Dental Laser Drilling: State of the Art with the Second Generation of Variable Square Pulse Erbium Dental Laser Systems

Matjaz Lukac[a], Marko Marincek[a], Ladislav Grad[b], Zelimir Božič[c]

[a] *Research Associate, Institute Jozef Stefan, Ljubljana, Slovenia*
[b] *Research Associate, Faculty of Mechanical Engineering, Ljubljana, Slovenia*
[c] *Fidelitas Dental Practice, Postojna, Slovenia*

Background and Objectives: The latest technological breakthroughs incorporated in the second-generation of Variable Square Pulse (VSP) erbium dental lasers involve two additional features: the SSP (Super Short Pulse) mode for extremely fine and minimally invasive laser ablation; and the MAX mode for maximum optical drilling speeds. The objectives of this study were to make a comparison between the two new VSP erbium laser modes and a mechanical handpiece to test their efficacy for apicectomy. In addition, the safety of the MAX mode was evaluated.
Study design/Materials and Methods: Laser drilling speeds on extracted human teeth was measured under different VSP laser mode conditions and compared with the previously published drilling speeds of mechanical handpieces. Electron microscope pictures of the holes made in the hard dental tissue with the erbium MAX mode were also made.
Results: The SSP erbium laser mode exhibits the largest single pulse energy drilling efficiency while the treatment procedure with the MAX erbium mode is 1.6 times faster than with a mechanical handpiece. The electron microscope pictures of the ablation holes made with the MAX erbium mode reveal no cracks or thermal damage to the ablated hard dental tissue.
Conclusions: The latest two erbium laser modes: the SSP (Super Short Pulse) mode for extremely fine and minimally invasive laser ablation; and the MAX mode for maximum optical drilling speeds, offer superior alternatives to mechanical drills, are more precise and less invasive without sacrificing safety, ease-of use or operating speeds.

INTRODUCTION

The erbium (Er:YAG) laser has been recognized as the dental laser of choice for effective, precise and minimally invasive ablation of hard dental tissues. Of all infrared lasers, the erbium laser wavelength of 2.94 μm has the highest absorption in water and hydroxyapatite (see Fig. 1) and is thus optimal for cold »optical drilling« of enamel, dentin and composite fillings.

The early standard technology erbium dental lasers failed to gain wide acceptance among the dental community, as their optical drilling speeds were substantially slower than the mechanical bur. This changed with the introduction of VSP dental lasers[1] and the incorporated Fidelis VSP (Variable Square Pulse) technology[2] which provides very short, almost square pulse-shaped erbium laser pulses of adjustable pulse duration. Tests have shown the ablation speed of the VSP technology-based Er:YAG lasers to be comparable to those obtained by classical means.

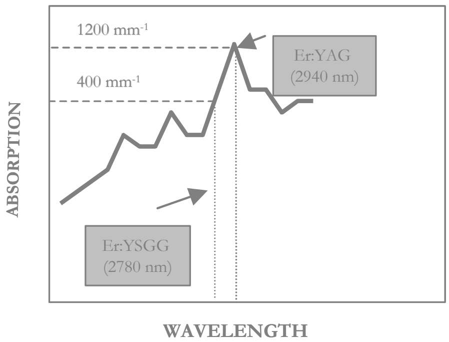

Fig.1: The Er:YAG (2.94 μm) laser has the highest absorption in water and hydroxyapatite. Another laser that emits in the 3 μm region is the Er:YSGG (2.78 μm) laser, however this laser exhibits already 300% lower absorption and is thus less suitable for laser drilling.

The latest technological breakthrough incorporated in the second generation of VSP erbium dental lasers[3] involves two features: the SSP (Super Short Pulse) mode[4] for extremely fine and minimally invasive laser ablation; and the MAX mode for maximum optical drilling speeds.

The objective of this in vitro study was to evaluate the efficacy and safety of the new VSP erbium laser modes for hard dental tissue treatments compared with the efficacy of the classic dental handpiece.

MATERIALS AND METHODS

Experiments were performed with the second generation Fidelis Plus II Er:YAG Variable Square Pulse technology dental laser (manufactured by Fotona d.d.). The following Fidelis laser pulse modes were used: VLP-1000 μs, LP-500μs, SP-300μs, VSP-100μs, SSP-50μs and the MAX mode. The non-contact R02-C Fotona handpiece was used to focus the laser beam onto the extracted human tooth. The spot diameter of the beam on the tooth was 0.9 mm.

In the first set of experiments (single pulse efficacy experiment), the efficacy of single pulse laser drilling was measured under water spray conditions at a low single pulse laser energy of 100 mJ and a low repetition rate of 1Hz for different laser pulse modes (durations).

In the second set of experiments (drilling speed experiment), the time required to fully cut through a 2 mm portion of the root was recorded using a stopwatch. Measurements were made on fifteen samples of extracted mature human teeth cut into 2 mm thick slices. Laser drilling of dentin with a water spray was performed with the laser operating in MAX mode at a high repetition rate of 20 Hz. The measured time was compared to previously published results with a mechanical drill (surgery reducing handpiece Intra 3614 N, KaVo, Biberach, Germany, with 4:1 reduction, used at 7,500 rpm with ISO size 12 fissure bur) under similar conditions.[5]

Electron microscope pictures of ablated holes in hard dental tissue obtained by the MAX erbium mode were also made.

RESULTS

Single pulse efficacy experiment

Figure 2 shows the previously published[4] dependency of the ablation efficiency on the pulse duration of the erbium laser. The following Fidelis laser pulse modes were used: VLP-1000 μs, LP-500μs, SP-300μs, VSP-100μs, and the newest SSP-50μs. As figure 2 shows, ablation efficiency increases with shorter pulse durations. The most effective mode is the new SUPER SHORT PULSE (SSP) mode where efficiency-reducing effects, the effect of heat diffusion, and the effect of debris screening are minimized. In addition, with SSP pulses the influence of light scattering in the emitted debris is minimal, and the quality and precision of the optically drilled holes is significantly improved.

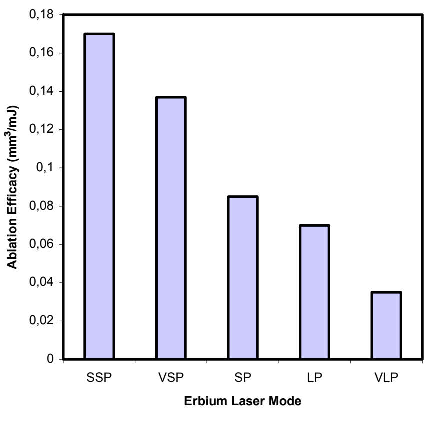

Fig.2: The ablation efficacy in dentin for different Er:YAG (2.94 μm) laser pulse duration modes, as already published in ref.4. The erbium laser SSP mode has the highest single pulse ablation efficacy.

Drilling speed experiment

A comparison of the times obtained with the stopwatch revealed a significant difference between the drilling speed of the erbium laser MAX mode and the previously published drilling speed of the mechanical handpiece.

	Mechanical handpiece[5]	**Laser MAX mode**
T (s)	3,6	**2,2**
SD (standard deviation)	0,95	**0,54**

Fig.3: Comparison of timing results in dentin obtained with a mechanical handpiece[5] and the erbium laser MAX mode. The MAX mode was found to be faster than the mechanical drill.

Electron microscope study

Electron microscope pictures of ablated holes in hard dental tissues with the erbium laser MAX mode revealed no cracks or thermal damage.

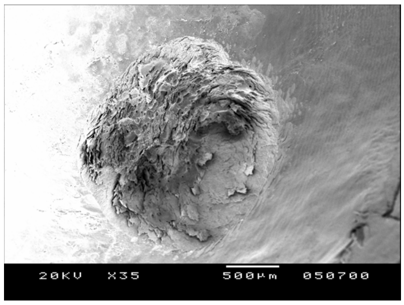

Fig.4: An example of an erbium laser MAX mode ablation hole in enamel. No cracks or thermal damage were observed.

DISCUSSION

The recent rapid technological advances in laser dentistry have been facilitated by similarly exciting developments in the theoretical understanding of the laser ablation of biological tissues.[6]

It is now accepted and understood that depending on the laser pulse duration and the laser pulse energy (or more correctly, laser fluence, i.e. the laser energy per surface area (in J/cm^2)) there are four ablation regimes (See Fig.5).

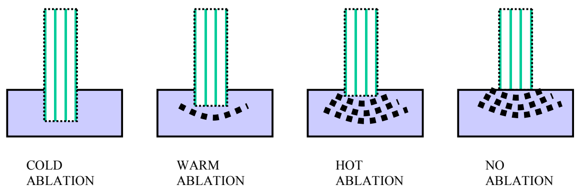

Fig.5: Schematic overview of the four ablation regimes.

At high energies and low pulse durations, the speed of ablation is faster than the diffusion of heat into the tissue with all of the energy used up for COLD ABLATION.

With decreasing energies and/or longer pulse durations, the thermally influenced layer of tissue becomes thicker by the end of the pulse. The thermal effects become more pronounced and the ablation efficiency is considerably reduced (WARM and at even lower energies HOT ABLATION). At energies below the ablation threshold there is NO ABLATION, consequently all the energy is released in the form of heat, independent of laser pulse duration.

It is important to note that by decreasing the laser energy, with the intention of working more safely, the operator may achieve precisely the opposite, i.e. more thermal effects in the tissue. The important factor that can be used to determine the effect of the laser energy on dental tissue is the Peclet[6] or the Laser – Tissue Number (LTN). LTN that is defined by:

LTN = Laser Intensity x LTF ,

where

Laser intensity = Laser Fluence/Laser Pulse Duration,

and the LTF (Laser Tissue Factor) is a constant factor that depends on the laser wavelength and the particular dental tissue physical properties:

LTF = 0.5 x Laser Absorption Coefficient x Tissue Thermal Relaxation Time/ Specific Heat of Ablation

For laser fluences above the ablation threshold the cold ablation regime is characterized by LTN >1.

To achieve cold ablation the operator must select laser parameters where LTN >1. When a particular pulse duration t_L is selected, the ablation starts at the ablation threshold energy. The ablation efficiency then grows with increasing energy until the pulse energy exceeds the value where LTN >1. Above this value, the ablation effect is the most effective, most "cold", and increases linearly with the laser energy.

In order to perform very precise and fine treatments at low laser energies, the laser pulses must be sufficiently short in order for LTN to be greater than 1. The safest regime is the regime where pulse durations are shorter than the tissue relaxation time where no warm and hot ablation regimes exist. For enamel, the thermal relaxation time equals approximately 100 μsec.

On the other hand, when high ablation speed is desired the best choice is to use high pulse energies at longer pulse durations, providing that LTN is kept well above 1. This is due to another effect that influences ablation dynamics. This effect is the debris screening, i.e. the absorption and scattering in the particles ejected from the ablation site. The debris screening depends on the density of the debris and is strongest at high LTN. Since the density of the debris depends on the laser beam intensity it is advantageous to achieve LTN >1 at longer pulse durations, i.e. at lower laser intensities.

The second generation of VSP erbium lasers enables the operator to select from the following modes: SSP (Super Short Pulse: 50 μsec), VSP (Very Short Pulse: 120 μsec), SP (Short Pulse: 300 μsec), LP (Long Pulse: 600 μsec), VLP (Very Long Pulse: 1000 μsec).

The SSP pulse durations are extremely short, approximately 50 μsec which is below the 100 μsec tissue relaxation time. The SSP pulses are therefore best suited for precise and fine ablation at low laser energies.

For standard work the VSP and SP pulses with LTN above 1 are recommended, while for maximum ablation speeds the MAX mode is most suitable because the MAX assures LTN >1 by fixing the laser energy and pulse duration to the optimal high values of 1000 mJ and 300 μsec pulse duration.

For soft tissue applications, where thermal coagulation effects are desirable, the LP and VLP modes are best suited.

Comparison of Er:YAG and Er:YSGG

Since the absorption coefficient of Er:YSGG is three times smaller than that of Er:YAG the range of safe parameters that can be used is considerably reduced when using Er:YSGG. Firstly, the ablation threshold energy is three times higher. Secondly, in order to achieve LTN >1, fluences that are three times higher are required. This is particularly difficult to achieve with fiber delivery systems that cannot deliver high energies and/or high intensities because of their high absorption and low damage threshold. It is for this reason that most Er:YSGG lasers operate at considerably lower ablation efficiency and closer or inside the warm/hot ablation regimes. The Er:YSGG dental lasers are thus slower, less safe and a less versatile choice for the dental practice.

CONCLUSIONS

For minimally invasive hard tissue laser procedures (where low pulse energies are used) the SSP mode, with a pulse duration shorter that the hard tissue relaxation time, (and LTN >1) was found to be the most suitable and safest. This is because it achieves the highest, and "coldest", single pulse laser drilling efficiency.

When maximum laser drilling speeds are required, the MAX mode was found to be a safe and fast, hard tissue laser dentistry tool. Laser drilling with the VSP MAX mode was found to be **1.6 times faste**r than the published[5] drilling speeds of standard mechanical handpieces.

With two new modes,: SSP and MAX, dental lasers have finally achieved their original goal: of replacing mechanical drills with more precise and less-invasive optical technology without sacrificing safety, ease of use or operating speed.

REFERENCES

1. Variable Square Pulse Technology is a proprietary technology of Fotona (www.fotona.si).
2. Fidelis[TM] denotes a family of dental laser systems developed and manufactured by Fotona. (www.fotona.si).
3. Fidelis Plus II (Er:YAG 2.94 µm and Nd:YAG 1.06 µm combined laser system) and Fidelis Er II (Er:YAG 2.94 µm laser system) are the products developed and manufactured by Fotona (www.fotona.si).
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