Recovery of Absolute Optical Absorption Coefficient in Quantitative Photoacoustic Tomography Using Monte Carlo Method

Yang Li and Chulhong Kim

Bio Optics and Acoustics Lab., Department of Biomedical Engineering, University at Buffalo

Abstract

The measurement of optical absorption coefficient is important because it is strongly related to oxygen saturation and total concentration of hemoglobin, which are crucial to the study of *in vivo* physiological functions such as tumor hyper-metabolism and brain functions. Two types of ultrasound-mediated optical tomography—**Photoacoustic Tomography (PAT)** and **Ultrasound-modulated Optical Tomography (UOT)**—are hybrid biomedical imaging techniques that can be used for this measurement. **In this project, we demonstrated the feasibility of quantitative optical absorption imaging of combined PAT and UOT using Monte Carlo simulation method.**

Background

PAT and UOT provides strong endogenous and exogenous optical absorption contrasts with high ultrasonic spatial resolution. It was found that PAT signals are directly proportional to the product of the local absorption coefficient and local optical fluence, while UOT signals are proportional to local optical fluence only.

Our hypothesis was that the ratio of PAT and UOT signals would recover the absolute absorption coefficient of an object. Also, the signals for optical fluence, F around an object would be significantly disturbed if another object is placed on top of it.

Method

The simulation parameters included a cylindrical-ultrasonic-focal zone of 2 mm in diameter and 20 mm in length, an ultrasonic pressure of 1.5 MPa, an ultrasonic frequency of 1 MHz, and an optical wavelength of 632 nm. One hundred millions of photons were used for each simulation. The simulation schematic is shown in Fig. 1. A pencil beam is normally incident along the Z axis on a scattering medium with a reduced scattering coefficient of 10 cm^{-1} and a background absorption coefficient of 0.1 cm^{-1}. Three optically absorptive objects were embedded in the scattering medium. Objects 1 and 2 with a μa of 6 cm^{-1} were positioned in the middle plane. Then, the object 3 with a μa of 10 cm^{-1} was included above object 1. Ultrasound waves were applied along the X axis.

We mapped the distribution of initial PA pressure waves in the medium by multiplying the known μa map with the F map acquired from the MC simulation. In a practical PAT system, the propagated PA waves are detected by an ultrasound transducer.

The recovery process of optical absorption coefficients includes the following steps:

(1) to form high-resolution P_0 images using PAT
(2) to form low-resolution F maps using UOT
(3) to compute high-resolution μa maps using $\mu_a \propto P_0/F$.

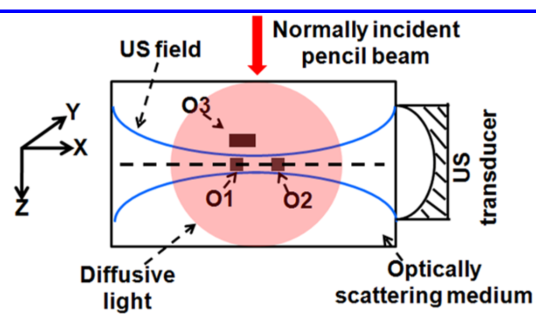

Fig. 1. Schematic of Monte Carlo simulation. US, ultrasound and O, objects.

Results

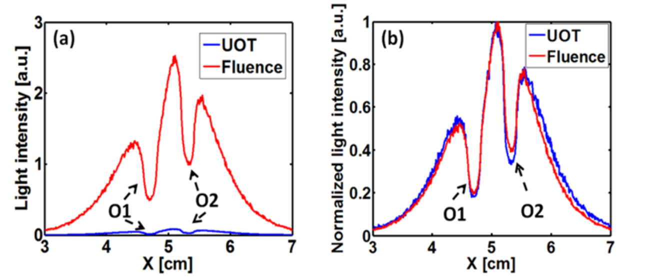

Fig. 2. Comparison of 1-D profiles of ultrasound-modulated light intensity and optical fluence, cut along the dotted line in Fig. 1. (a) Absolute light intensity and (b) normalized light intensity. O, objects.

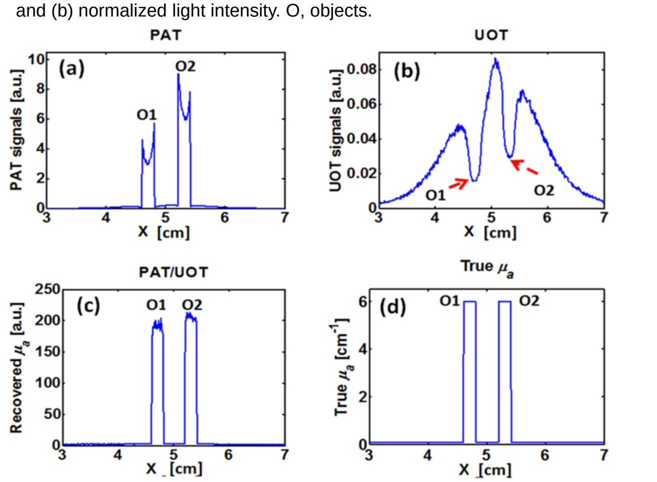

Fig. 3. Monte Carlo simulation results of recovered optical absorption coefficients (μ_a). (a) PAT A-line image cut along the dotted line in Fig. 1. (b) UOT A-line image. (c) Recovered μ_a by taking the ratio between PAT and UOT A-line images. (d) True μ_a. O, objects.

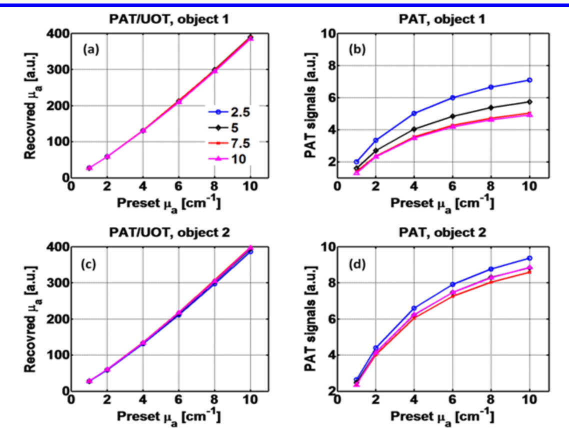

Fig. 4. Recovered μ_a of objects (a) 1 and (c) 2 by taking the ratio between PAT and UOT signals and PAT signals of objects (b) 1 and (d) 2 with varying the various μ_a of Objects 1 and 2 from 1 to 10 cm^{-1} and Object 3's μ_a from 2.5 to 10 cm^{-1}. The legend in Fig. 4a shows the various μ_a of Object 3.

Conclusion

The results from the Monte Carlo simulation successfully demonstrated that **the optical absorption coefficients can be accurately recovered by using the ratio between PAT and UOT signals.** No mathematical reconstruction algorithm and introduction of additional contrast agents are required for this method.

The recovered μ_a using both PAT and UOT signals is consistently immune to complex optical heterogeneities, thus the practicability of the combined system can be greatly enhanced to *in vivo* imaging.

Reference

1.) **C. Kim**, *et. al.*, **Chem. Rev.**, **110**, 2756-2782, (2010)

2.) **C. Kim**, *et. al.*, **Opt Letter, 32**, 2285–2287 (2007).

3.) **C. Kim**, *et. al.*, **ACS Nano, 4**, 4559-4564 (2010).

4.) L. V. Wang, **Dis Markers, 19**, 123–138 (2004).

5.) L.V. Wang, *et. Al.*, **"Biomedical Optics: Principles and Imaging",** (John Wiley & Sons, Inc, Hoboken, NJ, 2007).