11:00am

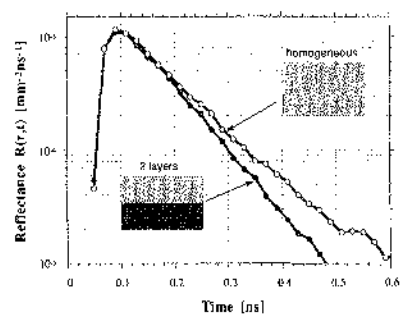## CTuG3 Time- and phase-resolved spectroscopy of multilayers tissues

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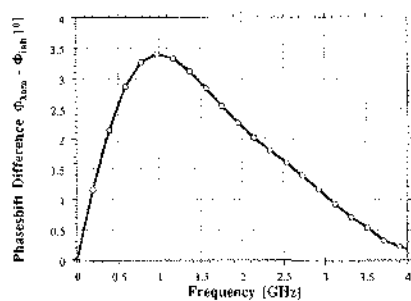
Imaging in medicine using light rather than potentially harmful ionizing radiation is a rapidly growing field of interest. The method of measuring the ballistic photons transmitted through homogenous media containing hidden absorbers seems to be a promising technique. However, little attention has been paid to the influence of multilayered tissues surrounding the tissue of interest, as, for example, the skull encapsulating the brain. In this work we report the possibilities of measuring the thickness of the layer (e.g., the skull) and the absorption and scattering coefficient (μ_a and μ_s) simultaneously by means of time- and phase-resolved spectroscopy.

A Monte Carlo model[1] was adapted to simulate time-resolved propagation of photons in a multilayered tissue that yielded the reflectance, $R(r,t)$, in mm^{-2} ns^{-2} at a radial distance, r, from the source of light. Studies in the frequency domain were simulated by taking the Fourier transform of $R(r,t)$ to yield the phase shift Φ (r,f) and demodulation M(r,f), where f is the intensity modulation frequency of the light source. It was found that a multilayered tissue system can easily be distinguished from homogenous systems by the $R(r,t)$ or the F (r,f) and M(r,f) measurements.

As an example, in Fig. 1, the reflectance at r = 1 cm from the source in a homogenous medium ($\mu = 0.2$ cm^{-1}) is compared to the reflectance of a two-layered medium ($\mu_a=0.2$ cm^{-1} in upper 6 mm, $\mu_a = 0.5$ cm^{-1} in lower layer). The scattering was $\mu_s = 62.5$ cm^{-1}, g = 0.92 for both media. After 200 ps, the curve corresponding to the two-layered medium starts to decay faster than the one representing the homogenous medium. The early photons travel a short path and encounter only the first layer. The later photons travel deep

enough into the tissue to reach the second layer, where they get relatively more absorbed. Thus, the curve of the two-layered tissue decays faster, after a characteristic time that is indicative of the thickness of the upper layer. The initial 200 ps contain enough information to determine the optical characteristics of the upper layer. The later part of the impulse response can be used to describe the optical properties of the lower layer.

Figure 2 shows the situation in the frequency domain. Here, the difference in the phase shift encountered in a homogeneous medium and a two-layered medium is displayed. Lower frequencies are less attenuated while traveling into the tissue than high frequencies.[2] Thus, high frequencies see only the upper layer, and the difference in phase shift between a homogeneous and a two layered system is small. Lower frequencies travel deeper into the tissue and are affected more strongly by the second layer. Thus, the difference in phase shift between the homogeneous and the two-layered systems is large. The phase shift at high frequencies can be used to determine the optical characteristics of the upper layer, while the phase shift at lower frequencies yields information about the optical properties of the lower layer. The frequency where the phase shift difference starts to deviate from zero is indicative of the thickness of the upper layer (in Fig.2 ~4GHz).

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1. L. Wang, S. L. Jacques, "MCML - Standard C Monte Carlo Modeling of PhotonTransport in Multi-Layered Tissues," submitted to Med. Phys.

2. J. Fishkin, E. Gratton, M. J. van de Ven, W. W. Mantulin, "Diffusion of Intensity Modulated Near-Infrared Light in Turbid Media," SPIE 1431: Time-Resolved Spectroscopy and Imaging of Tissues 1991, p. 122.

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CTuG3 Fig. 1. Comparison of a Monte-Carlo Simulation of the time-resolved reflectance at 1 cm from the source for homogenous tissue ($\mu_a = 0.2$ cm^{-1}, $\mu_s = 62.5$ cm^{-1}) and a two layered tissue ($\mu_a = 0.2$ cm^{-1} upper 6mm, $\mu_a = 0.5$ cm^{-1} lower layer).

CTuG3 Fig. 2. Phase shift difference determined through Monte-Carlo simulations of photon propagation between a homogenous tissue and a two layered system. Characteristic parameters are the same as in Fig. 1.