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Influence of Submillisecond Er-Laser Pulses on Mechanical Properties of Hard Tooth Tissues

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Abstract

In this paper the influence of pulse duration, pulse repetition rate, pulse number (at single point), and pulse energy of YLF: Er laser radiation with λ=2.84 μm on mechanical properties of human hard tooth tissues was studied. It was found that the multi-pulses action of this laser radiation with pulse energy below hard tooth tissues ablation threshold promotes increase in the microhardness of enamel at 25% and microhardness of dentine at 35%. Such research can open new perspectives in esthetic and preventive dentistry.

Introduction

Today Er–lasers with wavelengths near 3 microns are widely applied to ablation of hard tooth tissue [1]. The wavelengths are close to peaks of enamel and dentine absorption. The effects which are initiated in hard tooth tissues by action of Er-laser radiation with an energy density below hard tooth tissues ablation threshold are significant interest.

In [2] it was shown that the use of laser radiation both independently and in combination with the use of fluoride reduces enamel solubility in acid and increases its microhardness. It is also noted that dentin structures become denser under the action of laser radiation with subthreshold energy densities [3]. According to modern concepts, such effects in tissues appear due to local heating (from 100ºC to 1100ºC) which leads to the structural, chemical and crystalline changes in tissues [4–6]. It has been previously investigated the influence of carbon dioxide, erbium, holmium, excimer, and argon lasers radiation on the permeability of the solubility in acid and microhardness of tooth hard tissues [2, 4, 6–9].

In [10] it was shown that impact of YLF: Er laser radiation with λ=2.84 μm on hard tooth tissues leads to whitening or ablation of enamel and whitening, ablation or carbonization of dentine. We explain whitening as: laser energy is not enough for destruction and removal of tissues (ablation of enamel or dentine) but it is enough for changing dissipation. These changes could occur as a result of evaporation of water, occurrence of microcracks, reorientation of hydroxyapatite crystals, etc. In [10] the dependences of the threshold of effects that occurs as a result of YLF: Er laser impact (single pulse) on enamel and dentine of human teeth on pulse duration were investigated.

In present research we use diode pumped YLF: Er laser. In compare with flash-pumping the advantages of diode pumping of YLF: Er laser are: possibility of more effectively conversion of pumping energy to generation energy; simple change of wavelength, pulse duration, pulse repetition rate and spatial distribution.

This paper is devoted to the influence of temporal and energy parameters of YLF: Er laser radiation (λ=2.84 μm) with energy density less than energy density required for whitening effect on the mechanical properties of tissues: enamel and dentine microhardness.

Materials and methods

Teeth:

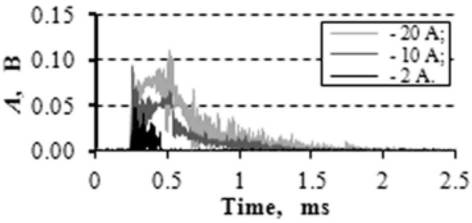
In this study, we used human teeth 25−40 years old. To preserve natural properties the samples were stored in a 0.1 % thymol water solution, at temperature of +4°C, in a light-proof place, for not more than two weeks.

Laser:

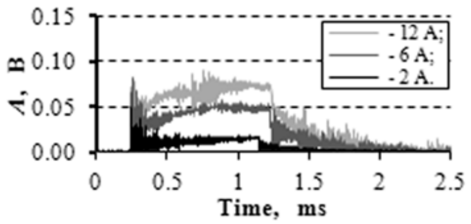
The impact on hard tooth tissues was carried out by single-mode YLF: Er laser radiation with diode pumping. It worked at free-running mode at wavelength of 2.84 µm. Energy and pulse duration of YLF: Er laser pulses depended on pumping current and pulse duration of diode laser. In work we used pumping pulse duration of 300 µs and 1000 µs, at pulse repetition rate of 3 Hz, 50 Hz, and 250 Hz. Oscillograms of laser pulses obtained at different currents and pulse durations of diode pumping are presented in Fig. 1

When the pump pulse duration is 300 µs (3 Hz) and pump current is 2-20 A, pulse duration of YLF: Er radiation varies from 185 µs to 330 µs, pulse energy reaches value near 2.1 mJ at pump current of 20 A. When the pump pulse duration is 300 µs (250 Hz) and pump current is 2-20 A, pulse duration of YLF: Er radiation varies from 240 μs to 300 μs, pulse energy reaches value near 0.84 mJ at pump current of 20 A.

When the pump pulse duration is 1000 μs (3 Hz) and pump current is 2-12 A, pulse duration of YLF: Er radiation varies from 900 μs to 1030 μs, pulse energy reaches value near 4.40 mJ at pump current of 12 A. When the pump pulse duration is 1000 μs (50 Hz) and pump current is 2-12 A, pulse duration of YLF: Er radiation varies from 610 μs to 1000 μs, pulse energy reaches value near 3.9 mJ at pump current of 12 A.



a)



b)

Fig. 1. Oscillograms of diode pumped YLF: Er laser pulses with λ=2.84 μm, at 3 Hz: a) pump pulse duration of 300 μs; b) pump pulse duration of 1000 μs.

Experiment:

Flat area was formed on the enamel and dentine surface with a diamond disk directly before the experiment. On the surface of this flat microhardness measurement by Vikkers manner was carried out for intact tissues. Microhardness tester "PTM–3M" (JSC "LOMO") was used at load of 100 g and time of 10 s. Then a texture was formed on this surface by YLF: Er laser radiation. The texture is the structure of sequenced points (elements of texture) at which laser impact was carried out. The distance between centers of texture elements was ~80 μm. The size of texture was ~400×400 μm (5×5 points). Laser treatment of tooth tissues was carried out in non-contact mode, without water cooling. Laser radiation was focused on the tissue surface. Next microhardness measurement was carried out for treated tissues at load of 100 g and time of 10 s. Relative change of microhardness (ΔHV) was calculated as:

$$\Delta HV = \frac{HV_{\text{tr.}} - HV_{\text{int.}}}{HV_{\text{int.}}} \cdot 100 , \qquad (1)$$

where: $HV_{\text{int.}}$ – microhardness of intact tissue; $HV_{\text{tr.}}$ – microhardness of treated tissue.

Treatment parameters:

We used different combination of laser parameters such as: pulse duration of 300 μs or 1000 μs, pulse repetition rate of 3 Hz, 50 Hz or 250 Hz, pulse number (at single point) of 3–600, pulse energy of 0.25–0.90 mJ.

For enamel treatment we used follow laser treatment regimes:

<u>Regime 1e:</u> pulses number (at single point) of 100, pulse repetition rate of 3 Hz, pulse duration of 300 μs, pulse energy of 0.90 mJ.

<u>Regime 2e:</u> pulses number of 100, pulse repetition rate of 250 Hz, pulse duration of 300 μs, pulse energy of 0.49 mJ.

<u>Regime 3e:</u> pulses number of 100, pulse repetition rate of 3 Hz, pulse duration of 1000 μs, pulse energy of 0.70 mJ.

Pulse energy was chosen 20% lower than the whitening threshold energy for all regimes.

For dentine treatment we used follow laser treatment regimes:

<u>Regime 1d:</u> pulse duration of 300 μs, pulse repetition rate of 3 Hz, pulse energy of 0.35 mJ, pulses number (at single point) of 10-200.

<u>Regime 2d:</u> pulse duration of 300 μs, pulse repetition rate of 250 Hz, pulse energy of 0.25 mJ, pulses number of 3-150.

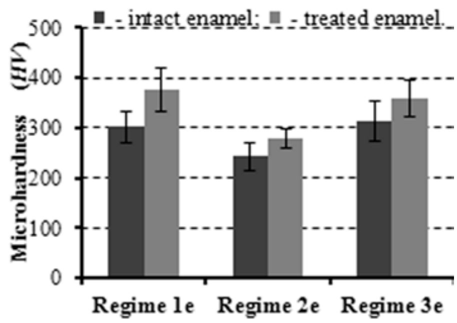
<u>Regime 3d:</u> pulse duration of 1000 μs, pulse repetition rate of 50 Hz, pulse energy of 0.42 mJ, pulses number of 200.

<u>Regime 4d:</u> pulse duration of 1000 μs, pulse repetition rate of 50 Hz, pulse energy of 0.54 mJ, pulses number of 55-600.

Pulse energy was chosen 30% lower than the whitening threshold energy for <u>Regime 1-3</u>, and 10% lower than the whitening threshold energy for <u>Regime 4</u>.

Results and discussion

The results are presented on fig. 2–6. Fig. 2 shows microhardness in absolute value (a), and relative change of microhardness in persents (b) for enamel. It is clear that the <u>Regime 1e</u> (pulse number of 100, pulse repetition rate of 3 Hz, pulse duration of 300 μs, pulse energy of 0.90 mJ) provides the most increase in relative change of enamel microhardness. It was of 25%.



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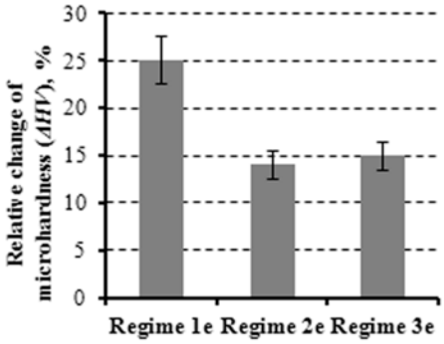
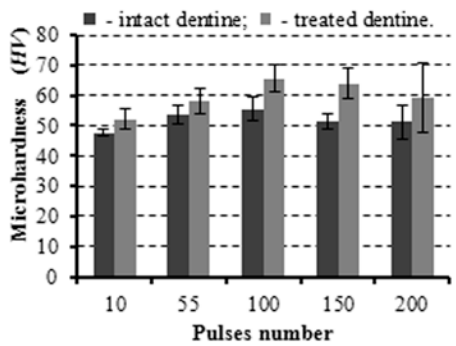


b)

Fig. 2. The results of study of enamel microhardness after YLF: Er laser impact at different regimes: a) microhardness in absolute value; b) relative change of microhardness in presents.



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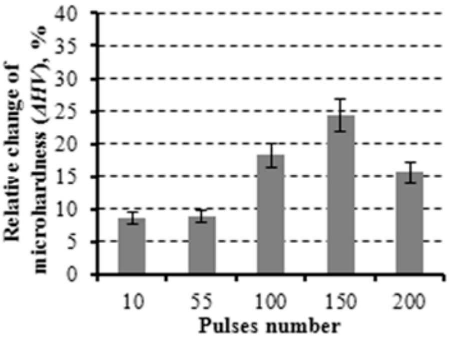
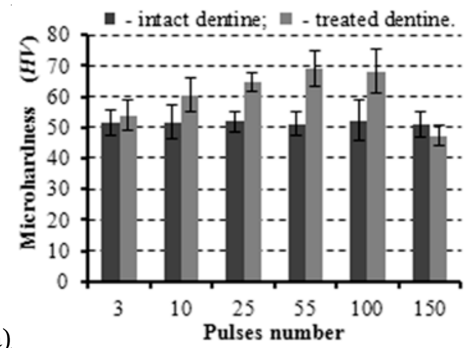


b)

Fig. 3. The results of study of dentine microhardness after YLF: Er laser impact at <u>Regime 1d</u> and different number of pulses: a) microhardness in absolute value; b) relative change of microhardness in presents.

The results of the study of dentine microhardness after laser treatment with a pulse duration of 300 µs and at various pulse repetition rate of 3 Hz and 250 Hz are shown in Fig. 3 and 4, respectively. It shows that <u>Regime 2d</u> is preferable, because the best results are achieved faster than when we worked in <u>Regime 1d</u>, in consequence of a higher pulse repetition rate and the lower number of pulses required to achieve the maximum increase in the microhardness (ΔHV =35%).



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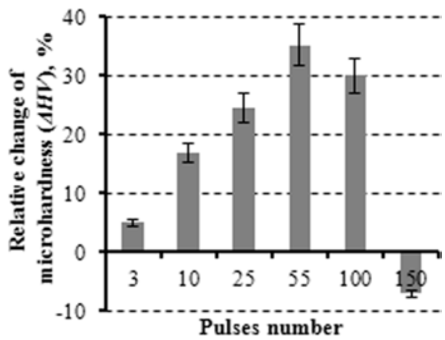
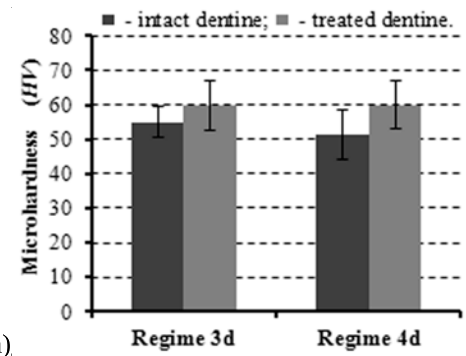
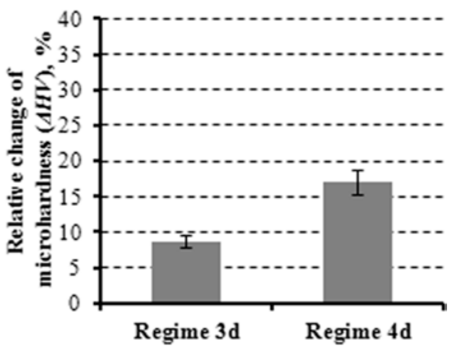


b)

Fig. 4. The results of study of dentine microhardness after YLF: Er laser impact at <u>Regime 2d</u> and different number of pulses: a) microhardness in absolute value; b) relative change of microhardness in presents.



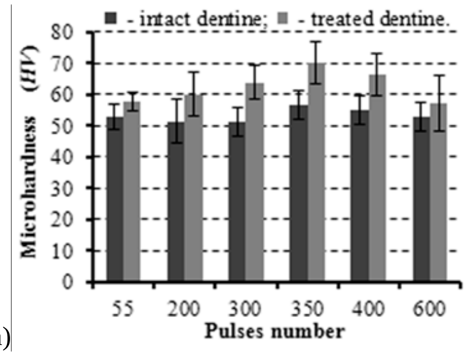
a)



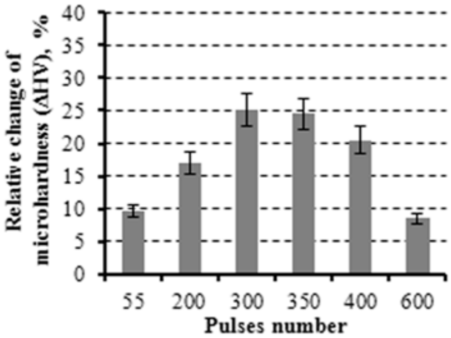
b)

Fig. 5. The results of study of dentine microhardness after YLF: Er laser impact at different regimes and number of pulses of 200: a) microhardness in absolute value; b) relative change of microhardness in presents.

The results of the study of dentine microhardness after laser treatment with a pulse duration of 1000 µs and at various pulse repetition rate of 3 Hz and 50 Hz at number of pulses of 200 are shown in Fig. 5. It was shown that Regime 4 leads to increase in dentine microhardness at 17% while Regime 3 leads to increase in dentine microhardness at 9% (at equal number of pulses). So next study was carried out for Regime 4.



a)



b)

Fig. 6. The results of study of dentine microhardness after YLF: Er laser impact at Regime 4d and different number of pulses: a) microhardness in absolute value; b) relative change of microhardness in presents.

Fig. 6 shows the results of the study of dentine microhardness after laser treatment with pulse duration of 1000 µs and at pulse repetition rate of 50 Hz, at different number of pulses (Regime 4d). It is seen that number of pulses of 300 leads to increase in dentine microhardness at 25%. It is the best result for this regime.

Conclusions

The influence of energy and temporal characteristics of YLF: Er laser radiation with λ=2.84µm on mechanical properties of human hard tooth tissues was studied. It was found that the multi-pulse impact radiation of this laser with pulse energy below hard tooth tissues ablation threshold promotes increase in the microhardness of enamel and dentine. It was shown that the best combination of laser parameters for increase in microhardness of enamel (at 25%) was: pulse duration of 300 µs, pulse repetition rate of 3 Hz, pulses number of 100, pulse energy of 0.90 mJ. The best combination of laser parameters for increase in microhardness of dentine (at 35%) was: pulse duration of 300 µs, pulse repetition rate of 250 Hz, pulse number of 55, pulse energy of 0.25 mJ.

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