Near infrared Nd:YAP laser radiation transmission through the human eye tissue structure

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ABSTRACT

Comparison of the eye tissue transmission for two (1.08 μm and 1.34 μm) Nd:YAP laser wavelengths was done. The lasers were working in pulsed free-running regime. The interaction energy of $\sim$ 100 mJ and spot diameter of 3 mm was used for both wavelengths yielding in the radiation fluence $\sim$ 0.51 J/cm^2. From the step by step transmission measurement of the human eye structures (in vitro) was recognized that the value of the absorbed energy in particular segments was different for monitoring wavelengths yielding in the two orders fluence difference on the retina. From the results follows that the 1.34 μm radiation is absorbed mainly by the anterior segments of the eye in contrast to 1.08 μm for which the main part of the radiation going through all eye layers.

Keywords: infrared laser, Nd:YAP, retina, ocular damage.

1. INTRODUCTION

Plasma breakdown generated by high power lasers is used in ophthalmic microsurgery for disruption of the different membranes, for example for a posterior capsulotomy.[1–6] For that purpose Nd:YAG laser generating plasma breakdown (laser spark) by nanosecond or picosecond pulses is used. In our previous papers we reported about application of both types of these pulses and success of treatments was shown.[6] It is understandable that a probability of a breakdown inside the eye is higher for picosecond pulses. It follows from the three order higher power of picosecond pulses compared with the nanosecond pulses. In the case, when the breakdown inside of the targeted tissue did not form, the whole energy can reach (is reaching) the retina. Due to defocusation of it is not big fluence but nevertheless some hazard exists here.[6] The aim of this work was to measure transmission of the transparent eye tissues for the Nd:YAP laser radiation operating at the wavelength 1.08 μm, which is very closed to commonly used radiation 1.06 μm (Nd:YAG laser) and compare it with the passage of the Nd:YAP laser radiation at other possible wavelength 1.34 μm. This wavelength is nearer to the so called "eye safe region" than Nd:YAG or Nd:YAP base wavelengths (1.06 μm and 1.08 μm). Through our measurement it could be seen where the energy is absorbed inside the eye medias.

2. EXPERIMENTAL SETUP

2.1. Sources of the laser radiations

As radiation sources Nd:YAP laser systems was used in an arrangement of oscillator and amplifier. Nd:YAP system composed of two crystals [$\varnothing\, 6 \times 120$ mm (oscillator) and $\varnothing\, 7 \times 120$ mm (amplifier)] with the ends cut in $2^\circ/2^\circ$ angle which were placed into an outer focus of a double elliptical silver coated cavity. The crystals were pumped by one xenon flashlamp being in a common focus of both cavity ellipses. For the investigated subject,

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the oscillator part of the whole laser system was used only. The mirrors of an open resonator determined which wavelength was generated. The 1.34 μm resonator of Nd:YAP laser was formed by a concave ($r = 10$ m) mirror M_1 with the reflectivity 100 % and 1 %, and a flat mirror M_2 with the reflectivity 70 % and 1 % for $\lambda = 1.34\,\mu$m and 1.08 μm, respectively. The resonator for the generation of 1.08 μm radiation was formed by the concave mirror ($r = 10$ m) M_3 and flat output coupler M_4 with the reflectivity $R_{M3} = 100\,\%$ and $R_{M4} = 30\,\%$ (for wavelength 1.08 μm), respectively. The lengths of all resonators were 46 cm.

For transversal mode control of this resonator, a diaphragm with the diameter 2 mm was placed inside the resonators. The laser was working in free running regime and the output energy of this system was adjust to be $\sim$ 30–180 mJ for both wavelengths.

2.2. Measuring instruments

For measurement of the output laser energy and through the eye transmitted radiation, a computer-operated two channel Molectron JD2000 Joulemeter/Ratiometer with two Molectron detectors (J25, voltage responsivity 8.59 V/J) was used. Spectrophotometer Specord NIR61 was used to find out of vitreous humor and lens low energy level transmission. For post operation record a microscope Nicon SMZ-2T, Mitsubishi CCD color video camera (CCD-100) and PC computer were used as well as a scanning electron microscope - JEOL (JSM 6400).

2.3. Experiment arrangement and tissue preparation during the experiment

For the interaction investigation the human eye tissues (in vitro) were used. The experimental arrangement is illustrated on Figure 1. Up to the experiment the eyes were stored at the temperature 4 °C in a saline solution. Chosen radiation was directed vertically into the eye by a proper mirror **M** which reflectivity under the angle of 45 ° was $R_{45^\circ} = 100\,\%$ for 1.08 μm or 1.34 μm, and $R_{45^\circ} = 90\,\%$ for 0.63 μm (guiding He-Ne laser beam). To determine the value of the energy falling into the eye, the 4 % energy of the laser beam was declined before the mirror **M** by the beam splitter **BS** and this energy was measured by Molectron detector **D1**. The eye was placed on a special holder **EH** which allows the passage of the radiation into the eye. Above the eye, the second Molectron detector **D2** was placed to find out the transmitted energy. After the calibration measurement (without the eye tissue), the above mentioned arrangement allows us to have the value of the transmitted energy in every laser shot.

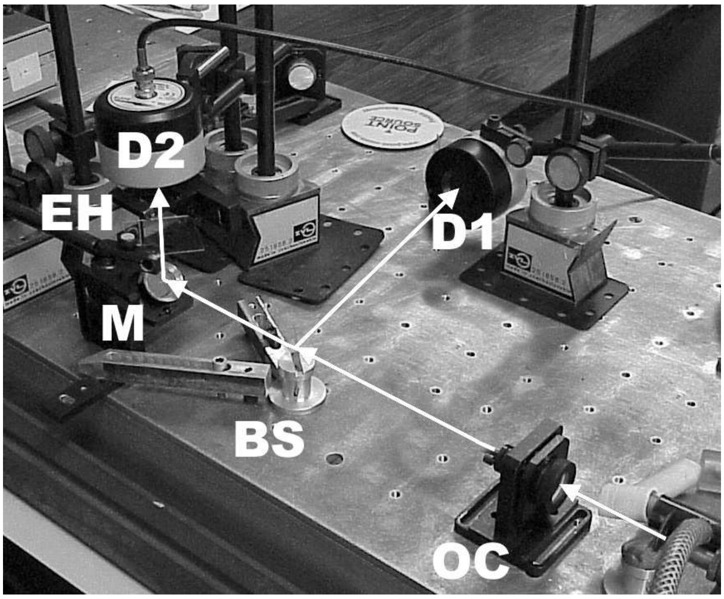

Figure 1. Photography of experimental arrangement for measurement of eye structures transmission. (**OC** – laser resonator output coupler, **BS** – beam splitter, **EH** – eye holder, **D1**, **D2** – energy detectors.)

The measurement was divided into 4 steps - the transmission of following tissues was measured:

a) cornea, aqueous humor - anterior chamber fluid, lens, and vitreous humor;
b) cornea, aqueous humor, and lens;
c) cornea, and aqueous humor;
d) cornea itself.

Ad a) In the first measurement the value of the energy falling during the straight laser irradiation onto the retina was measured. Therefore the posterior pole of the eye was cut and the energies passing the cornea, aqueous humor, lens, and vitreous humor were measured for six various input energy from 30 mJ up to 180 mJ. The transition measurement for the every energy was repeated 20 times. The obtained data was automatically recorded via Molectron Joulemeter to the computer. Then the vitreous humor was removed and measured separately in spectrophotometer NIR61.

Ad b) The rest of the energy after its pass through the cornea, aqueous humor, and lens was measured. In the following step the lens was removed and measured separately.

Ad c) The transmission of the cornea and aqueous humor was measured.

Ad d) At the end the cornea transmission was investigated. This procedure was repeated for both compared wavelengths – 1.08 μm and 1.34 μm.

2.4. Eye tissue analysis

The experiments were monitored by the Mitsubishi CCD color video camera (CCD-100) via Nikon SMZ-2T microscope, and also eye tissues were immediately photographed after the laser treatment. PC computer was used for the notation and storage of records (the interaction changes). After the final treatment the solid tissues were stored in formaldehyde solution and prepared for histological examination. It was done in the Department of pathology of Central Military Hospital, Prague.

3. RESULTS

Above described method was used for transmission measurements of four human eye samples at wavelength 1.08 μm and three samples at wavelength 1.34 μm. From this measurements and recalculation it was seen that the cornea absorbs $\sim$ 14 % input energy of 1.08 μm and 21 % of 1.34 μm; in the aqueous humor 9 % of 1.08 μm and $\sim$ 31 % of 1.34 μm were lost. The lens absorbed 23 % 1.08 μm energy and 33 % energy of 1.34 μm. Father $\sim$ 5 % energy of 1.08 μm, and 11 % energy of 1.34 μm is absorbed in the vitreous humor. By adding absorptions of eye tissues altogether we can conclude, that approximately 50 % energy of 1.08 μm wavelength reaches the retina, in a contrast with 0.5 % of 1.34 μm energy reaching the retina after passage through the all eye tissues. From the measurements calculated results (applications of Lambert–Beer's law) are summarized in the Table 1 and Table 2.

Table 1. Results of human eye tissue transmission measurements at wavelength 1.08 μm.

Wavelength:	1.08 μm			
Water absorption:	0.153 cm^{-1}			
Part of the human eye	*Thickness*	*Transition*	*Abs. coeff.*	*Abs. energy*
Cornea	1 mm	85.9 ± 6.9 %	$1.55 \pm 0.80\,cm^{-1}$	14.1 %
Aqueous humor	2 mm	89.8 ± 7.3 %	$0.55 \pm 0.41\,cm^{-1}$	8.7 %
Lens	5 mm	70.1 ± 2.9 %	$0.71 \pm 0.08\,cm^{-1}$	23.1 %
Vitreous humor	16 mm	85.3 ± 3.1 %	$0.10 \pm 0.02\,cm^{-1}$	4.8 %
All layers in front of retina	**24 mm**	**49.3 ± 4.7 %**	$\mathbf{0.30 \pm 0.04\,cm^{-1}}$	**50.7 %**
Energy reach retina				49.3 %

Table 2. Results of human eye tissue transmission measurements at wavelength 1.34 μm.

Wavelength:	1.34 μm			
Water absorption:	2.18 cm^{-1}			
Part of the human eye	*Thickness*	*Transition*	*Abs. coeff.*	*Abs. energy*
Cornea	1 mm	78.8 ± 4.0 %	$2.40 \pm 0.51\ \text{cm}^{-1}$	21.2 %
Aqueous humor	2 mm	61.2 ± 1.8 %	$2.22 \pm 0.14\ \text{cm}^{-1}$	30.6 %
Lens	5 mm	31.5 ± 5.9 %	$2.35 \pm 0.38\ \text{cm}^{-1}$	33.0 %
Vitreous humor	16 mm	2.9 ± 0.9 %	$2.24 \pm 0.20\ \text{cm}^{-1}$	10.7 %
All layers in front of retina	**24 mm**	**0.5 ± 0.1 %**	**$2.22 \pm 0.08\ \text{cm}^{-1}$**	**99.5 %**
Energy reach retina				0.5 %

4. DISCUSSION

Goal of our work was to measured the transmission of the particular optic system (cornea, aqueous humor, lens, and vitreous humor) for wavelengths 1.08 μm and 1.34 μm. From that the value of the transition, absorption coefficient, and absorbed energy percentage part was calculated. The results were compared with the measured water absorption (it was comparable with work of Boulnuois[7]). For the wavelength 1.08 μm some differences exist (see Table 1), what probably means that also other tissues molecules except of H_2O play significant role at this wavelengths. For the wavelength 1.34 μm measured absorption coefficient was close to value water absorption for all investigated tissues (see Table 2).

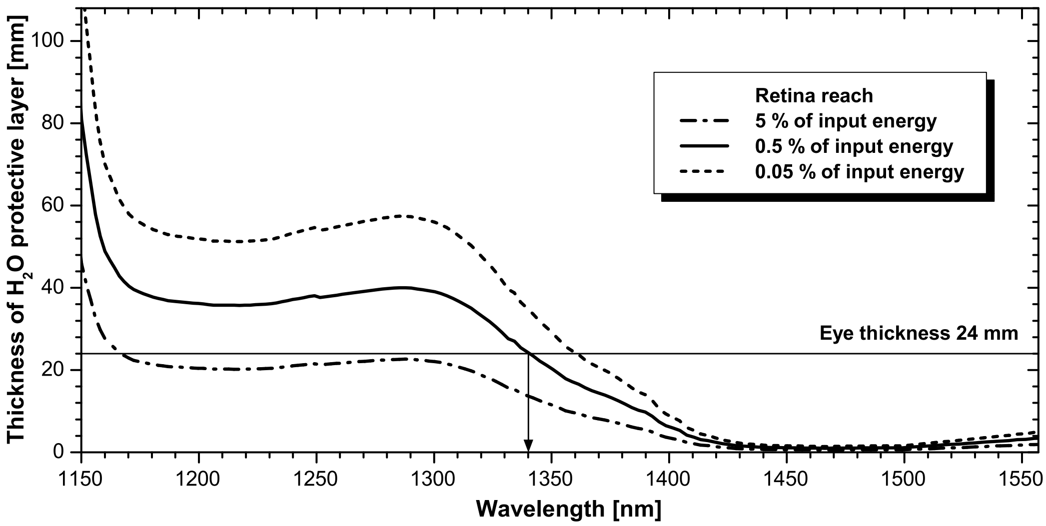

Figure 2. Protective layer of water – thickness of water which block 99.5 % of input radiation energy in dependence on radiation wavelength.

On the consumption, that the tissue absorption dependencies are the same like water also in the vicinity of wavelength 1.34 μm, the water layer thickness with defined transmission was calculated for wavelengths in range from 1150 nm up to 1550 nm. By this way is possible to find the thickness of the water which allow to transmit only specified part of input radiation. This "protective layer of water" in mentioned range of wavelengths was calculated for the following transmission values: 5 %, 0.5 %, and 0.05 %. This value is showing how much % energy from the input one reaching the retina. The "protective layer of water" thickness can be compared with the dimension of the eye and from the Figure 2 it is seen that the wavelength 1.34 μm is limiting value for the

0.5 % from the input which could reach the retina. This is the significant result from the point of view of the experiments done by Zuclich, etal.[8] Here is written that effect of 1.34 μm radiation in retina is worst during the time than effect of 1.06 μm. Therefore lowering energy dose which could reach, in the accident case, the retina is significant.

5. CONCLUSION

Comparison of the transparent eye tissue transmission for two Nd:YAP laser wavelengths (1.08 μm and 1.34 μm) was done. The interaction energy of $\sim$ 100 mJ and spot diameter of 3 mm was used for both wavelengths yielding in the radiation fluency $\sim$ 0.51 J/cm^2. From the step by step transmission measurements of the transparent human eye tissues (in vitro) was recognized that the value of the absorbed energy in particular segments was different for monitoring wavelengths yielding in the two orders fluence difference on the retina. From the results follows that the 1.34 μm radiation is absorbed mainly by the anterior segment of the eye in contrast to 1.08 μm for which the main part of the radiation is transmitted through all transparent eye layers.

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