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Numerical Simulation Studies for Optical Properties of Biomaterials

Alexey Seteikin, Ilya Krasnikov

Amur State University
E-mail: seteikin@mail.ru

1. Introduction

The paper concerns the propagation of optical radiation of different spectral regions in biological tissues using the Monte Carlo method. The modeling results give a visual representation of the absorbed energy density distribution in a biological medium.

There are many types of lasers with different wavelength used in modern medicine. It is well known, that laser therapy is more effective than other traditional methods. Frequently, laser therapy is used for curing protracted or chronic deceases, when traditional cure is not very effective. Therapeutic equipment based on semiconductor lasers with red and near infrared wavelength is more widespread in medicine [1], [2].

2. Modelling of photodynamic therapy

There are many factors apart from the light fluence affecting the efficacy of photodynamic therapy (PDT). Among all these factors, local tissue temperature during PDT is one of the most important. Monte Carlo simulated laser energy deposition inside tissue may also be used to compute light dosage for photodynamic therapy of various diseases. This research aims to investigate the tissue thermal response to laser irradiation before a PDT application in dermatology to minimize the possible adverse effects and complications associated with the laser intervention. A multilayer model based on the physical structure of human skin is employed to predict the temperature distribution of living tissues when they are treated with lasers. We performed Monte Carlo simulation light distribution and the distribution of the induced by the irradiation, heat [3].

Homemade software (C+) based on Monte Carlo method was used to calculate the density of absorbed light energy distribution in the skin [3]. The software validated by comparing the results of simulation of diffuse reflectance for a semi-infinite scattering medium with known analytical results [1], [4].

3. Sunscreen nanoparticles in skin

Skin protection against excessive doses of solar radiation causing skin cancer is a challenging task. Skin is a multilayered structure consisting of layers with specific physical properties [2]. Optical parameters of various skin layers such as absorption and scattering coefficient, refractive index and anisotropy of scattering, differ. The superficial skin layer (stratum corneum) serves as a natural protecting barrier for deeper-located layers containing living cells. From the optical point of view, its function is to prevent penetration of ultraviolet (UV) radiation into epidermis and dermis. In order to increase intrinsic protection of these layers by the upper-located stratum corneum, sunscreens containing chemical light-absorbing components were developed. Currently, to achieve better UV protection, light-absorbing and scattering nanoparticles of zinc oxide (ZnO) or titanium dioxide (TiO_2) are used to partially replace chemical components in sunscreens [15].

We have found that increasing amount of the absorbed radiation (15-30-40%) is accumulated in the 3-μm-thick superficial part of stratum corneum before and after administration of 1% (in 3 μm) and 5% (in 1 μm) + 1% (in 2 μm) TiO_2 nanoparticles. In case of both heat transfer sources (convection on the skin surface and blood perfusion inside the skin), the temperature increases by 0.2°C in presence of TiO_2 nanoparticles for the simulated sunlight, thus posing no heat overload to skin [3].

4. Conclusions

In case of one million packets of photons, computational error does not exceed 1%. The proposed method is very flexible, adapts well to environments with different geometry, and allows obtaining two- and three-dimensional information on the distribution of light in tissue. The algorithms based on MC method applied for the diagnosis of structural changes of the biological tissue of any internal geometry; calculation of the temperature field and the boundaries of degradation of tissue during laser therapy.

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References

[1] I.Meglinski, A.Doronin in: Adv. Biophotonics: tissue optical sectioning, Edited by V.V. Tuchin, R.K. Wang, Taylor & Francis, Chapter (2012).

[2] Tuchin, V. (ed.), [Handbook of Optical Biomedical Diagnostics], SPIE Press, Washington (2002).

[3] A.Seteikin, I.Krasnikov, E.Drakaki and M. Makropoulou J. Biomed. Opt.**18**(7) (2013) 075002.

[4] A.Doronin, I. Meglinski, J. Biomed. Opt. **17**(9) (2012)090504.

[5] B.Innes, T. Tsuzuki,H. Dawkins,J.Dunlop, G.Trotter, M. R. Nearn, and P. G. McCormick Cosmetics, Aerosols and Toiletries in Australia **15**(2002) 10-24.