Full Wave Numerical Model for Thermoacoustic Imaging of the Human Breast with a Concave 1.5D Ultrasound Array

Hongbo Zhao* (1), Srishti Saraswat(1), Jinpil Tak(1), Waleed Ahmad(1), Min Liang(1),
Chandra Priya Karunakaran(2), 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

Microwave-induced thermoacoustic imaging (TAI) can not only be used as an advanced imaging modality for cancer detection, but also for noninvasive thermometry, which makes it potentially invaluable for monitoring hyperthermia or ablation treatment of breast cancer using focused microwave therapy (FMT). Our goal is to develop an integrated TAI-FMT closed-loop system for monitoring tissue properties and temperature during thermal therapy. This requires combining an ultrasound (US) receiver with a microwave transmitter array for local heating of tissue. This study employs full wave simulations to assess the performance of small-foot print matrix US array for reflection-mode 3D TAI of the breast.

We developed a complete toolset for TAI modeling of breast cancer based on publicly available 3D dielectric models of the human breast (Zastrow et al, Univ. of Wisconsin-Madison) with different density classes. A 10-mm diameter tumor (dielectric constant in range of $50\varepsilon_0$ to $60\varepsilon_0$) was added to each breast model. In the simulation, a 1.2-GHz microwave pulse (1 μs) is delivered through a mineral oil-filled waveguide to the breast for TAI. Propagation of the microwaves and conversion to specific absorption rate (SAR) were simulated with CST Studio. The pseudospectral time-domain (PSTD) method determined the TA pressure at each position in the domain. A 1.5D concave US transducer (18×7, 5 cm × 3 cm, focus = 35 mm) detected the TA signals. TA images were generated using 3D sum-delay beamforming from signals collected on the array.

The breast tumor was visible using TAI for the different breast classes (Fig. 1) when the US array was centered near the tumor. Figure 1 illustrates that strong signals at the tumor boundary are visible with TAI and correlate well with the SAR images of the breast with the tumor (for class I and class IV breast models). The calculated resolution of our imaging system was approximately 3.0 mm in axial direction. Continued optimization of our model should help guide and refine ongoing bench-top TAI experiments, which closely match the described model and will be used in the future to monitor tissue properties during FMT.

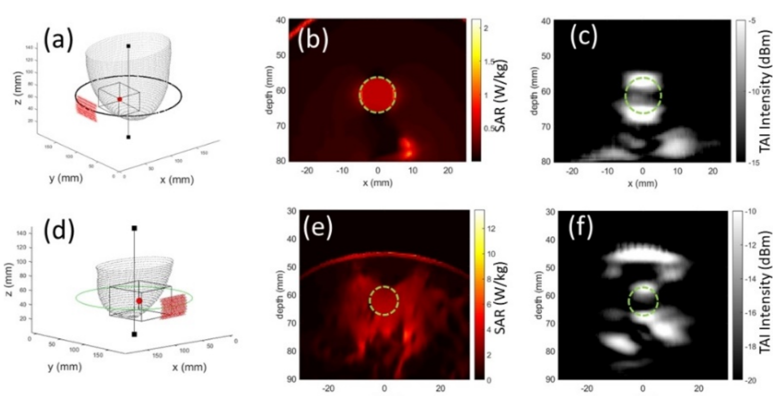

Fig 1. Domain for human breast model and relative position of matrix US array (a,d), SAR (b,e), and TAI XZ cross section within the field of view of the US probe (c,f) for class I (top row) and class IV (bottom row) breast models with tumor placed in fatty (b,c) or dense region (e,f). Dashed circle indicates actual tumor position. Skin also generates a strong TA signal, as exhibited in f.