



Three-dimensional bio-heat transfer simulation of sequential and simultaneous retinal laser irradiation

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ABSTRACT

Transient simulation of retinal laser irradiation is performed for a square array comprising 3×3 uniformly distributed spots under sequential and simultaneous mode. A finite volume formulation of the Pennes bio-heat transfer model is employed as the governing equation to generate the temperature distribution within the eye domain. Temperature distribution developed due to laser power of 0.2 W/spot and time duration of 100 ms/spot is used to compare the merits of sequential and simultaneous irradiation of spots. Simultaneous mode is preferred when the time of surgery is limited, with possible excess heating in the inter-spot retinal regions. The inter-spot spacing D is also varied between one diameter and one and half diameter of the spot size (diameter) to evaluate the safe placement of consecutive spots. $D \geq 0.75$ mm can be considered as the optimum spot distance for non-interference due to excess heating. Effect of pulsation of incident laser power is observed to favorably reduce the average temperature of the irradiated regions of the retina toward photocoagulation temperature.

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1. Introduction

Laser finds frequent application in a process called Pan-Retinal Photocoagulation (PRP), a surgical treatment for diabetic retinopathy and macular degeneration of the human eye. PRP treatment for retinal ailment selectively coagulates retinal regions (Retinal Pigmented Epithelium – RPE) through laser irradiation. The success of such laser surgical process depends on the prediction and control of temperature in the irradiated tissue, in order to selectively destroy the target regions without affecting surrounding regions. Overheating could disrupt cellular mechanism in regions adjoining the target tissue, resulting in malfunction or damage to the eye [1–3]. Thus prior knowledge of temperature distribution in the entire region of treatment is essential to control the temperature and prevent damage to healthy tissue.

Accurate experimental determination of temperature field during such live surgical process is not yet possible due to limitations in non-invasive measurement of temperature and also ethical constraints and pain tolerance of patient with invasive processes

[4]. Hence analysis and computer modeling of such bio-heat transfer process can assist ophthalmologists in prescribing safe and efficient procedures.

The Pennes bio-heat model [5] is often preferred for its simplicity, validity and its wide-spread applicability in less vascularized tissues. Considering eye as a homogeneous tissue, Taflve and Brodwin [6] reported a model using a finite difference method of solution, assuming a constant convection heat transfer coefficient over the entire surface of the eyeball.

Using a computational grid that approximated the shape of the lens and other structures, models of the human and rabbit eyes were presented by Legendijk [7]. Employing an explicit forward difference scheme, both transient and steady-state calculations were performed. A two-dimensional finite element model of heat transport in the human eye was reported by Scott [8], using the bio-heat transfer equation. Steady-state temperature variation was considered in the human eye when exposed to infrared radiation. Another two-dimensional finite element model by Scott [9] calculated temperature change in the intra-ocular media in the human eye exposed to infrared radiation. This model considered both transient and steady-state solutions.

A numerical heat transport mode of human eye considering laser-ocular media interaction was presented by Amara [10]. A similar model was presented recently by Cvetkovic et al. [11]. Their models

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