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Simulation of low-level laser propagation through the skin on the human back using the Monte Carlo method

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Abstract

Nowadays, lung diseases are increasing due to many different reasons, usually concerning pleural effusion syndrome. Low-level laser therapy has made significant progress in the biomedical field regarding diagnostic and therapeutic capabilities. For applying low-level laser in treatment, it is necessary to understand the absorption, propagation, and positive effects of the laser on each biological tissue and optimize the identification of biological stimuli in tissues. Therefore, many researchers have used the Monte Carlo method to simulate the propagation of low-level lasers through multiple layers of tissue. This paper uses the Monte Carlo method to simulate the propagation of low-level laser light at wavelengths (633 nm, 780 nm, 850 nm, 940 nm) from the human back skin surface through the skin tissues to the lung. As a result, each treatment's appropriate wavelengths, dose, and energy can be selected.

1 Introduction

Biomedical optics, or the interaction of light with tissue, is a rapidly evolving scientific topic. That is because, of the development of laser application in medicine, especially in medicine and dermatology. In the interaction of light with tissue, it is important to know the propagation of light in

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biological tissue during laser irradiation. The propagation of light in tissues depends on optical parameters: absorption coefficient, scattering coefficient, anisotropy coefficient, in addition, the refractive index of the medium.

One way to understand the distribution of light in tissues is based on solving the radiation transmission equation (RTE) [1]. Since it is very difficult to solve complex geometries, the Monte Carlo method is an effective simulation method for solving RTE equations and finding the propagation of light through multiple layers of tissue. The highly flexible Monte Carlo simulation method within complex geometries, with high accuracy, has been tested experimentally, then can model light propagation for any geometrical source even strong light-absorbing materials. But because of its statistical nature, it requires tracking a large number of photo paths to get reasonable results which leads to a loss of time.

This paper presents the modeling and propagation of a low-level laser from the dorsal skin surface through the incoming skin tissues using the Monte Carlo method. This simulation is based on the well-known and popular Monte Carlo method for simulating light transmission in multilayer tissue, anatomical structural parameters in the human body, as well as optical parameters of biological tissues. learn. These simulation results show the distribution of power density in the range ($10^0 - 10^{-4}\ W/cm^2$) of specific wavelengths (633 nm, 780 nm, 850 nm, and 940 nm), corresponding. These results demonstrate the ability of low-level laser beams to work effectively on the treated tissue based on the bio-stimulation effect. From there, it is possible to choose the appropriate wavelength, optical power, and dose for treatment.

2 Materials and Methods

2.1 The Monte Carlo method

In this paper, using a Monte Carlo simulation method to model the propagation of light in biological tissues, refers to the transport of an infinitely narrow beam of photons incident perpendicular to a multilayer tissue [2]. Each layer is infinitely wide and is described by parameters: thickness, refractive index, absorption coefficient, scattering coefficient, and anisotropy coefficient. The refractive index to be supplied is not only the refractive index of the tissue layers, but also the refractive index of the top ambient such as air, and the refractive index of the bottom medium.

In the Monte Carlo simulation, “photons” are introduced into the tissue at the location defined by the Cartesian coordinates (x, y, z). The direction of the current photon is determined by a unit vector, r, which can be equivalently described by directed cosines.

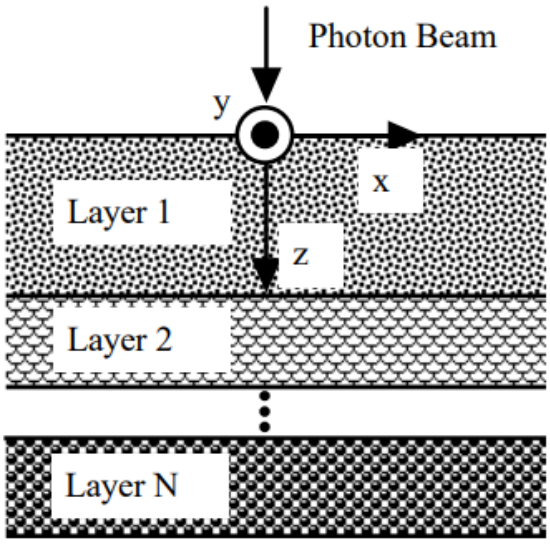

Figure 1: A schematic of the Cartesian coordinate system set up on multi-layers tissues

2.2 Simulation models

The model construct was used to simulate the propagation of light from the dorsal skin surface at the major Rhomboid site to the lung during expiration for objects with a BMI between 20 and 24.9 including skin, subcutaneous fat, muscle, pulmonary fluid, and lung with indexes of 0.3 cm, 0.6 cm, 1.3 cm, 0.5 cm, and 4 cm, respectively [3, 4].

Absorption coefficient and scattering coefficient are probability density functions, their reciprocals can be interpreted as mean distances for absorption and scattering. The total attenuation factor is the sum of the absorption coefficient and the scattering coefficient, which characterizes the interaction of the average photon per unit path length. The anisotropy coefficient g, the value of the cosine of the mean scattering angle θ - the angle between the direction of the scattered photons and the incident photons, characterizes the isotropic property of the medium. All these parameters are specific to the properties of each tissue layer and are referenced from reputable international publications and are presented in table 1.

The layers	**Wavelength** $\lambda\ [nm]$	**Absorption coefficient** $\mu_a\ [cm^{-1}]$	**Scattering coefficient** $\mu_s\ [cm^{-1}]$	**Anisotropy coefficient** **g**	**Refractive index** **n**
Skin	633	0.334	272.9	0.9	1.4
	780	0.142	197.3	0.9	1.4
	850	0.1223	175.73	0.9	1.4

	940	0.1905	156.7	0.9	1.4
Subcutaneous fat	633	0.128	125.5	0.91	1.44
	780	0.0846	114.67	0.91	1.44
	850	0.086	110.9	0.91	1.44
	940	0.168	108.6	0.91	1.44
Muscle	633	1.32	89.6	0.93	1.37
	780	0.331	71.2	0.93	1.37
	850	0.295	66.0	0.93	1.37
	940	0.401	58.1	0.93	1.37
Pulmonary fluid	633	0.32	220	0.95	1.35
	780	0.042	216	0.95	1.35
	850	0.035	202	0.95	1.35
	940	0.01	174	0.95	1.35
Lung	633	1.1	205	0.96	1.42
	780	0.87	155	0.96	1.42
	850	0.52	138	0.96	1.42
	940	0.38	121	0.96	1.42

Table 1: The optical parameters of the tissues [5-7]

3 Results

The figure shows the simulation results from the dorsal skin surface to the lung with the total input energy of the Gaussian laser beam of 4 J, the radius of the projection spot is 0.14 cm. The horizontal axis is z (cm) which is the inward normal to the tissue surface representing the depth of light that can reach the tissue. The vertical axis is r (cm) which is the axis of the cylindrical coordinate system representing the radial coordinates referring to the diffusion of light. The black line represents the wavelength of 633 nm with the density power of 10^{-4} (W/cm^2) which has the lowest absorbed energy compared to the wavelengths of 780 nm, 850 nm, and 940 nm and does not enter the lung fluid layer. The absorbed energies at 780 nm and 850 nm are shown by the similarity of green and blue

lines. For the wavelength of 850 nm, the absorption energy in tissues is the highest, and the absorbance value of the lung fluid is small.

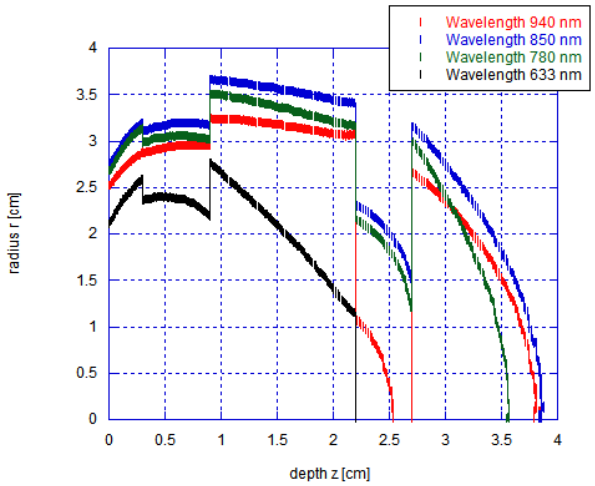

Figure 2: The absorbed energy density of tissues according to the depth of wavelengths of 633 nm, 780 nm, 850 nm, and 940 nm from the skin surface on back to the lungs with 4 J input energy

The graph depicting the photon absorption energy of the tissue layers for each specific wavelength (633 nm, 780 nm, 850 nm, 940 nm) also gives an overview of the penetrating power of each wavelength. At a wavelength of 633 nm, a power density of 10^{-4} (W/cm^2) with the convolutional parameters mentioned above, the photon is capable of penetrating up to 2.2 cm from the skin surface, The largest effective radius is reached in the muscle layer with a size of 2.95 cm.

The wavelengths of 780 nm, 850 nm, 940 nm are capable of penetrating deep into the lung tissue layer. The wavelength of 850 nm has the largest effective area and penetration at 3.67 cm and 3.88 cm, respectively.

4 Conclusions

With a view towards realizing the application of low-level laser equipment for the rehabilitation of pleural effusion lesions, the propagation of the laser beam into biological tissue was simulated by the Monte Carlo method. From simulation results, low-level lasers with wavelengths of 780nm, 850nm, 940nm can completely affect the lung fluid layer from the dorsal skin surface. These wavelengths are very useful and suitable for developing low-level laser therapy devices. As the irradiation time increases, the penetration depth and radius of impact of the beam also increase.

This simulation result paves the way for future research into the use of low-level lasers with wavelengths of 780 nm, 850 nm, and 940 nm in non-invasive laser therapy for pleural effusion. Assist in minimizing damage when treating pleural effusion caused by incorrect aspiration. The propagation of the power laser at two wavelengths, 780 nm and 850 nm, produces similar results. Since then, a low-level laser device has been developed that uses the two-wavelength effect while improving the laser's ability to affect biological tissues as well as the ability of the beam to penetrate deeply into the body.

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The authors declare that they have no conflict of interest.

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