Super VSP Er:YAG Pulses for Fast and Precise Cavity Preparation

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Purpose: The aim of this in vitro study was to measure the influence of heat diffusion and debris screening on the ablation efficiency of Er:YAG laser pulses in enamel, and to maximize cavity preparation speeds by using super short (50 µs) laser pulses.

Materials and Methods: Extracted human teeth were irradiated with Er:YAG laser pulses with fixed pulse energy of 450 mJ and variable pulse durations from 50 (super short pulse) to 1000 µs (very long pulse). The depth and diameter of the craters was measured as a function of pulse duration. The dynamics of ablation debris screening was measured by monitoring the transmission of He-Ne laser light during the formation of the ablation debris cloud.

Results: The analysis of the results show that the ablation efficiency increases by a factor of 5 when pulse durations are decreased from 1000 to 50 µs. The typical debris cloud formation time at 2 mm above the ablated surface was determined to be approximately 50 µs.

Conclusion: The study shows that optimal erbium dental laser pulses are of approximately 50 µs duration. At this duration, both the heat diffusion and debris screening effects are minimized, leading to very efficient laser "drilling". The laser ablation speeds under these conditions are larger than those achieved by classical mechanical burs.

Key words: lasers, dental cavity preparation, Er:YAG laser irradiation, super short laser pulses, enamel.

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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.[1] Of all infrared lasers, the erbium laser wavelength of 2940 nm has the highest absorption in water and hydroxyapatite and is thus optimal for cold "optical drilling" of enamel, dentin, and composite fillings.[2]

The early standard technology erbium dental lasers failed to gain wide acceptance by the dental community as their optical drilling speeds were slower compared to the mechanical bur. This has changed with the introduction of the VSP (Variable Square Pulse) laser technology,[3] that provides erbium laser ablation speeds comparable to those obtained by classical means. The major advantage of VSP is its ability to generate very short, almost square-shaped laser pulses. Research has shown that with VSP pulses shorter than 110 µs, the speed of ablation is higher than the speed of thermal diffusion. This results in a very effective and "cold" ablation of hard dental tissues.[4]

In this study, we have improved upon already superior ablation efficacy of the VSP technology by studying the additional effects of debris screening on the ablation process. Namely, it is known that the absorption and scattering of laser light in the debris that is being ejected from the ablated area during the laser pulse can influence the ablation efficiency and optical quality of the laser beam.[4] Our goal was to determine the typical time

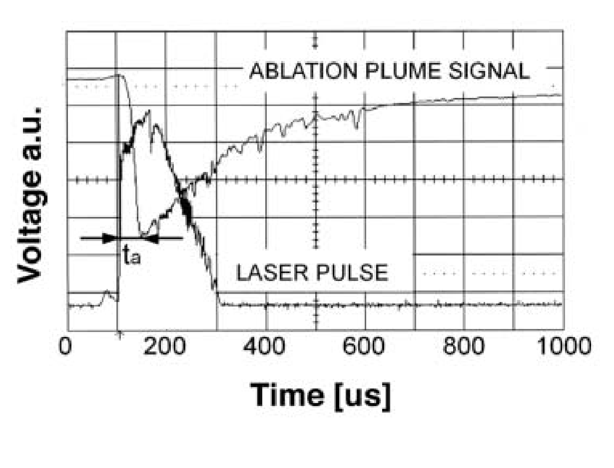

Fig 1 The evolution of the ablation plume signal during and after the Er: YAG laser pulse.

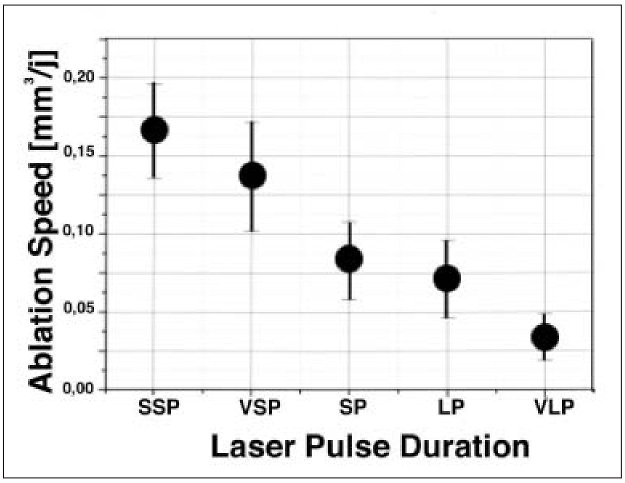

Fig 2 Dependence of the ablation speed on the Er: YAG (Fidelis) pulse duration mode. Standard erbium lasers achieve ablation speeds of ca 0.057 mm^3/J. A much higher ablation speed of 0.165 mm^3/J is achieved by the shortest SSP laser mode.

at which the debris cloud is formed above the ablated area, and then to measure the ablation efficiency and the quality of ablated holes at laser pulse durations shorter or comparable to this debris "screening" time.

MATERIALS AND METHODS

A free generating Er:YAG laser (Fidelis II laser, Fotona, Ljubljana, Slovenia) provided pulses with controlled constant laser energy (450 mJ) and adjustable variable square pulse (VSP) pulse duration. Pulse durations of 1000 µs (VLP), 500 µs (LP), 300 µs (SP), 100 µs (VSP) and 50 µs (SSP, super short pulse) were used in this experiment. A noncontact handpiece (Fotona R02) was used to focus the laser beam to achieve a constant laser fluence of 40 J/cm^2 . All drilling experiments were performed on freshly extracted human teeth, cut longitudinally into 2-mm-thick slices and stored in 4% formaldehyde solution. During irradiation, a mild water spray was applied to the tooth surface in order to avoid the effects of desiccation.[4] Twenty-one consecutive pulses at a slow repetition rate of 0.5 Hz were applied to each spot. Fifteen spots were made for each measurement point. Depths and diameters of the resulting craters were determined by optical stereomicroscopy.

The ablation plume signal during erbium laser irradiation was measured by monitoring the transmission of the He-Ne laser light during the formation of the ablation debris cloud at 2 mm above the tooth surface.

RESULTS

A typical signal of the ablation plume dynamics vs laser pulse is shown in Fig 1. The measurement shows the characteristic time delay(ta) for the debris screening to be approximately 50 µs.

Figure 2 shows the dependency of the ablation efficiency on the erbium laser pulse duration. The ablation efficiency increases towards shorter pulse durations as expected from the heat diffusion theory.[4] The most effective is the 50 µs super short pulse (SSP) mode where both efficiency-reducing effects are minimized: the effect of heat diffusion, and the effect of debris screening. In addition, visual inspection of the ablated holes showed the quality and the precision of the optically drilled holes to be significantly improved when SSP pulses were used. This is attributed to the reduced scattering of the laser light in the emitted debris.

DISCUSSION

It has been shown that at pulse durations shorter than the thermal diffusion time, heat diffusion effects during the laser pulse can be neglected.[4] The characteristic diffusivity value for enamel has been estimated to be 110 μs, indicating that the shortest pulse lengths used in this test were probably close to the range of negligible heat diffusion. The observed increase in the ablation efficiency as the pulse is shortened to 50 μs indicates that the diffusivity value might be shorter than 100 μs. However, to make the final conclusion, the relative contribution of the reduced debris screening to the observed ablation efficiency increase should be determined. As laser pulse durations are increased, the ablation efficiency is reduced because of the conductive loss of heat from the interaction layer. The experiment shows that the efficiency is reduced by a factor of approximately 5 when the pulse duration is increased from 50 to 1000 μs.

CONCLUSION

The study shows that the optimal erbium dental laser pulses are of approximately 50 μs duration. At this duration, not only is the ablation speed faster than heat diffusion but also the screening effects by the ablation debris are minimized. Under the conditions of this study, the drilling efficiency and the quality of drilling provided by the erbium laser are unmatched by the classical turbine bur or any other laser.

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