

Monte Carlo method for the laser-tissue interaction with application in laser dermatology

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Abstract

Predicting light propagation in skin tissues is of theoretical importance to improve the clinical efficacy in laser treatment of dermatosis, for example, port wine stains (PWS). The Monte Carlo (MC) method is a versatile and easy-to-parallel approach that has great potential in biomedical optics. In this method, features of a sizeable number of photon packets are collected to build the statistical behavior of light transportation. Biological tissue is usually geometrically and constitutionally complicated in terms of computation. For instance, non-uniform energy distribution by selective photothermolysis is caused by various optical properties in different skin tissues, leading to preferential absorption in blood vessels rather than in other skin tissues (epidermis, dermis, hair follicles, etc.). With regard to light propagation in geometrically complex biological tissue, voxel-based Monte Carlo (VMC) has attracted much attention. In VMC method, the model geometry is represented by a group of 3D stacked hexahedron voxels. Currently, researchers believe that VMC exhibits good adaptability for complex tissue models. However, tissue interface (especially curved boundary, such as vessel wall) is approximated by artificial serrated polygonal boundary, leading to the deviation of photon reflection and refraction.

To adapt the complex tissue structure, a body-fitted tetrahedron-based MC (TMC) method was developed to simulate laser propagation in tissue to improve smoothness of tissue interface shape. Results show that the energy deposition error by TMC in the interfacial region is one-tenth to one-fourth of that by VMC, yielding more accurate computation of photon reflection, refraction, and energy deposition. Simulation of light absorption in tissues embedded with two cross-bridge vessels showed that the energy shadow is also larger than the geometrical shadow, since the scattering is more important than transmission for deep vessel. Light propagation in the multi-coaxial vessel cluster proved that an artificial vessel distribution could be used to predict absorption characteristics in real tissue with similar blood volume fraction because the highest deviation of blood energy absorption was lower than 4% among different distribution modes when vessel number is large then 20.

Keywords: Monte Carlo, Laser Dermatology, Port Wine Stain, Natural Beauty, Natural comfort