Diffuse Optical Tomography System for Breast Cancer Imaging

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Introduction

Breast cancer causes about 40,000 deaths a year, with one in eight women being diagnosed with the disease in their lifetime. [1,2].

Neoadjuvant Chemotherapy (NACT) is a cancer treatment that is given prior to surgery for patients with locally-advanced breast cancer. With an increasingly wide range of chemotherapy agents available, the timing and selection of certain agents can be better optimized by monitoring the patient's response to treatment.

Using non-invasive imaging to monitor tumor response to therapy one can potentially develop personalized treatment that minimizes toxicity, cost, and time, while improving patient outcomes [3].

Diffuse Optical Tomography

Diffuse optical tomography (DOT) has been explored over the past decade as an alternative modality for cancer diagnosis and therapy monitoring. DOT uses harmless, non-ionizing, near-infrared light to illuminate tissue from multiple points, and detects the light that has passed through the tissue. From this data three-dimensional maps 3D maps of oxy- and deoxy- hemoglobin, lipid, and water concentration inside the breast can be calculated with model-based iterative image reconstruction algorithms.

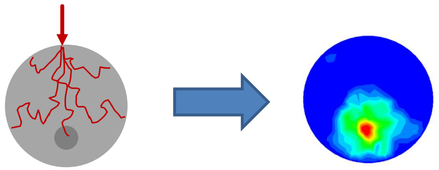


Figure 1. Two dimensional example for diffuse optical tomography.

Growing tumors require increased vasculature to provide nutrients and remove waste products. However, the new vessels are poorly formed and tend to be shunted, tortuous, and hyperpermeable. It has been shown that DOT can visualize these vascular changes by observing changes in the concentrations of oxy- and deoxy-hemoglobin, lipids and water in the tumor region [4].

The goal of this project is to develop a dynamic breast imaging system that allows to monitor vascular changes during NACT. Design criteria were increased speed and reliability of image procedure as well as increased patient comfort compared to existing DOT imaging system.

Methods

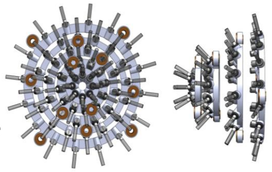
Breast Imager

- Continuous-wave system with 4 illumination wavelengths (λ=765nm, 808nm, 827nm, 905nm).
- Fast data acquisition allows for dynamic imaging.
- 3D imaging of both breasts simultaneously [4].

Patient Interface

Translating ring design for interfacing the optical fibers with the breast:

- Semi-seated position.
- No breast compression required.
- Accommodates a wide range of breast sizes.
- Camera mounts allow the angle of the rings to be adjusted for each patient.
- Can be precisely positioned for longitudinal studies



Three-dimensional reconstructions were obtained using a partial-differential-equation (PDE)-constrained multispectral imaging method, which uses the diffusion approximation as a model for light propagation[3].

Figure 2. Ring settings on patient interface are used to create three-dimensional mesh volumes that are used to solve the models for light propagation.

Experimental Protocol

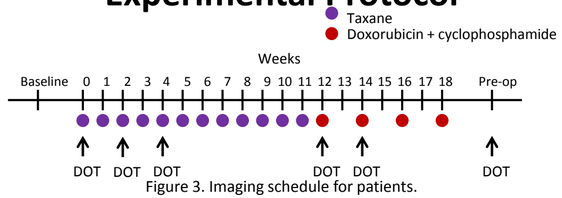
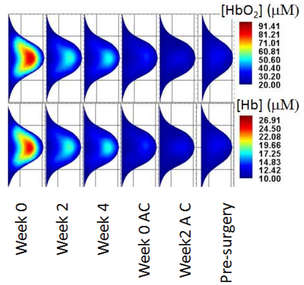


Figure 3. Imaging schedule for patients.

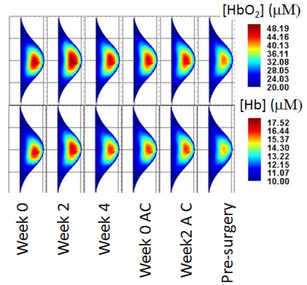
- HIPPA compliant protocol approved by the Columbia University IRB.
- DOT imaging performed at Week 0, 2, 4, 12, 14, and pre-surgery.

Results

Complete Response



Partial Response



The patient with the complete response shows a drop in both oxy-hemoglobin and deoxy-hemoglobin by week 2. The subject with the partial response shows gradual decrease in hemoglobin concentrations. There are eight patients that have finished the study with two having a complete response to treatment. Patients with a complete response show a drop at week two of 31.8% and 23.8% from the baseline of oxy- and deoxy-hemoglobin, respectively. Those that did not have a complete response showed an average drop of oxy-hemoglobin of 1.7% and an increase in deoxy-hemoglobin of 0.34%. Both oxy- and deoxy-hemoglobin parameters show statistical significance ($p<0.01$ and $p<0.05$).

Conclusion

DOT is a non-invasive, fast, safe, and inexpensive imaging modality. This imaging method does not use potentially harmful X-ray radiation, compression, or radioactive dyes. Instead this approach employs harmless non-ionizing near-infrared light to probe breast tissue and provides information about the spatial distribution of oxy-hemoglobin and deoxy-hemoglobin. Initial results are promising and if further confirmed DOT could become a valuable imaging modality for monitoring treatment response in neoadjuvent therapy and other diseases.

Acknowledgments

This research was supported in part by the Witten Family Fund. In addition Jacqueline Gunther was supported in part by a Fellowship provided by the NSF IGERT program on Optical Techniques for Actuation, Sensing, and Imaging of Biological Systems at Columbia University, and Molly Flexman was supported in part by the Natural Sciences and Engineering Research Council of Canada (NSERC). Emerson Lim was supported by Komen Foundation Postdoctoral Fellowship Clinical Research Grant.

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