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Inaccuracy of the classical Monte-Carlo simulation in the general case of 1D turbid biological media

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Abstract **- Solution of the direct problem of light transport in 1D turbid media by Monte Carlo simulation (MC) was compared with exact analytical results based on improved Kubelka-Munk approach. The divergence of these two solutions was observed. Improvement of MC was proposed to satisfy the exact approach.**

Keywords - Monte Carlo; tissue optics; optical spectroscopy; light transport in tissues; Kubelka-Munk approach.

I. INTRODUCTION

Due to a lack of exact analytical solution of the general radiative transfer equation (RTE), the Monte Carlo simulation (MC) for light propagation in turbid media is often utilized, especially in tissue optics [1]. In that area MC is adopted as a reference method for computation of light transport in tissues, so different less accurate models (e.g. diffuse approximation, modified Beer-Lambert law, etc.) are often compared with MC [2]. Despite an established opinion about the accuracy of MC, the purpose of our research is to compare the classical MC [3] with a strict analytical solution introduced in [4].

II. METHODS

Recently, the strict analytical solution for the general case of 1D turbid media was obtained with the use of the improved two-flux Kubelka-Munk set of equations [4]:

$$\begin{cases} dF_-(x)/dx = -\beta_1 F_+(x) + \beta_2 F_-(x) \\ dF_-(x)/dx = \beta_1 F_-(x) - \beta_2 F_+(x) \end{cases}, \quad (1)$$

where $F_+(x)$ and $F_-(x)$ are forward and backward fluxes respectively; β_1 and β_2 are optical properties of the medium. For the classic Kubelka-Munk approach (KMA):

$$\beta_1 \sim (\mu_a+\mu_s);\ \beta_2 \sim \mu_s\ , \quad (2)$$

where μ_a and μ_s are the absorption and scattering coefficients in RTE. For the improved KMA (IKMA) [4]:

$$\beta_1 = f_1(\mu_a,\mu_s) \neq (\mu_a+\mu_s);\ \beta_2 = f_2(\mu_a,\mu_s) \neq \mu_s\ . \quad (3)$$

It allows one, contrary to (2), to obtain the exact solution for boundary (backscattered or transmitted) fluxes. We tried to compare results of IKMA and the classical MC when the mean free path length "l" and a scattering/absorption probability "P" was taken as usual: $l = -\ln\xi/(\mu_a+\mu_s)$; $P = \mu_s/(\mu_a+\mu_s)$.

III. RESULTS

We revealed that classical MC results diverge with results of IKMA based on (3) (Fig.1).

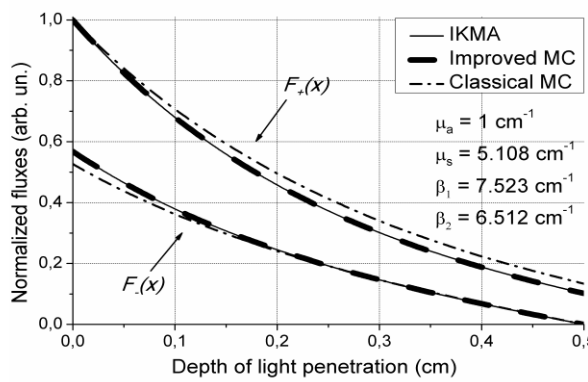

Fig. 1. Forward $F_+(x)$ and backward $F_-(x)$ fluxes computed in different approaches. The formulation of the problem is similar to [4].

It was shown that to obtain an accurate solution by MC in the general case of turbid media with non-divided optical coefficients (3) it is necessary to use the following expressions:

$$l = -\ln\xi/\beta_1;\ P = \beta_2/\beta_1, \quad (4)$$

where β_1 and β_2 are taken as (3); ξ is a random number between 0 and 1.

IV. CONLUSION

At modeling of light propagation in one-dimensional turbid biological and non-biological media, the classical MC results diverges with a strict analytical ones based on IKMA. Equations (3) and (4) for the mean free path length and the scattering/absorption probability should be used in order to equalize the MC model with the exact method.

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