Water/Fat Separation MR Improves Optical Breast Imaging

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C. M. Carpenter[1], S. Jiang[2], B. W. Pogue[2], and K. D. Paulsen[2]

[1]Radiation Oncology, Stanford University School of Medicine, Stanford, CA, United States, [2]Thayer School of Engineering at Dartmouth, Hanover, NH, United States

Background

Optical imaging may be added to MR mammography to provide absolute concentration images of oxygenated and deoxygenated hemoglobin, water, and other endogenous and exogenous molecular agents. This is beneficial because hemoglobin and tissue oxygenation have been shown in several studies to have high specificity to breast cancer [1]. This combined optical/MR instrument has been shown to improve upon the spatial resolution limitations of optical imaging [2]. However, insufficient spectral sampling, either due to the need to achieve higher temporal resolution, or due to the non-linear response of optical detectors, can introduce significant errors in tissue quantification. In particular, oxyhemoglobin (HbO) and water have similar spectral features below 850nm, as shown in Figure 1, which leads to cross-talk. For optical imaging in breast tissue, this issue is particularly important, as the most sensitive photodetectors (photomultipler tubes) have extremely low photocathode sensitivity to longer wavelengths where the water absorption peak is more pronounced. In this study, MRI water/fat separation was used to provide water quantification to reduce crosstalk between oxyhemoglobin and water. This is shown to greatly improve hemodynamic quantification when photomultiplier tubes are used, and when spectral sampling is sparse.

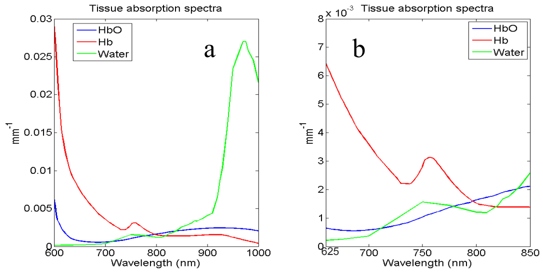

Figure 1: (a) Typical tissue optical absorption spectra, (b) an enlargement of this spectra reveals the spectral similarities between water and oxyhemoglobin (HbO).

Methods

Optical images were obtained by measuring the near infrared light attenuation through an optical breast phantom with 15 photodetectors from 16 source positions. Six wavelengths of light were sequentially collected. Water/fat separated images were calculated using the IDEAL MR sequence [3]. A model-based image reconstruction was used to fit tissue properties to a model for light propagation in breast tissue. The data/model misfit, δ, is minimized along with controls for system noise by minimizing:

$$\Omega = c_d \delta^T \delta + c_\mu \left(\mu - \mu_{prior}\right)^T \left(\mu - \mu_{prior}\right)$$

where c_d and c_μ are the expected noise of the measurements and contrast of the tissue properties(μ), respectively. Specifically, c_μ sets contrast limits for each of oxyhemoglobin, deoxyhemoglobin, water, and tissue scattering. This non-linear reconstruction algorithm is minimized by iteratively updating the estimate of the optical properties, starting from an initial guess μ_{prior}.

Two approaches to forming images of tissue properties are investigated. The first, standard approach, uses an initial guess based on an optical homogenous fit to the tissue properties. This method ignores information available from MR water/fat separation. Because of this, this method suffers from inaccuracies due to both spectral sampling and to poor photodetector response. A second method, termed the *Joint Weighted Estimation* approach, uses the MR water image as the initial guess to the optical properties. Because the MR may suffer inaccuracies of its own, due to T1 relaxation or B1 inhomogeneity, the expected error from the MR water images is input into c_μ. In this study, the inaccuracy in IDEAL water/fat separation was taken from Bernard et al.[4] as 3.7%.

Results

Optical spectra were recorded from a 86mm diameter gelatin phantom, shown in Figure 2, with porcine blood added to mimic the optical properties of breast tissue. 2:1 contrast in oxyhemoglobin was added to a 15mm inclusion to simulate a breast tumor mass. Figure 2b shows the reconstructed errors in hemoglobin recovery when using 3 wavelengths in the reconstruction vs. using 6 wavelengths. The bars to the left of Figure 2b indicate reconstructions without MR water quantification, while the bars to the right incorporate MR water. These results show that using 3 wavelengths yields poorer recovered values of hemoglobin than using 6 wavelengths. This is expected, due to spectral undersampling. However, when MR water is used to guide the water contrast, errors in hemoglobin recovery are significantly reduced, especially when only 3 wavelengths are used, as errors decrease by at least 20% in all cases. In one case (yellow bars), the non MR-water guided reconstruction recovers a 225% error due to its reliance on the 849nm wavelength, which is nearly beyond the sensitivity capabilities of the detectors. This finding has significant implications for optical imaging, as faster systems incorporating fewer wavelengths may be used without suffering from errors in quantification if water/fat separation is incorporated into the optical reconstruction.

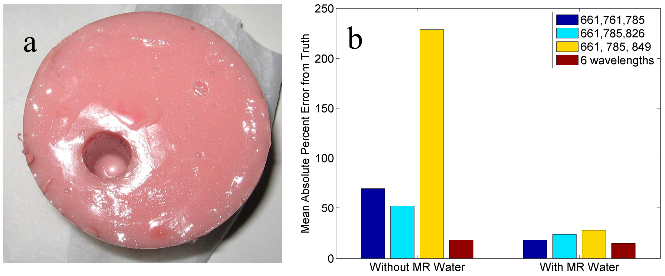

Figure 2: (a) Gelatin phantom with porcine blood added for optical contrast. 2:1 contrast was added to the inclusion. (b) Mean absolute errors in quantifying oxyhemoglobin. Shown are the cases where 3 wavelengths and 6 wavelengths of data are incorporated into the standard (bars to the left) and MR water-aided (bars to the right) reconstructions.

Conclusions

MR water/fat separation has found utility in breast imaging, liver imaging, and other anatomical regions. This study finds an additional use for MR water/fat imaging, by improving the imaging abilities of optical imaging. By incorporating the MR water values into the optical reconstruction, errors in hemoglobin quantification were minimized due to the reduced cross-talk between oxyhemoglobin and water. This method accounts for inaccuracies in MR water/fat quantification by incorporating an error term into the parameter contrast.

Acknowledgements

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