

INFLUENCE OF REPETITION FREQUENCY ON SELECTIVE RETINAL PHOTOCOAGULATION FOR MACULAR DISEASES

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ABSTRACT

The conventional retinal photocoagulation treatment uses continuous wave (CW) lasers which results in pathophysiologic thermal environment to the surrounding normal tissues such as neural retina, choroid, and photoreceptors. Selective photodamage of retinal pigment epithelium (RPE), thus sparing photoreceptors can be achieved by using short pulsed lasers. The problem associated with the usage of short pulsed laser is that it is difficult to determine the correct dosimetry parameters. The present study investigates the laser-tissue interaction by numerically analyzing the transient temperature rise in the neural retina and RPE by varying two important pulsed laser parameters. Results reveal that low values of repetition frequency (ν) e.g. 100 Hz and low number of exposures, less than 10 pulses, produces better selective treatment. However, higher power requirement for these parameters leads to low safety margin. Optimized values of frequency and number of pulses are required to have better selectivity and safety margin.

INTRODUCTION

Laser retinal photocoagulation is used to treat number of macular diseases such as age-related macular degeneration, diabetic maculopathy, central serous retinopathy, choroidal neovascularization, etc. Most of the macular diseases are related to the decline in RPE cell function. Hence therapeutic thermal dosage of the laser treatment is associated only with the selective damage of the RPE. Although there have been several experimental studies, the influence of each laser parameter are not well quantified owing to the difficulty in measuring the actual temperature rise during the photocoagulation. The current study aims at finding therapeutic range of laser parameters by numerically studying temporal and spatial variation of temperature rise profiles, extending the previous study [1] which focuses on wavelength and pulse duration.

METHODOLOGY

The simulation of laser-tissue interaction is carried out by solving the transient heat conduction equation throughout the various ocular regions using finite volume discretization technique,

$$\rho C \frac{\partial T}{\partial t} + S(z, r, t) = \nabla \cdot (k \nabla T) \quad (1)$$

where k – thermal conductivity, ρ – density, C – specific heat capacity, and S – volumetric laser source term is given by

$$S_{vis} = q''(z, r, t) = \frac{\alpha_{vis} I_0}{\pi R^2} \exp(-\alpha_{vis} z) \quad (2)$$

The finite volume method is used to solve the governing equation with $\sim 60K$ quadrilateral elements.

RESULTS

The ratio of maximum temperature rise (ΔT) at RPE to that of neural retina $5 \mu m$ away from RPE and neural retina interface, $\Delta T_{RPE}/\Delta T_{Neural}$, is used as a measure to study the selectivity. A higher value means better selectivity and localization of deposited energy, while lower value signifies the spreading of energy to neural retina.

Effect of repetition frequency

The repetition frequency, or duty factor, is a critical parameter for selective retinal photocoagulation. Mainster [2] used repetition frequency in the range of 100 to 1000 Hz. In this study the influence of repetition frequency is analyzed by investigating four cases; 100, 500, 1000, and 5000 Hz. In all cases, 10 numbers of $2 \mu s$ pulses with energy of $10 \mu J$ /pulse are applied.

Fig 1.A shows the transient ΔT at the center of RPE for all repetition frequencies. The ΔT in the RPE remains same at the end of every pulse for 100 Hz and does not show any additive effect. In case of 100 Hz, the pulse off duration is sufficiently long enough for the RPE to cool to its initial temperature. For 5000 Hz, since the pulse off duration is less, the temperature augmentation is significant. Fig 1.B shows the comparison of ΔT for all frequencies along the center line of the laser beam at the end of final pulse. High ΔT_{max} of 58.33 K is observed for repetition frequency 5000 Hz while low ΔT_{max} of 27.2 is observed for 100 Hz. The value of selectivity $\Delta T_{RPE}/\Delta T_{Neural}$ is 44.59 for 100 Hz pulse and it is 2.23 for 5000 Hz. For 100 Hz, significant diffusion during the pulse off cycle helps in minimizing the ΔT in the neural retina. The higher frequencies don't allow enough time in between pulses for temperature decay and hence tend to produce

similar effects as that of CW. The low repetition frequencies are found to be more effective in localization of thermal damage.

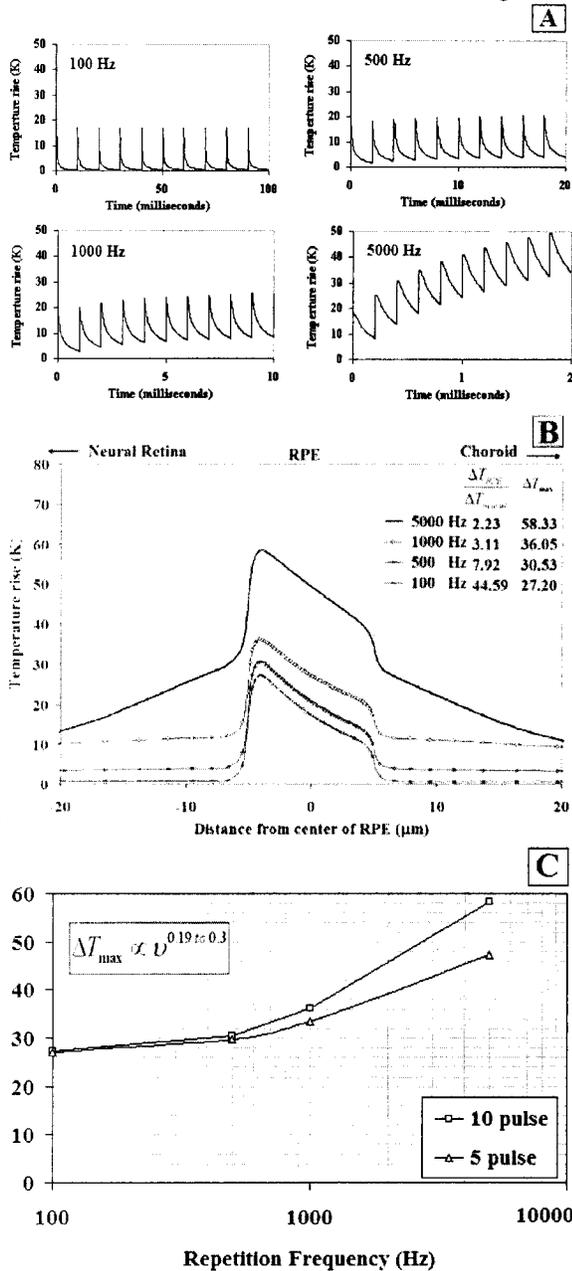


Figure 1. A. Transient temperature rise at the center of RPE
 B. Comparison of axial temperature rise
 C. Variation of ΔT_{max} , for frequencies 100, 500, 1000, 5000 Hz

Fig 1.C shows the comparison of ΔT_{max} obtained for different frequencies. The ΔT_{max} is proportional to repetition frequency $\sim \nu^\gamma$ for a fixed pulse width and pulse energy. The value of γ ranges from 0.19 for very low number of exposures at low frequencies to 0.3 for high number of exposures at high frequencies. Due to less additive effect of ΔT and low ΔT_{max} , low frequencies will require more energy to produce the same therapeutic effect as that of high frequencies.

Consequently, this increase in required threshold energy will reduce the safety margin between retinal burn and retina hemorrhage [2]. Thus, in order to have better safety margin and better selectivity, a moderate repetition frequency is preferred.

Effect of number of pulses

Fig 2 shows the comparison of $\Delta T_{RPE}/\Delta T_{Neural}$ for different repetition frequencies versus number of exposures. The selectivity always decreases with the number of exposures for all repetition frequencies. However, the influence of number of pulses is insignificant for higher number of exposures (i.e., curve flattens out). In order to have better selectivity, the number of pulses should be low (< 5). However, when the number of exposure is low, the amount of power or temperature required to break the brunch membrane will be very high. This leads to very low safety margin (Framme et. al. [3]). Hence, a moderate amount of number of pulses must be used. Based on the $\Delta T_{RPE}/\Delta T_{Neural}$ results, for higher number of exposures, the number of pulses is not a critical factor for selectivity.

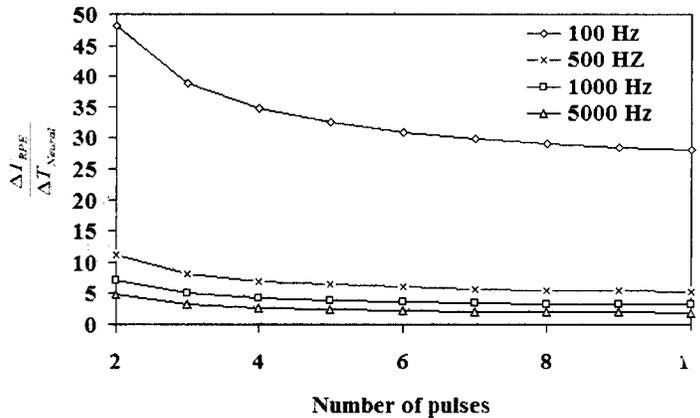


Figure 2: Variation of selectivity with pulse number for frequencies 100, 500, 1000, 5000 Hz

CONCLUSION

The laser-tissue interaction during retinal photocoagulation was analyzed by varying laser parameters. *Repetition frequency*: The low repetition frequency is effective in localization but produces lower ΔT . This, in turn, requires higher pulse energy $\sim \nu^{0.25}$, which leads to low safety margin. The high frequency produces higher ΔT , but has similar spreading effect as that of CW. Hence, an optimized protocol for repetition frequency in conjunction with pulse duration and pulse power is needed for improved clinical outcome. *Number of Exposures*: The thermal localization is unaffected by the variation in number of pulses for higher number of exposures.

REFERENCES

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