Improving the accuracy of the chromophore reconstruction in diffuse optical tomography by using structural and functional-priors from MRI

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Introduction

Near-infrared (NIR) diffuse optical tomography (DOT) is a relatively new imaging modality that is intrinsically sensitive to oxy-hemoglobin (HbO2), deoxy-hemoglobin (Hb), water, and lipid, the primary NIR absorber chromophores in breast tissue. This method provides unique quantitative physiological information directly related to tumor vascularity and oxygenation, with in-expensive, non-ionizing, and non-invasive instrumentation. Photomultiplier tubes are the ideal choice of detectors for DOT systems due to their superior sensitivity and low noise. However, their sensitivity degrades for the wavelengths above 850 nm, where water and fat absorption is dominant. Therefore, a bulk water and fat content is generally assumed in the calculations based on average values for breast tissue. However, the water content of the breast varies from 10% to 70% with subject's breast size and changes significantly during the aging process, menstrual cycle, and chemotherapy treatments [5-8]. Thus, assumptions about the bulk concentration of water affect the calculated total hemoglobin and oxygen saturation values. In the past, magnetic resonance imaging (MRI) has been used in conjunction with DOT mainly to provide high-resolution structural and contrast-enhanced images as spatial-priors for the optical reconstruction algorithm to improve the accuracy of the reconstructed optical parameters [1]. In this study we constructed an ethanol-based multi-modality phantom to investigate the advantage of using functional-priors, specifically water concentration, from MRI to further improve the accuracy of the chromophore reconstruction in DOT.

Methods

To model the interaction of NIR light with the breast tissue, we conducted a series of studies using solid and liquid phantoms with optical properties similar to breast tissue. Fat-water emulsion phantoms with high fat concentrations showed very high scattering in the NIR region, which made them not suitable for optical imaging. In contrast, ethanol-based phantoms have low scattering and also the NIR absorption spectrum of ethanol is very similar to fat. Therefore, in this study we prepared liquid phantoms with different concentrations of water and ethanol for MR-guided optical imaging. Indian ink was used as absorber material and an intralipid solution with very low concentration (1%) was used as scattering material. A shell phantom with irregular solid compartment and a small circular inclusion was also constructed with optical properties similar to tissue [9]. Ethanol-water solutions filled the space between the solid compartments and the circular inclusion (Figure 1). Water and ethanol concentration maps were obtained by a 4T MR system, using the three-point Dixon (3PD) technique [2] as shown in Figure 1. The imaging parameters were as follows: gradient echo (TR = 3500 ms, TE = 20 ms), field of view 150 mm, and matrix size 256 x 256. Structural information from MR images served as spatial-priors to provide the boundary information for the optical reconstruction algorithm and the water concentration obtained from 3PD method was employed as functional-prior.

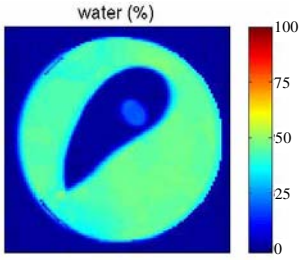

Figure 1. Water concentration map obtained by 3PD MRI.

Our DOT system is a frequency domain instrument [3]. NIR laser diodes with wavelengths 680, 785, and 830 nm are sequentially modulated at the frequency of 110 MHz. A multi-source multi-detector ring shape fiber optic interface is utilized to acquire optical data from the phantom. A finite element (FEM) reconstruction algorithm based on the diffusion equation is used to directly generate the chromophore concentration maps based on the absorption and scattering spectra of the chromophores [4].

Results

In construction of the phantoms, the volume concentration of the Indian ink in liquid compartments and the irregular solid compartment were set to 1.5% and 4%, respectively. The water content of the background and the small circular object were set to 50% and 20%, respectively (as can be also seen in the MRI image). Figure 2 shows the reconstructed water and Indian ink concentration maps obtained from DOT with and without a priori information from MRI. The chromophore concentration maps in the top row have been reconstructed only by using the optical data, without any structural or functional information. As can be seen, the water and Indian ink distribution cannot be recovered without a priori informaion. Later, the boundary of the irregular and small circular object as well as the water content information obtained from 3PD MRI were used as structural and functional-priori information to guide the optical reconstruction algorithm. A priori information from MRI improved the accuracy of the reconstructed images significantly as shown in the bottom row. The volume concentrations of the Indian ink in the liquid and solid compartments were recovered with 15% and 30% error, respectively.

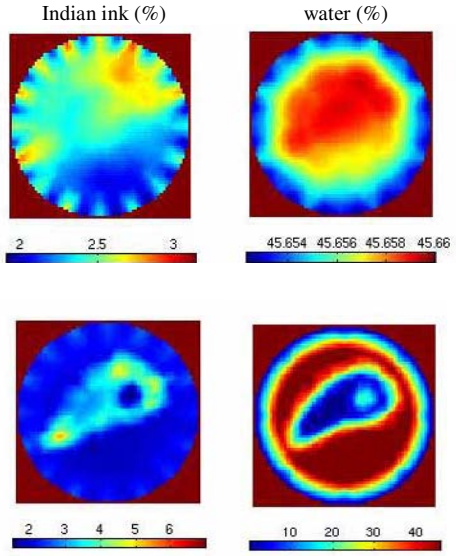

Figure 2. Reconstructed water and Indian ink concentrations obtained from DOT without a-priori information from MRI (top row), with structural and functional-priori from MRI (bottom row).

Discussion

The results of this study demonstrate that applying structural and functional-priori from MRI can improve the accuracy of the chromophore concentrations obtained by DOT. An important goal of NIR breast imaging is assessing total hemoglobin concentration and oxygen saturation. Using MRI to define structural information within the imaging volume and to quantify the water content of the tissue allow quantitatively accurate estimates of these parameters. This study also demonstrated that the use of ethanol-based phantoms enables optical measurement of different water concentrations, which has not been possible with fat-water emulsion phantoms. Therefore, ethanol-based phantoms provide a new platform for combined MR and optical imaging to assess the effect of water content on the accuracy of other chromophore concentrations.

References

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