Study of spatially resolved diffuse reflection at small source-detector separations

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Steady-state diffuse reflectance based on P_3 approximation is studied at short source-detector separations. In many practical applications, we can only measure the diffuse reflectance light close to the source, and attempt to derive the optical parameters of tissues from the collected data. In this paper, diffuse reflectance with different absorption coefficients and scattering coefficients at short source-detector separations is measured, and the experimental results are compared with that of P_3 approximation. These studies show that P_3 approximation can be used to describe the light contribution close to the source, and can be used to study strong absorption medium.

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With the success of introducing laser into medical diagnose and treatment, the propagation of photon in biological tissue has been paid attention increasingly. There is a significant need for methods that accurately quantify optical properties of small source-detector separations and highly absorbing media such as small volumes of superficial tumors, P_3 approximation[1] of transport equation was used to deal with this kind of problem. In our experiment, we study the diffusing reflectance in different scattering and absorbing phantoms in the region near the source. In 1999, Bevilacqua and Depeursinge[2,3] found that the determination of absorption coefficient and scattering coefficient was influenced when they measured optical properties of small tissue volume with the technique of spatially resolved diffuse-reflectance. This work should be significant for the determination of optical properties of small volume tissue.

The schematic of experimental setup is shown in Fig. 1. The laser was operated at 650 nm. Both illuminating fiber and detecting fiber used a kind of optical fiber with a numerical aperture of 0.2 and a core diameter of 125 μm. The two fibers were setting on two plates with smooth surface to protect them. Each time before or after used the fibers were cleaned using alcohol. The position of detecting optical fiber was controlled by a stepping motor with a precision of 2.5 μm, in our measurement, the source-detector separation ranges approximately between 0.3 and 3.0 mm with a spacing of 0.125 mm. The diffusely reflected light through the fiber detected using a electron-multiplier phototube, then the signal acquired was digitized by a 16-bit analog/digital card (National Instrument PCI-6014). A computer was used to control the instrument and to process the data.

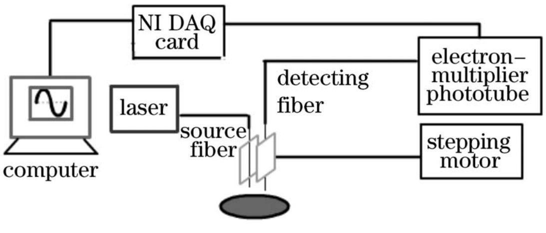

Fig. 1. Experimental setup for measuring spatially resolved reflectance.

The tissue phantoms with different scattering and absorption characteristics at 650 nm were prepared from 10% intralipid, containing 10 g soybean oil, 1.2 g lecithin, 2.25 g glycerin and 86.1 g water per 100 ml solution. The anisotropy factor g of intralipid is 0.82 and the absorption coefficient of Intralipid is 0.00034 mm^{-1} at 650 nm[5].Methylene blue was dissolved in distilled water to a concentration of 0.000535 mol/L. The absorbing coefficient of MB can be calculated by $\mu_a = 2.303ec$, where e is extinction coefficient, it is 62654 L/cm·mol at 650 nm, c is the molar concentration of MB[6]. The intralipid was diluted by distilled water to different concentrations to change the scattering coefficient of the phantom, therefore the phantoms with different μ_s were made. Their optical parameters were listed in Table 1, where μ_s were determined according to their proportional relation[4,5], and μ_a was considered invariant because the absorption coefficient of pure water is 0.00034 mm^{-1} at 650 nm[7]. MB was added in varying concentrations to the 10% intralipid to change the absorption coefficient, therefore

Table 1. Optical Parameters of the Phantoms with Different μ_s

Samples Concentration 10% Intralipid	μ_s (mm^{-1})	μ_a (mm^{-1})
10% (16 ml)	35	0.00034
5% (16 ml)	17.5	0.00034
3% (16 ml)	10.5	0.00034
2% (16 ml)	7.0	0.00034
1% (16 ml)	3.5	0.00034
0.5% (16 ml)	1.75	0.00034

Table 2. Optical Parameters of the Phantoms with Different μ_a

Samples Concentration 10% Intralipid	μ_s (mm^{-1})	μ_a (mm^{-1})
10%+0.1 ml(MB)	35	0.0482
10%+0.2 ml (MB)	35	0.0962
10%+0.3 ml (MB)	35	0.144
10%+0.4 ml (MB)	35	0.192
10%+0.5 ml (MB)	35	0.240
10%+0.6 ml (MB)	35	0.288

the phantoms with different μ_a were made. Their optical parameters were listed in Table 2, where μ_s was considered invariant.

Figure 2 shows the measuring spatially-resolved diffuse reflectance for the phantoms with different μ_s. The curves is sensitive to the change of μ_s, and the height of the curves falls with the decrease of μ_s. Figure 3 shows the measuring spatially-resolved diffuse reflectance for the phantoms with different μ_a. The curves is sensitive to the change of μ_a, and the height of the curves falls with the increase of μ_a. In Figs. 2 and 3, we can find that the trend of the curves with increase of μ_a is quite different to the trend of the curves with decrease of μ_s, and this fact implies that we can reconstruct the optical parameters from the spatially-resolved diffuse reflectance. The spatially-resolved diffuse reflectance from tissue close to the source is sensitive to the change of μ_a and μ_s, and this advantage is vary useful for us to measure optical properties of tissue, for example, a measurement of strong absorption of tissue is allowed. But, compared with diffuse approximation, function relationship of between reflectance curve and optical parameters is much complicated, and some studies show that a higher order optical parameter is needed[3].

P_3 approximation is an approximation of the transport equation, and its an analytic solution for a semi-infinite medium has been obtained[1]. We calculated P_3 approximation diffuse reflectance with the parameters in Tables 1 and 2, and high-order moments of scattering phase function is $g_n = g^n$. Figure 4 shows the calculational spatially-resolved diffuse reflectance for the μ_s=35, 17.5, 10.5, 7.0, 3.5, 1.75, and keep μ_a=0.00034 mm and g = 0.82 invariable. Comparing Fig. 4 with Fig. 2, we found a good consistency of trend in the region of ρ>0.35 mm. In Fig. 5, spatially-resolved diffuse reflectance for μ_a=0.0482, 0.0962, 0.144, 0.192, 0.240, 0.288mm^{-1}, and keep μ_s=35 mm^{-1} and g = 0.82 invariable. Comparing Fig. 5 with Fig. 3, we found again a the good consistency of trend in the region of ρ>0.35 mm.

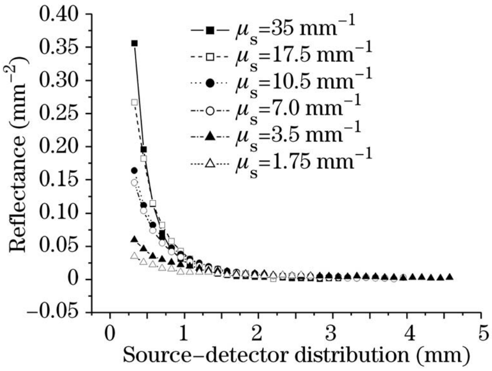

Fig. 2. Experimental diffuse reflectance with different μ_s .

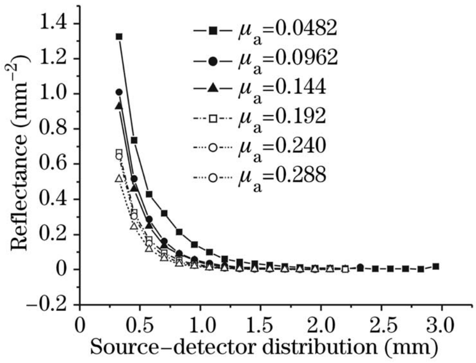

Fig. 3. Experimental diffuse reflectance with different μ_a.

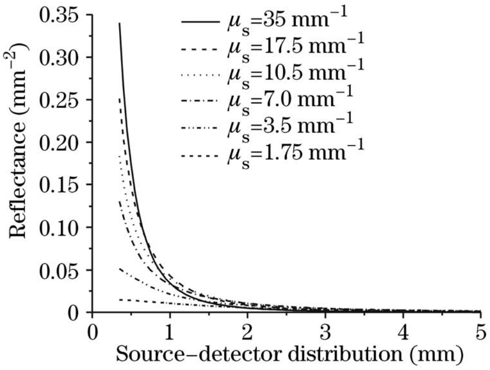

Fig. 4. P_3 approximation diffuse reflectance with different μ_s.

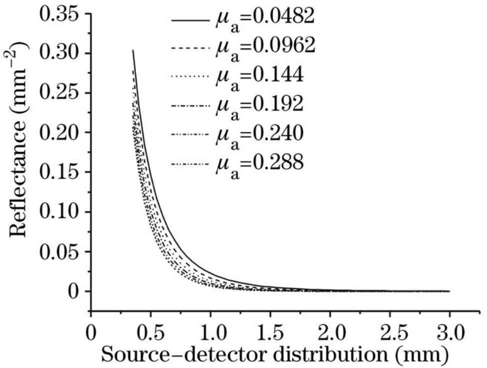

Fig. 5. P_3 approximation diffuse reflectance with different μ_a.

Our experimental results showed that spatially-resolved diffuse reflectance is sensitive to the optical parameters, and μ_s and μ_a took different ways to influence curves. Our studies also showed that P_3 approximation theory can be used to describe the diffuse reflectance at small source-detector separations, especially P_3 approximation theory models the radiance in highly absorbing media correctly.

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