolouration of the substrate and this in turn acts as a photoinitiator [7]. Surface absorption then occurs and penetration of the radiation into deeper tissue is inhibited followed by vaporisation and melting of the surface. Cooling using a water spray has little beneficial effect as the initial heating may occur deep within the tissue and thermal damage can occur in all directions from the point of absorption. Subsurface structural changes may therefore occur in those areas of dentine that are irradiated, but where no surface charring is seen.

The material lining the area irradiated with the Nd:YAG laser was either melted or partly melted dentine which had resolidified as the radiation source passed on to other areas. The high temperatures generated by the interaction of the laser beam with the dentine, vaporises the constituent organic and inorganic components. The resolidified material produced on cooling is an amorphous mass with a high mineral content [20], lacking the structure of the original tissue.

The emission wavelength of the Er:YAG laser exactly matches the absorption peak of water and is close to that of hydroxyapatite [21]. Since water is a substantial component of biological tissues, this leads to a high absorption of the radiation at the point of interaction. Operating the laser under water spray also enhances the effect. The high absorption of the energy delivered results in little energy dissipation in heating the tissue.

Irradiation with both lasers produced a rough dentine surface and the stability of this surface has not yet been evaluated. If the melted material produced by the Nd:YAG laser was not well attached to the underlying dentine then loss of this layer could result in a more permeable surface. Surface roughness would also lead to the accumulation of deposits in vivo and this may have a detrimental effect on treatment.

Er:YAG radiation appeared to completely remove the surface leaving a rough flaked area below. A 'halo' was

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noted around some of the exposed tubules which may be due to the presence of peritubular dentine although this may have been caused by differential charging of the specimen within the SEM. The Er:YAG laser operated at a low frequency and produced craters of similar diameter as the beam passed across the target. However, the Nd:YAG laser operated at a much higher frequency and the craters, when formed, were irregular in size and extended into furrows where the fibre tip was drawn across the surface. The pattern of concentric circles seen in some craters following irradiation with the Er:YAG laser, suggested that the intensity of the beam varied across its diameter. The beam profile is normally Gaussian, the intensity being greater in the centre of the beam than at the periphery.

This produces a crater with a deep central area and walls that rise smoothly up to the rim. The resolidified material produced by irradiation with the Nd:YAG laser seemed to occlude some of the tubules in the walls of the craters. However, a substantial proportion of the tubules remained open. Although tubule occlusion may reduce the permeability of the dentine, failure to occlude a sufficient number may still permit fluid flow within the tubules resulting in continued dentine sensitivity.

Multiple impacts with radiation from both lasers on the root surfaces produced deeper craters, but the surface anatomy of the crater walls was essentially the same as the craters produced in single pass specimens. If it is assumed that the objective of laser treatment of dentine sensitivity is to achieve tubule occlusion by altering the dentine surface and reducing permeability, then neither of these lasers provides a consistent means of achieving this.

Conclusions

This study shows that irradiation with Nd:YAG and Er:YAG lasers caused significant disruption of dentine surfaces on both root surfaces and also on dentine discs. Nd:YAG radiation produced irregular melting and resolidification of the dentine with some occlusion of open dentine tubules which may in turn reduce dentine permeability. Er:YAG radiation caused ablation of dentine and produced craters with open tubules in dentine discs, but closed tubules on most root surfaces. Irradiation using a HeNe laser produced no noticeable surface effect.

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