Dental ablation with 1064 nm, 500 ps, Diode pumped solid state laser: A preliminary study

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Background: The Er:YAG laser in conservative dentistry is a good alternative to conventional instruments. Though several studies show the advantages of these devices, some drawbacks and unsolved problems are still present, such as the cost of the device and the large dimensions of the equipment.

Purpose: In the present study, the effectiveness of dental surface ablation with a picosecond infrared diode-pumped solid-state (DPSS) laser was investigated. In vitro tests on extracted human teeth were carried out, with assessment of the ablation quality in the tooth and thermal increase inside the pulp chamber.

Materials and Methods: A solid-state picosecond laser was used for the experiments. The samples were exposed to laser energy at 1064 nm at a frequency of 30 kHz and a 500 ps pulse width. The target teeth were cooled during exposures. The internal temperature of the pulp chamber was monitored with thermocouples.

Results: Optical microscope images showed effective ablation with the absence of carbonisation and micro-cracks. The cooling maintained the temperature rise in the pulp chamber below the permitted 5.5°C.

Discussion: The main problem with the use of lasers in dentistry when teeth are the target is the heat generated in the pulp chamber of the target teeth. With lasers operating in the femtosecond mode, a better management of the internal temperature is possible, but is offset by the high cost of such devices. With the ps domain system used in the present study together with cooling using chilled water, effective and clean ablation could be achieved with a controlled thermal effect in the pulp chamber.

Conclusions: In this preliminary study with a picosecond domain DPSS laser using water cooling for the target, effective hard tissue ablation was achieved keeping the thermal increase in the pulp within the permitted range. The results suggest that this system could be used in clinical practice with appropriate modifications.

Key words: laser ablation • enamel • pulp chamber • laser dentistry
Sue is due to the affinity of its wavelength of 2940 nm with water and hydroxyapatite, without the risk of micro- and macro-fractures that have been observed with conventional rotating instruments. Dentin treated with laser energy appeared clean, with no smear layer and with the tubules open and clear. The temperature increase (ΔT) in the pulp that occurs during Er:YAG laser exposure was comparable to that caused by conventional instruments under the same conditions of air/water spray spread. Moreover, the 2940 nm wavelength was also able to disinfect and decontaminate the treated tissues by destroying aerobic and anaerobic bacteria.

The most interesting aspects of this new technology are related to the main goal of modern conservative dentistry: to be minimally invasive. The Er:YAG laser can reach spot dimensions smaller than 1 mm, with the possibility of performing selective ablation, avoiding damage to healthy tissue and allowing very limited restorations. Several in vitro studies have demonstrated that the preparation of enamel and dentin with the Er:YAG laser, followed by orthophosphoric acid etching, enhanced the efficacy in terms of reduced micro-leakage and increased bond strength. Recently, simultaneous biostimulatory effects on target tissues have been described, which might explain, together with the short pulse duration in the order of 50 µs, the reduction or absence of pain reported by patients during laser-assisted dental procedures.

The Er:YAG laser, however, has some disadvantages and a number of unsolved problems, such as the cost of the device and the large size of the systems due to the complexity of the device. In addition, with this technology, the treatment time is longer compared to the use of traditional instruments. Articulated arm delivery systems ensure low energy loss, but these have very poor ergonomics and flexibility. For these reasons, several other wavelengths have been investigated for ablation of hard dental tissues (i.e., CO2, Nd:YAG, Excimer, and Argon); however, no promising results have yet been obtained.

In the present study, the effectiveness of dental hard tissue ablation was investigated using a picosecond domain diode pumped solid-state (DPSS) laser. In vitro tests on extracted human teeth were undertaken, followed by evaluation of the ablation quality and temperature increase inside the teeth.

MATERIALS AND METHODS

The laser utilised was the Helios 5W (Innolight GmbH), emitting at wavelength of 1064 nm. The repetition rate (RR) of this device is tuneable between 30 and 70 kHz. The pulse duration is a function of the RR, between 500 ps at a RR of 30 kHz and 800 ps at a RR of 70 kHz. The mean output power (measured after optics) ranges from 4.05 at RR of 30 kHz to 4.81 at RR of 70 kHz. The experimental set-up is presented in Fig. 1.

The set-up included a half wavelength plate and a polariser for external attenuation of the beam, as the...
laser had to work at maximum power to maintain output power stability. A mirror was then placed in order to direct the beam onto the exposed sample. A 70 mm focal length lens was utilised to focus the beam onto the sample.

Teeth samples were exposed to laser radiation at a RR of 30 kHz, pulse duration of 500 ps and mean output power of 4.05 W. The time of exposure was set to between 4 and 15 min. The samples were placed on a 30 mm × 30 mm plate and fixed as shown in Fig. 2. A hole was drilled in the teeth before exposure in order to insert the thermocouple probe responsible for monitoring the temperature. A water flow system (Fig. 3) was used to provide a continuous flow of water to the exposed tooth in order to cool the sample during exposure.

RESULTS

Various tests were carried out on extracted human teeth. Holes were drilled in the tooth enamel with the DPSS laser at the settings given above. Optical microscope images proved the ablation to be of a good quality, as may be seen in Fig. 4. In this image it is possible to observe that there was no evidence of...
cracks or carbonisation. The avoidance of these two effects was obtained by cooling the sample during the exposure.

Two sets of tests were undertaken: the first using water at room temperature and the second with chilled water at 10°C. In both cases, it was possible to control the rise in pulp chamber temperature ($\Delta T$) from the initial value. The accepted maximum $\Delta T$ is 5.5°C. An average $\Delta T$ of 7.1°C was measured while using water at room temperature, whereas an average of 4.3°C, below the permitted 5.5°C, was measured while using the chilled water. Without the cooling system, temperatures of 40-50°C were measured, corresponding to a $\Delta T$ of more than 20°C.

DISCUSSION

The main problem related to the use of laser technology in medicine and dentistry is the control of temperature increase in the tissue. Many solutions have been devised to control temperature increase but achieve the desired effect in the tissue, such as Q-switching, and the pulsed and superpulsed mode of the laser beam \(^{22}\), the association of an air/water spray \(^{23}\) and energy reduction \(^{24}\). In conservative dentistry, the $\Delta T$ limit of 5.5°C must not be exceeded in the pulp chamber to avoid the loss of tooth vitality. This is the reason why the erbium family of lasers (Er:YAG and Er, Cr:YSGG), which emit in the µsec domain, work under the conditions of air/water spray cooling. The utilisation of lower pulse duration diode-pumped devices, such as the ps DPSS system used in the present study, may have the main advantage of avoiding thermal damage due to the lower heat dispersion, as well as a high likelihood of decreased pain for the patient. Although several studies have investigated the utilisation of femtosecond domain laser sources with very good results \(^{25,26}\), this technology is unfortunately still very expensive, which may be an obstacle for its clinical utilisation.

CONCLUSION

This in vitro preliminary study demonstrated that a picosecond domain DPSS laser was effective at ablating dental enamel, with an intra-pulpal temperature during irradiation within safe limits for tooth vitality. Modifications would be required to the system to produce a self-contained, free-standing system appropriate for actual clinical practice, such as the development of an appropriate beam delivery device, handpiece, aiming beam, air/water spray system and so on. Neverthe-less our preliminary results suggest that the DPSS laser could be used in actual dental practice with several advantages over the traditional solid-state lasers that are presently in use.

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