# Simulation of Optical Breast Density Measurements Using Structured Light Illumination in A Patient-Specific Anatomical Breast Model Built from 3D MRI-Segmented Breast Density

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**Purpose:** Breast density has been proven as an independent risk factor associated with development of breast cancer, and many research studies have been performed to quantitatively determine the volume and percentage of fibroglandular tissue (dense tissue) within the breast [1]. Mammography is the most commonly used imaging modality, but because projection images are acquired, it is difficult to measure quantitative volumes despite of the availability of two FDA approved volumetric analysis software (Quandra® and Volpara®). Breast tissues can be segmented on 3D imaging modalities and the density can be quantitatively determined. Among all 3D modalities, MRI-based analysis is the most well established and often used as the gold standard for validation of other density imaging methods, but the high-cost and limited accessibility to many women prohibit its widespread use. In this study we tried to develop a Diffuse Optical Imaging method using structured light illumination (SLI). As the first approach, we simulate what this method can measure based on the density of women segmented on 3D MRI. If successful, optical imaging may provide a feasible density measurement modality that can be widely used due to its low cost and bed-side imaging capabilities. By illuminating patterns of near-infrared light onto the breast, the transmitted light through the breast can be measured and used to reconstruct tissue chromophores, particularly fat, water, oxy- and de-oxy hemoglobin, which are the stronger absorbers of light in the breast tissue. Previous studies showed that concentration of these chromophores are directly related to the breast density together with tissue scattering [2]. However, none of those studies utilize SLI based optical imaging. The purpose of our study is to design and optimize the SLI-based optical imaging methods. The MRI of healthy breast was segmented to obtain a 3D model of the breast and the dense tissue within the breast, and they were used for SLI simulation. The measured percent density was compared to the true density measured by MRI.

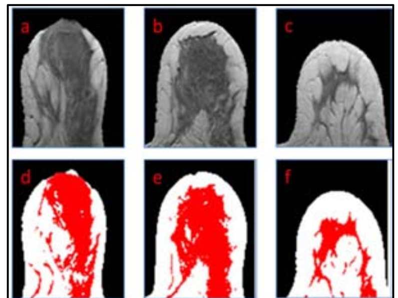


**Figure 1.** Slices of MR images (a-c) and their corresponding segmented fibroglandular tissue, shown in red, and whole breast masks, shown in white (d-f).

**Methods:** MRI from four subjects were obtained for analysis. The segmentation was done on non-fat-saturated T1-weighted breast MR images, and they were used to create masks of the entire breast and the dense tissue (**Fig. 1**) in MATLAB. The region of interest was chosen to include the entire breast, as close to the chest wall as possible. These masks were used to create a 3D model of the breast and dense tissue, which was imported into Comsol to generate a Finite Element (FEM) mesh, (**Fig 2**). This mesh was used as an input for the FEM-based forward and inverse solvers developed in our lab for optical imaging. The forward solver utilizes a diffusion equation to model light propagation in breast tissue, while the inverse solver recovers the absorption and scattering coefficients [3]. In this simulation study, 16 distinct illumination patterns were generated and used. These patterns consisted vertical and horizontal striped patterns, and the sum of the lines forms a checkerboard pattern (**Fig 3**). Using the very same patterns on the detection site allowed single point measurements and brought the number of the measurements, the combination of illumination pairs, to 256 (16 x16). In these preliminary simulations, the absorption coefficient of each breast tissue was assigned using literature values and synthetic SLI measurements were calculated using the forward solver. **Figure 4** shows the configuration of the illumination source and the measurement detector relative to the model. Afterwards, the 3D absorption images are reconstructed using these synthetic measurements as an input for inverse solver, representing the high absorbing fibroglandular tissue (**Fig 5**). The number of dense tissue elements within the reconstruction was calculated and used to compute the percentage of dense tissue to the whole volume of the breast.

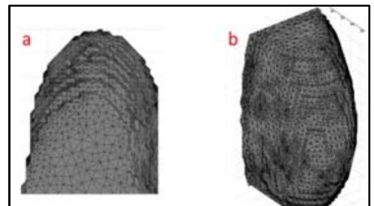


**Figure 2.** FEM mesh generated with Comsol. Fig 3a shows the meshed MRI slices in sequence. Fig 3b shows the assembled 3D mesh of the breast.

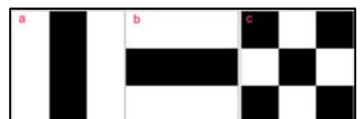


**Figure 3.** Three of sixteen illumination patterns for SLI. White and black colors represent bright and dark areas projected onto the mesh.

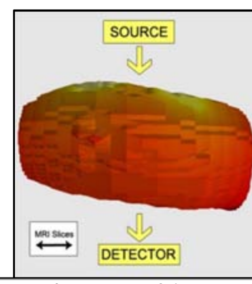


**Figure 4.** Patterns of light are projected onto the breast and photon propagation is simulated through the tissue, then synthetic measurements are collected at the detector side.

**Results:** The results from these 4 cases are shown **Fig 6.** The original MR images, segmented dense tissue maps on MRI, and absorption maps obtained from the SLI optical imaging simulation are shown. Due to the limited spatial resolution optical imaging cannot fully reconstruct the actual shape of the dense tissue, but the measured percent density from the reconstruction is highly correlated with the percent density measured by MRI, with r = 0.9866 (**Fig 7**).

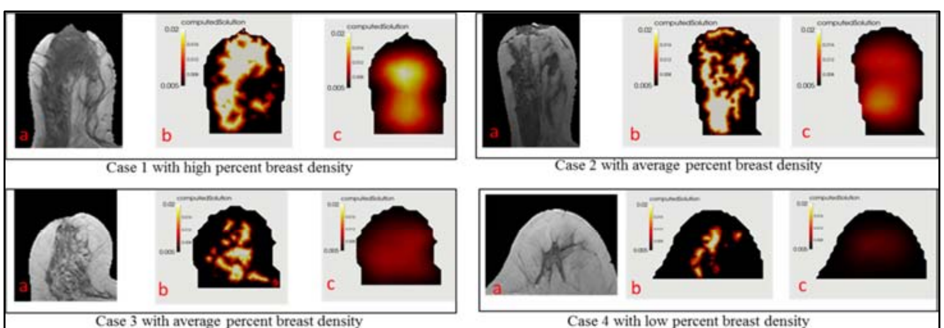


**Figure 6.** Four cases were reconstructed. (a) the original MR images. (b) the dense tissue segmented from the MR images depicted as an absorption map, with brighter values representing the dense tissue with higher absorption. (c) the reconstructed absorptions from the SLI simulations.

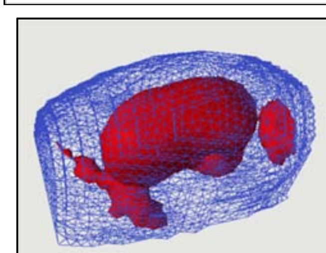

**Figure 5.** Reconstruction of the absorption coefficients based on the SLI simulation.

**Discussion:** SLI-based optical imaging may provide an alternative to MRI-based analysis of breast density through its simplicity and low-cost. We have shown that our reconstruction algorithm can determine breast density values similar to those found in MRI studies, but still a work in progress. The reconstruction algorithm will be improved and expanded to detect chromophores and scattering coefficients, and an imaging system will be built based on the design for experimental validation.

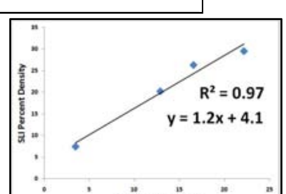


**Fig 7.** Correlation of density measured by SLI and MRI.

**References:** [1] Boyd et al. N Engl J Med. 2007; 356:227-236. [2] Srinivasan et al. PNAS 2003; 100(21)12349-12354. [3] Jiang et al. JOSA A. 1996; 13(2):253-266