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Dental laser drilling: Achieving optimum ablation with the latest generation Fidelis laser systems

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Abstract

This paper provides an overview of the scientific principles of hard dental tissue laser procedures and discusses the influence of laser wavelength, pulse duration and pulse energy. Erbium lasers have been found to be a safe and efficient technological solution for the manipulation of hard dental tissues. The ability to precisely control laser pulse duration enables the practitioner to determine the nature of the ablation, which can range from cold to hot ablation. To work in a cold ablation regime laser pulse duration and pulse energy must be matched in order to create the right laser action. The latest generation Fidelis laser systems, manufactured by Fotona, feature an Er:YAG laser source that can deliver precisely controlled pulse durations, using Variable Square Pulse (VSP) Technology control. This enables a range of laser drilling techniques including very fine, precise "cold" ablation and MAX mode, enabling the fastest, most efficient hard tissue ablation available. These two new modes, SSP and MAX, mean that dental lasers have finally achieved their original goal; replacing mechanical drills with more precise and less-invasive optical technology, without sacrificing in safety, ease-of-use or operating speed.

Keywords: hard dental tissue, Er:YAG laser, wavelength, pulse duration, pulse energy, cold ablation, warm ablation, hot ablation

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.

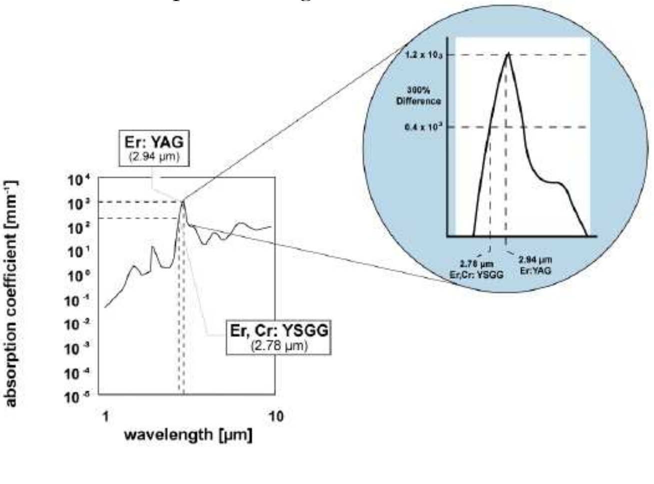

Fig.1: The Er:YAG (2.94 μm) laser has the highest absorption in water and hydroxiapatite. An alterantive laser that emits in the 3 μm region is the Er,Cr:YSGG (2.78 μm) laser, however this laser has a 300% lower absorption and is thus less suitable for laser drilling.

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

The most recent technological breakthroughs that have been incorporated into the latest generation of Fidelis dental lasers (Fidelis Plus III and Fidelis Er III)[3] are: SSP (Super Short Pulse) mode[4] for extremely fine and minimally-invasive laser ablation; and MAX mode for maximum optical drilling speeds - even faster that those obtained by mechanical burs. With these two additional modes, dental lasers have finally achieved their original goal: to replace mechanical drills with more precise and less-invasive optical technology without sacrificing either ease-of-use or operating speed.

SCIENTIFIC PRINCIPLES

Exciting developments in the theoretical understanding of the laser ablation of biological tissues[5] have facilitated recent rapid technological advances in laser dentistry.

It is now well understood that there are four ablation regimes (see Fig. 2), defined by the relationship between 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).

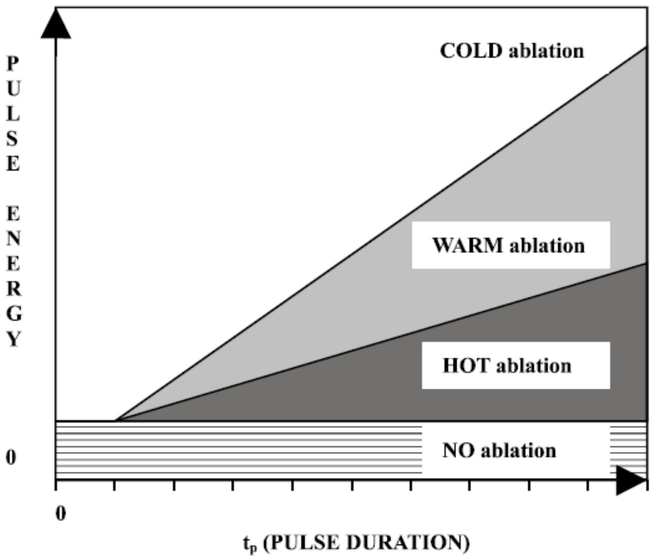

Fig.2: Schematic overview of the four ablation regimes.

At high energies and low pulse durations, the speed of ablation is faster than the rate of diffusion of heat into the tissue, so that all of the laser energy is used up in COLD ABLATION (See Fig. 3). With decreasing energies and/or longer pulse durations, the layer of tissue, that has been thermally-influenced by the time the pulse ends, becomes thicker. Thermal effects become more pronounced and, with these, ablation efficiency is considerably reduced (WARM ABLATION and, at even lower energies, HOT ABLATION). At energies below the ablation threshold there is NO ABLATION and all the energy is released in the form of heat, independent of the laser pulse duration.

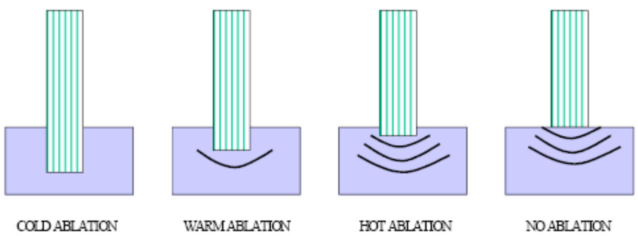

Fig.3: The effect of the laser beam on hard dental tissue in the four ablation regimes.

Many practitioners might assume that, in order to work more safely, laser energy should be decreased. Paradoxically this is not the case. Indeed the opposite is true. If the operator reduces the energy of the laser for a given pulse duration, he may achieve precisely the opposite result, i.e. more thermal effects in the tissue.

THE LATEST GENERATION FIDELIS LASER MODES

The latest generation Fidelis lasers enable 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).

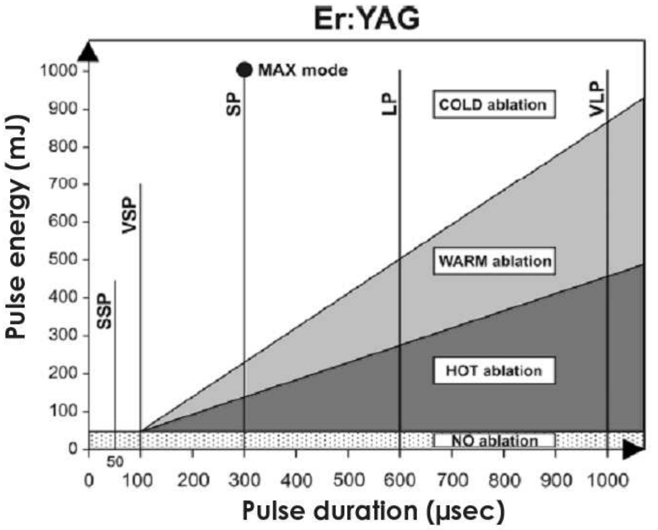

Fig.4: Cold and hot regimes for Fidelis Er:YAG lasers. Nominal pulse durations that apply to situations at high laser energies are depicted for different mode durations.

The SSP pulse durations are extremely short (approximately 80 μsec) which is below the 100 μsec Tissue Relaxation Time for enamel. The SSP pulses are therefore best suited for precise and fine ablation at low laser energies. For standard work, VSP pulses are recommended. And for maximum speed of ablation, MAX mode is most suitable, since, by fixing the laser energy and pulse duration to the optimal high values, MAX Mode can ensure cold ablation. The LP and VLP modes are best suited to soft tissue applications where thermal coagulation effects are desirable.

COMPARISON OF Er:YAG WITH Er,Cr:YSGG

Since the absorption coefficient of Er,Cr: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,Cr:YSGG. The ablation threshold energy is therefore three times higher.

Secondly, the range of the Er,Cr:YSGG laser pulse durations is limited to longer pulse durations only. In this respect, the Er:YAG laser is at an advantage, since it offers variable pulsewidths down to 50μs while the Er,Cr:YSGG laser is due to the long cross-relaxation time of the Cr^{3+} ion limited to a minimum pulsewidth of approximately 500µs. To illustrate this limitation, Fig. 5 displays measured pulse durations of an Er: YAG laser system (Fidelis Plus III, Fotona), and of an Er,Cr:YSGG laser system (Waterlase MD, Biolase). Note that the Waterlase MD laser system employs relatively short pump pulses of only 140 ms in the H mode, and 700 µs in the S mode. In spite of this, due to the presence of the Cr^{3+} ion in the Er,Cr:YSGG laser crystal, the generated laser pulses are much longer, and are in the shortest H pulse mode on the order of 600 µs, and in the longer S mode on the order of 1200 µs.

PULSE MODE	PULSE DURATION
Er:YAG (Fidelis Plus III)	
SSP	80 µs
VSP	150 µs
SP	200 µs
LP	500 µs
VLP	800 µs
Cr,Er:YSGG (Waterlase MD)	
H	600 µs
S	1200 µs

Fig.5: Available pulse durations for the Er:YAG (Fidelis Plus III, Fotona) and Er,Cr:YSGG (Waterlase MD, Biolase) laser systems. Note that pulse durations vary slightly with laser pulse power. The shown pulse durations are for low to medium laser pulse powers.

One of the key factors that determines the regime and efficiency of laser ablation is the laser pulse duration. If the energy required is delivered into the target within a very short time, then the energy has little time to escape from the ablated volume, and so less heat is diffused into the surrounding tissue (see Fig. 6).

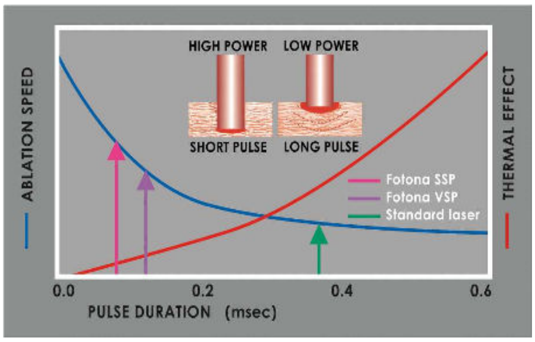

Fig.6: Keeping the pulse energy constant, the ablation efficiency increases, and the thermal effects decrease towards shorter pulse durations. Due to the long cross-relaxation time of the Cr^{3+} ion, the Er,Cr:YSGG cannot be operated bellow approximately 500 µs.

Based on the above wavelength and pulse duration considerations, the Er,Cr:YSGG laser is found to be suitable for soft tissue applications where some level of thermal coagulation effects are desirable but has limitations when used on hard tissues. On the other hand, the Er:YAG laser, especially when pumped with variable square pulse (VSP) pump technology can be operated at adjustable pulse durations, from super short pulses (SSP) that are ideal for precise ablation of hard tissues, to very long pulses (VLP) for soft tissue procedures (See Fig. 5).

CONCLUSIONS

For precise, hard-tissue laser procedures, erbium lasers offer the safest and most efficient solutions. Careful control of the pulsewidths enables the nature of the ablation to be controlled.

Of the different erbium laser technologies, Er:YAG has the optimum absorption characteristics for hard tissue procedures, with cold ablation possible using far lower energy values, and thus greater safety.

The latest generation of Fidelis laser systems from Fotona utilize an Er:YAG laser source, delivered using precise VSP control of the pulsewidth. This enables a range of laser drilling techniques including very fine, precise "cold" ablation and MAX mode, enabling the fastest, most efficient hard tissue ablation available.

The two new modes, SSP and MAX, mean that dental lasers have finally achieved their original goal: 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.com).
2. Fidelis™ denotes a family of dental laser systems developed and manufactured by Fotona. (www.fotona.com).
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DISCLAIMER

application has been approved or cleared to be marketed and sold in your country.
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