Experimental study of concentration effects in tissue phantoms

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ABSTRACT

Experimental study and computer modeling of light propagation in a turbid media with different content of scattering particles were done. Latex phantoms as a model of living tissue have been investigated. Experimental results have shown saturation of transmittance and reflectance at selected wavelengths with concentration. This saturation effects are explained by changes of packing factor of scatterers and should be included in description of living tissue optical properties changes due to homeostasis.

Keywords: phantoms, turbid media, scattering spectroscopy, inverse adding-doubling method

1. INTRODUCTION

Non-invasive imaging of the interior of highly scattering tissues and the prediction of light distribution in tissue is one of the important problems in biomedical optics. The scattering properties of tissue are related to tissue morphology. Most tissues are inhomogeneous turbid media in which the optical radiation transfer is complex. Tissue-like phantoms are widely used for study of light propagation in tissues[1-11]. Real tissues are usually densely packed systems of scatterers, therefore concentration effects should be accounted for. Latex as a phantom medium uses to simulate of tissue scattering properties. This paper presents the results of experimental study and computer modeling of effects of scattering particles concentration (latex emulsion) on light propagation through turbid media.

2. MATERIALS AND METHODS

In this study we used a commercially available computer-driven CARY-2415 spectrophotometer with integrating sphere to make total transmittance, and diffuse reflectance measurements of samples in the 400-700 nm wavelength range. For each phantom diffuse reflectance R_d and total transmittance T_d were measured. The diffuse reflectance was calibrated on the basis of reflectance from standard reflectance plate (BaF_2).

Investigated phantoms were prepared from the latex emulsion diluted by distilled water. Concentration of emulsion in the samples was 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, and 5% (vol/vol). Latex phantoms model the living tissue. Samples were poured into 3-mm cuvette. Sizes of the latex particles were determined by optical microscopy. The mean radius of the scatterers was 1 μm.

We used the inverse adding-doubling method that was developed by *Prahl et al.*[12] to calculate the reduced scattering coefficients of turbid media (phantoms) from measured values of total transmittance and diffuse reflectance. To obtain optical properties of the investigated phantoms we used a computer program of *S.A. Prahl* (Oregon Medical Laser Center, USA; www.omlc.ogi.edu).

We have investigated concentration dependence of efficiency factor for scattering $Q_s^{'}(r,\lambda)$, defined as the ratio of the scattering cross section and the geometrical cross section:

$$Q_s^{'}(r,\lambda) = \frac{\sigma_s^{'}(r,\lambda)}{\pi r^2}, \tag{1}$$

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where $\sigma_s'(r,\lambda) = \sigma_s(r,\lambda)(1-g)$, σ_s is the cross section for scattering of a particle, g is the average cosine of the scattering angle, πr^2 is the geometrical cross section, r is the radius of the scattering particle.

In a multiple-scattering medium, the reduced scattering coefficient, μ_s', is related to σ_s' by[13-16]

$$\mu_s' = N\sigma_s' \frac{(1-\eta)^4}{(1+2\eta)^2}, \qquad (2)$$

where N is the total number of scattering particles per unit volume, i.e., the number density. N can be given as $\frac{\eta}{(4/3)\pi r^3}$, where η is the volume fraction of the particles relative to the total volume. From Eq. 2 we can find the reduced cross section for scattering σ_s'.

3. RESULTS AND DISCUSSION

Figs. 1-4 show the experimental results of study of the latex phantoms with various concentrations of the scatterers. Figs. 1 and 2 present the diffuse reflectance spectra and the total transmittance spectra of the samples. Fig. 3 presents the latex emulsion concentration dependence on the diffuse reflectance at three wavelengths. In this figure we can see that the diffuse reflectance has a slight saturation which depends on concentration (expressed in volume fraction) of the latex emulsion. Fig. 4 shows concentration dependence of the optical density of the latex phantoms. Optical density is defined as $D = -\log(T_d)$. We can see that the optical density saturates as concentration of latex goes up. The saturation of optical density and diffuse reflectance are connected with change of scattering properties of phantoms.

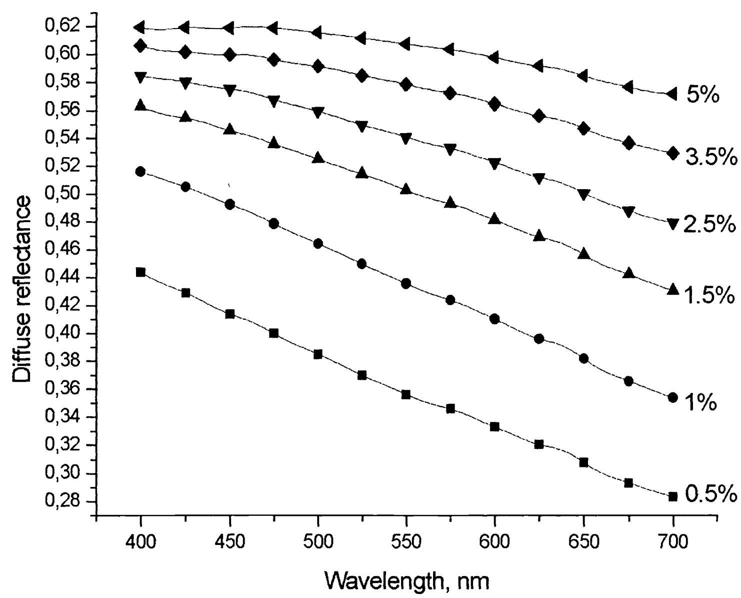

Figure 1. Diffuse reflectance spectra of the latex emulsion phantoms with various volume fractions.

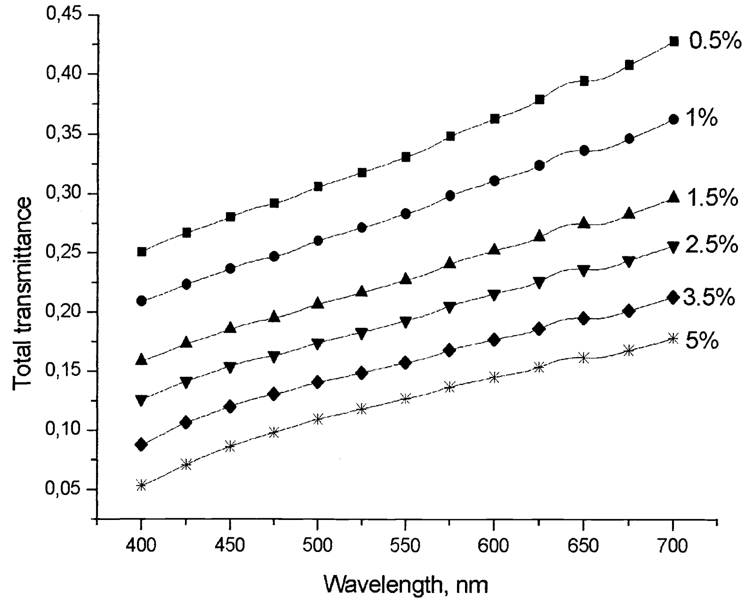

Figure 2. Total transmittance spectra of the latex emulsion phantoms with various volume fractions.

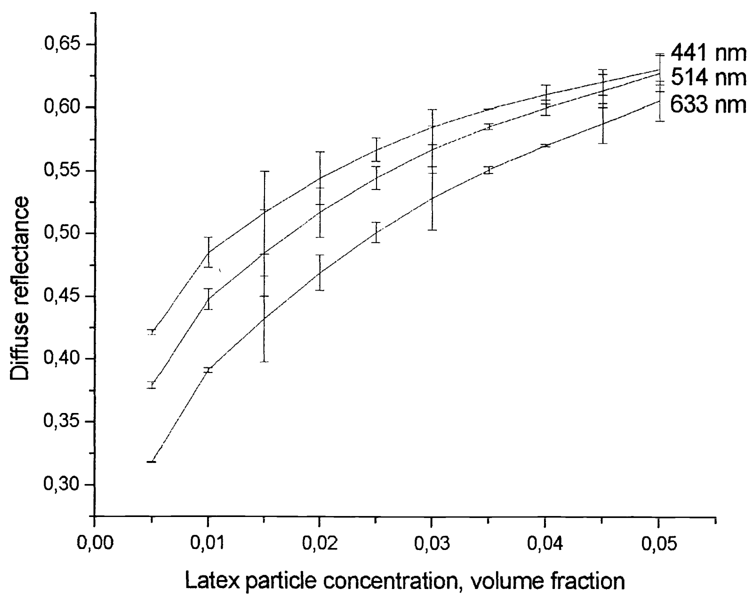

Figure 3. The diffuse reflectance of the latex emulsion phantoms with various volume fractions versus concentration.

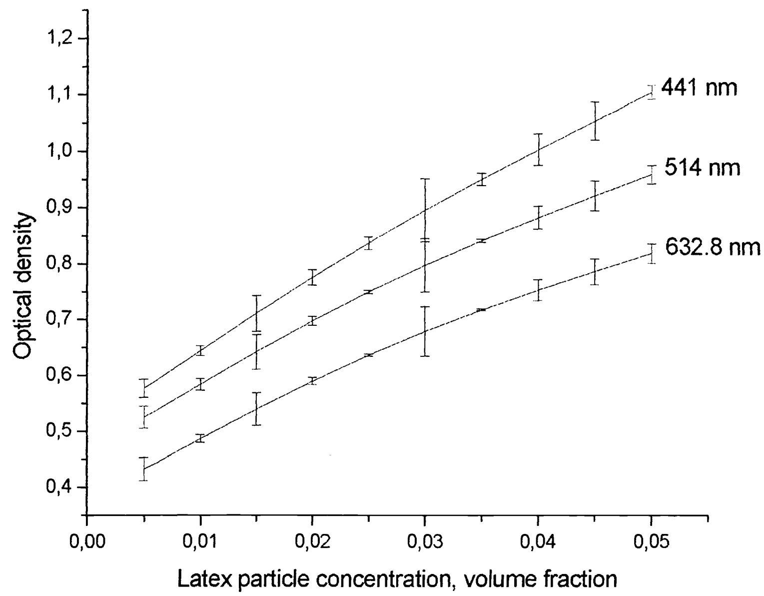

Figure 4. The optical density of the latex emulsion phantoms with various volume fractions versus concentration.

Using inverse adding-doubling method the reduced scattering coefficients of the phantoms were obtained. Results of our calculations are presented in Fig. 5. It is well seen that the scattering coefficients of the phantoms decrease with increasing of the wavelength. With increasing of latex emulsion concentration into the phantoms the increasing of the reduced scattering coefficients is observed.

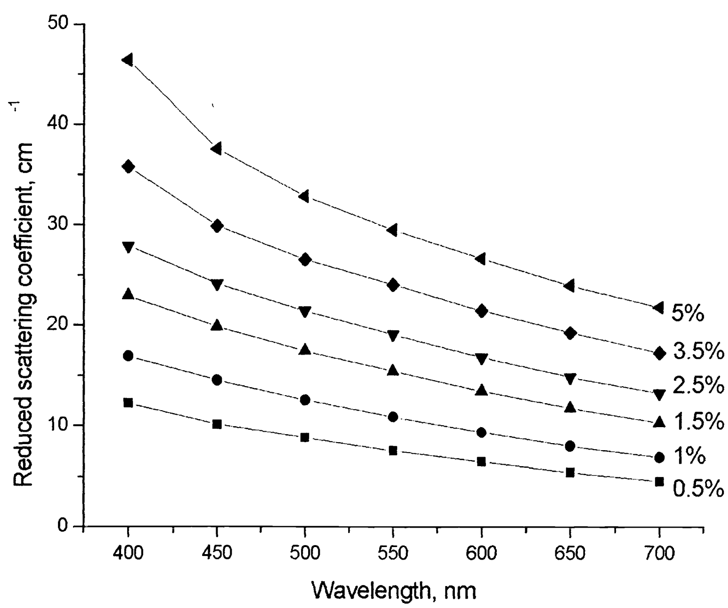

Figure 5. The wavelength dependence of the reduced scattering coefficient of the phantoms with various concentration of latex emulsion.

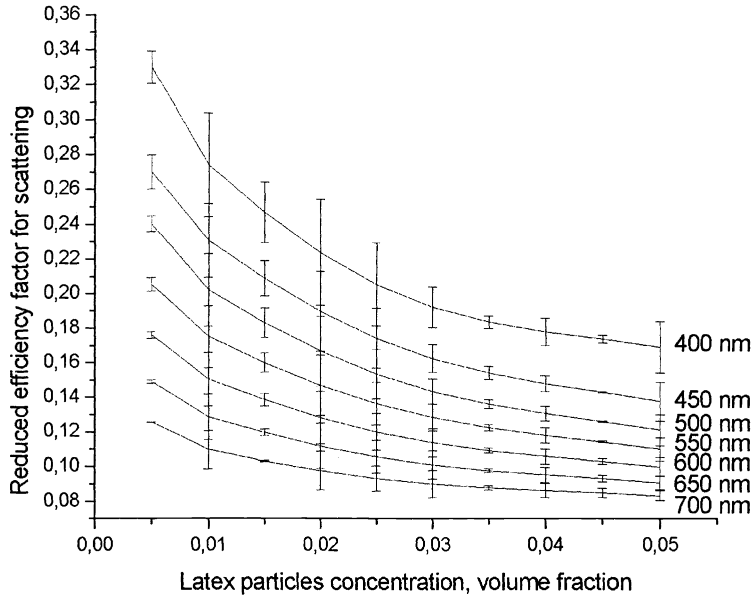

Figure 6. Concentration dependencies of the reduced efficiency factors for scattering of the latex phantoms.

Fig. 6 shows concentration dependence of the reduced efficiency factor for scattering. The values of this parameter were defined from Eq. 1. It is well seen that the reduced efficiency factor for scattering is decrease on 40% if the concentration of latex in the phantoms is increase from 0.5 to 5 %. Decreasing of this parameter is observed, in general, in phantoms with small concentration of latex emulsion (to 2%). Further increasing of the concentration influences on the behavior of this factor slightly.

4. CONCLUSION

This paper discusses some aspects of the optical properties of tissue-like phantoms. Experimental results and computer simulation of light propagation in phantoms with various concentration of latex emulsion are presented. The saturation of transmittance and reflectance of the phantoms in dependence on volume fraction of the scatterers was revealed. The inverse adding-doubling method was applied to obtain the reduced scattering coefficient of latex phantoms. It was investigated the concentration dependence of reduced efficiency factor for scattering. The change of the volume fraction of scatterers in the phantoms causes the change of the reduced efficiency factor for scattering if the scatterer concentration is small.

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