Calculation of thermal conductivity and attenuation of pulsed laser radiation in the eye tissue.

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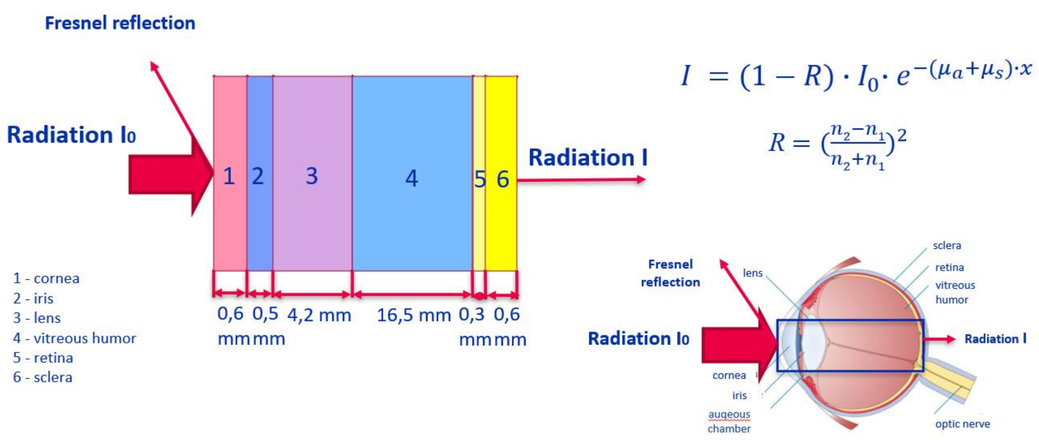
Introduction

In this work, we simulate the attenuation of laser radiation in the eye tissue and the temperature distribution in the retina of the eye during panretinal laser coagulation. In the MATLAB software package, an optical model of the attenuation of laser radiation from six eye tissues and a model of the temperature distribution in the retina have been developed. Simulation of the attenuation of laser radiation was carried out according to the Bouguer-Beer law, taking into account the Fresnel reflection. This takes into account the scattering and absorption of each tissue and reflections at the tissue boundaries. These relations were obtained for six tissues of the eye. Temperature propagation is simulated according to the heat conduction equation. Thus, such thermophysical properties of the fabric as thermal conductivity, specific heat capacity, and density are taken into account. The program allows obtaining graphs of the dependence of the sample temperature on the irradiation time, the sample temperature on its thickness and the temperature distribution in the sample.

Modeling the propagation of radiation in eye tissues

Modeling of attenuation of laser radiation intensity

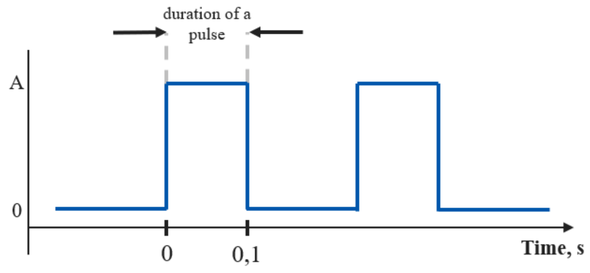


$$I = (1 - R) \cdot I_0 \cdot e^{-(\mu_a + \mu_s) \cdot x}$$

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Laser parameters for simulating intensity attenuation

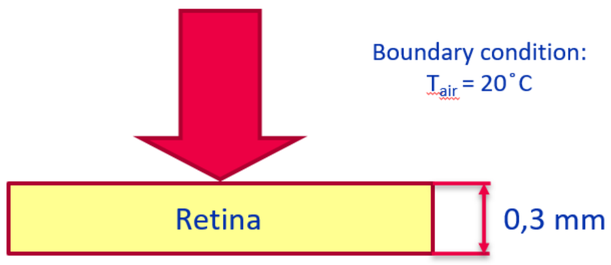
Laser parameters:
λ = 532 nm
P = 400 mW
$d_{обл}$ = 100 μm
f = 4 Hz
$t_{имп}$ = 0,1 s
$t_{облуч}$ = 0,1 s
I = 5096 W/sm^2



Modeling the thermal conductivity of laser radiation

Boundary condition:
T_{air} = 20˚C

Initial condition:
T_{body} = 37˚C



Heat conduction equation:

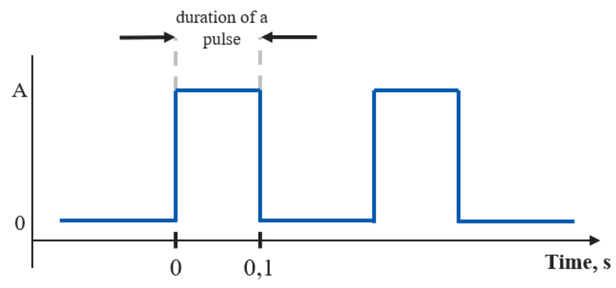
$$\rho \cdot c \frac{\partial T(x,t)}{\partial t} = \kappa \cdot \frac{\partial^2 T(x,t)}{\partial x^2} + Q(x),$$

$$Q(x) = \mu_a \cdot \varphi(x) \cdot \frac{E_0}{\tau_p}$$

ρ – density, c – specific thermal capacity, t – time, κ - thermal conductivity, Q - volumetric density of radiants, μ_a – absorption coefficient, $\varphi(x)$ – illuminance, E_0 – radiation energy density, τ_p - burst time

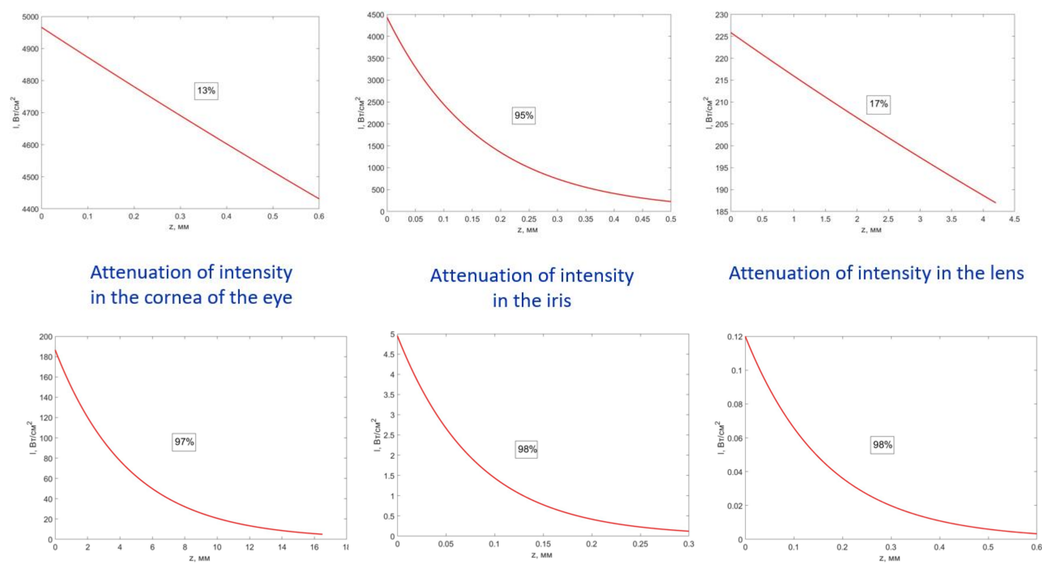
Laser parameters for modeling thermal conductivity

Laser parameters:
λ = 532 nm
P = 150 mW
$d_{обл}$ = 250 μm
f = 4 Hz
$t_{имп}$ = 0,1 s
$t_{облуч}$ = 0,1 s
I = 306 W/sm^2



Results and disscussions

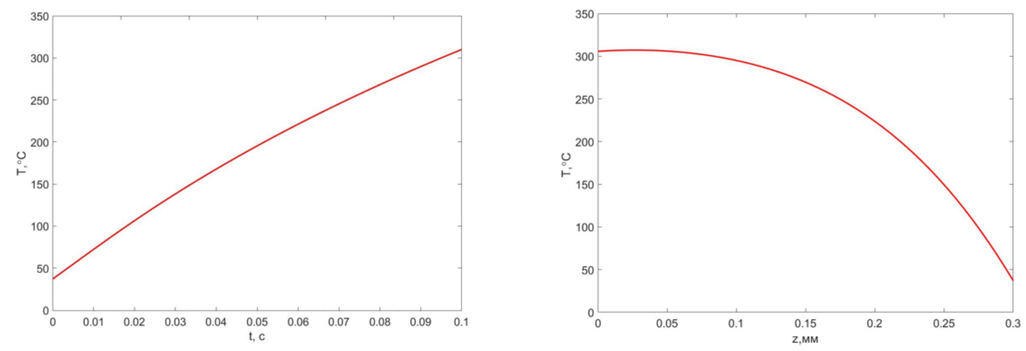
Results of modeling the attenuation of laser radiation intensity



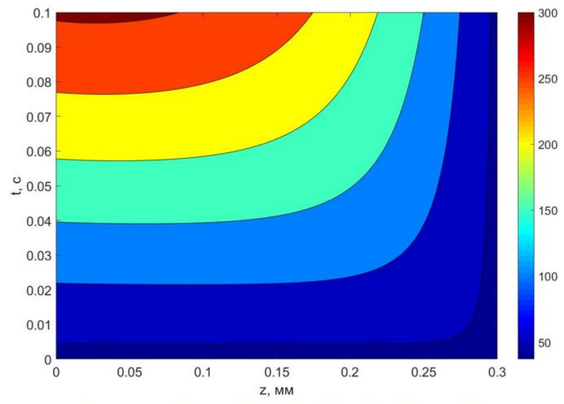
Attenuation of intensity in the cornea of the eye
Attenuation of intensity in the iris
Attenuation of intensity in the lens
Attenuation of intensity in the vitreous humor
Attenuation of intensity in the retina
Attenuation of intensity in the sclera

This model allows to find out the intensity of radiation at any thickness of the eye, and therefore to assess the degree of effect on the tissue.

Results of the thermal conductivity modeling



Temperature distribution in the retina depending on the time of exposure
Temperature distribution in the retina in spatial coordinates



Temperature distribution in the retina

The maximum heating temperature of the retina was 305 ° C. The maximum temperature remains up to a depth of about 0.06 mm, after which it decreases to 37 ° C. This model makes it possible to determine the temperature at any thickness of the retina at any time of irradiation.

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