Full-wave Numerical Model for Thermoacoustic Imaging of the Human Breast and Detection of Breast Cancer

Hongbo Zhao* [(1)], Sovanlal Mukherjee[(1)], Srishti Saraswat[(1)], Jinpil Tak[(1)],
Min Liang[(1)], Russell S. Witte[(2)], and Hao Xin[(1)]
(1) Dept. of Electrical and Computer Engineering, University of Arizona, Tucson, AZ 85721
(2) Dept. of Medical Imaging, University of Arizona, Tucson, AZ 85724

Early detection and appropriate medical intervention are paramount for surviving breast cancer. X-ray mammography, along with palpation and biopsy, is the gold standard for early detection and diagnosis of the potentially deadly disease. However, X-ray mammography fails to detect over 40% of breast cancers, including early stage tumors void of calcifications, and is typically insensitive to cellular and molecular changes that indicate a response to therapy. Microwave-induced thermoacoustic imaging (TAI), on the other hand, has specific advantages for breast imaging compared with other modalities, including high spatial resolution, high contrast, and relatively low cost. TAI is based on the absorption of a short microwave pulse, transient heating, and generation of acoustic waves that are detected to form an image. The goals of this study were to develop a realistic full-wave computational model for TAI of the human breast, and assess its performance for detecting small tumors placed in existing dielectric breast models with different class densities.

Our full-wave model for TAI consists of four stages: the propagation and absorption of microwave energy in the human breast, the generation of specific absorption rates (SARs), conversion to thermoacoustic pressure, and propagation of acoustic waves, and, finally, the reconstructed 3D image and morphology of the breast. In our model, a pulsed 2.5-GHz microwave with 1-μs pulse width was directed through a waveguide to the realistic human breast phantom submerged in castor oil. Dielectric properties of the whole human breast for different class densities (I-IV) were derived from a public repository at University of Wisconsin. For each type of breast, a 10-mm-diameter tumor was added to a dense region of the breast. SARs in the breast were first calculated using EM simulation software (CST Studio). Thermoacoustic waves were generated from the absorbed energy, and its propagation through breast and surrounding media was simulated using the pseudospectral time-domain (PSTD) method. Thermoacoustic signals were detected by more than 1500 point sensors (0.5 MHz center frequency, 80% bandwidth) surrounding the breast. Finally, Gaussian noise and Hann filter (0.1-0.9 MHz) are applied to the acoustic pressure before the universal back-projection algorithm was used to generate 3D tomographic TA images of each breast.

The simulation was completed for all four classes of breast densities, including breasts from almost fatty to very dense. Our simulations show that tumor can be reliably identified in TAI for all classes. The resolution of TAI is better than 2 mm. The imaging quality is quantified. For the type IV breast, which is the densest and most difficult to simulate, the contrast-to-noise ratio in the tumor region is ~10, the signal-to-noise ratio is at 30 dB. This work shows the feasibility of using TAI for tumor detection in realistic breasts. Comparable or better results are found in simulation of breast with lower classes. In future work, more realistic patch transducer array will be used in the simulation, and experimental verification will be carried out.