B1+, SAR, and temperature distributions in the breast with different tissue ratio: FDTD simulations and experimental RF field and temperature measurements at 7T

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[Target Audience] Researchers who are working on numerical calculation of B_1^+ and SAR in the specific body organs.

[Purpose] Accurate prediction of the electromagnetic (EM) field distribution at high field MRI is important to ensure the safety of the subject and to protect the electrical hardware. Numerical calculation using finite-difference time domain (FDTD) method has been widely used in various part of human organs to closely investigate the transmit field (B_1^+) distribution as well as the power deposition in the tissue (SAR) (1,2). In this study, four different anatomically detailed breast models were used for quantitative analysis of the B_1^+ and SAR distribution. In addition, the B_1^+ map and temperature change at four locations were acquired for the breast phantom at 7T MRI and compared with the FDTD calculation result.

[Methods] ***FDTD modeling and calculation;*** 3-dimentional (D) geometry of the RF array (Eight Channel Tx/Rx) with conductivity and dielectric constants of copper, acrylic and air were set for the 300 MHz and created using MATLAB (Mathworks, MA). Four 3D breast model developed from Univ. of Wisconsin Madison (htt://uwcem.ece.wisc.edu/phantomRepository.html) was used for the FDTD calculation. The breast models used in this study are 1) mostly fat breast model (mFBM), 2) scattered fibroglandular (FG) tissue breast model (sFGBM), 3) heterogeneously dense breast model (hDBM) and 4) very dense breast model (vDBM) type defined by the American College of Radiology (figure 1). B_1^+ Homogeneity (standard deviation (SD)/mean) was calculated in sagittal, coronal, and transverse plane and whole volume (figure 2 and 3). SAR distribution at calculated B_1^+ map was then compared with temperature change during RF heating at four locations (figure 4). ***MR imaging;*** Scans were performed using a 7T whole body scanner (Siemens Medical Imaging, Erlangen, Germany). 3D B_1^+ map was acquired using GRE-sequence with variable flip angle (12 steps). Homogeneity of the B_1^+ was measured at sagittal, coronal, transverse and whole volume to compare with the simulated result (figure 3). Four fiber optic thermal probes were inserted at four locations in the phantom to measure the temperature change during the RF heating (X-, Y- ,Z-gradients were turned off). Note that the detail of the RF array used for this study can be found in the 2013 ISMRM abstract #4370.

[Results] Figure 2 shows B_1^+ map of the model and phantom. The B_1^+ homogeneity of the four different models and phantom are shown in figure 3. The B_1^+ homogeneity calculated from sagittal, coronal, and transverse plane in four different models and breast phantom are; 0.21, 0.07, and 0.22 in mFBM, 0.19, 0.06, and 0.22 in sFGBM, 0.17, 0.06, and 0.20 in hDBM, 0.16, 0.04, and 0.19 in vDBM, 0.26, 0.23, and 0.27 in breast phantom, respectively. The SAR (per a mean B_1^+ field of 2uT) distribution associated with the calculated B_1^+ field is shown in figure 4. Average/peak SAR (W/Kg/10grams of tissue) calculated at all models are 0.45/1.48 in mFBM, 0.64/1.75 in sFGBM, 0.56/1.41 in hDBM and 0.52/1.25 in vDBM. Highest temperature change was measured in probe #4 (0.52 C° over five RF heating scans, #1 – 0.31 C°, #2 – 0.12 C° and #3 – 0.30 C°).

[Discussion and conclusion] The highest homogeneity was calculated in vDBM and the homogeneity decreased as fat ratio increase (figure 3). In each model, area close to the chest wall had relatively low B_1^+, however, the SD was also low in the coronal plane thus the high homogeneity was achievable, 4-7%. In the sagittal and transverse plane, larger SD due to the B_1^+ decay at the chest wall resulted in lower homogeneity, 16-22%. Due to the anatomical difference between the models and breast phantom (low B_1^+ at the cyst masses, see figure 2), lowest homogeneity was measured in breast phantom in all three planes. The peak to average SAR ratio was 3.28 in mFBM, 2.73 in sFGBM, 2.51 in hDBM and 2.40 in vDBM, respectively. The ratio decreased when the breast model had less fat composition. Regardless of the model, the peak SAR was measured relatively close to the skin and chest wall where the conductivity was high (figure 4A). The temperature measurements at four location show similar distribution as the SAR calculated in the sFGBM (figure 4A and B). In summary, we used four different tissue composition breast models for precise calculation of B_1^+ and SAR via full wave FDTD method and compared with the breast phantom. Although the geometry (dimension) and tissue composition altered the B_1^+ and SAR, good agreement within the models and between the models and phantom was achieved. Further in vivo study with different tissue ratio (FG/fat) is necessary to closely investigate the EM behavior in the breast tissue.

[References] (1) Bob van den Bergen et al. JMRI. Vol. 30 194-202, 2009 (2) Ji Chen et al. IEEE Transaction on Biomedical Eng. Vol. 45, No. 5, 1998.

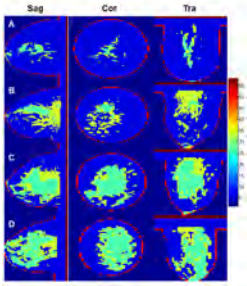

Figure 1 Dielectric constant map of the breast models used for FDTD calculation (A-D). (A) Mostly fat breast model (mFBM, <25% glandular, 60*71*50 grid cells in x, y, z-direction), (B) scattered fibroglandular (FG) tissue (sFGBM, 25-50% glandular, 57*70*61 grid cells), (C) heterogeneously dense (hDBM, 50-75% glandular, 43*73*49 grid cells) and (D) very dense (vDBM, >75% glandular, 40*65*42 grid cells). Note the unit is farads/meter.

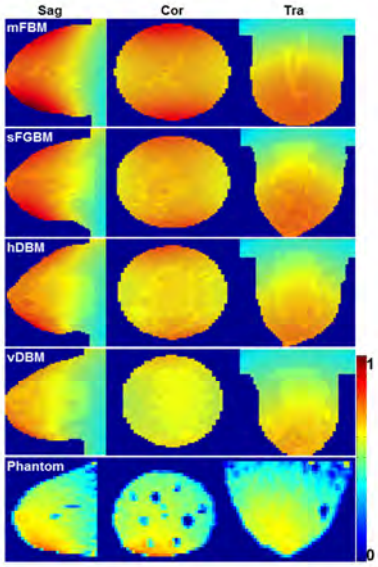

Figure 2 B_1^+ map calculated from FDTD simulation in the breast model and acquired from breast phantom at 7T MRI. Note, the B_1^+ map of each model and the phantom was normalized with maximum B_1^+ intensity calculated (mFBM – 6.02*10^{-2} uT/V).

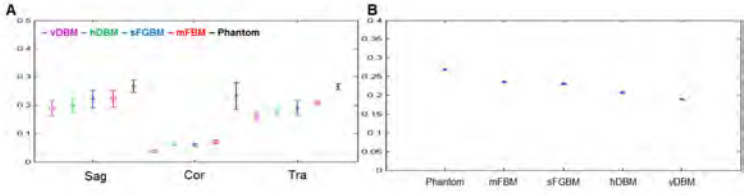

Figure 3 Calculated/measured B_1^+ homogeneity in the breast models/phantom. ~5% Homogeneity variation was measured between the models at each of three different planes (A). Homogeneity measured at whole volume of the model and the phantom (B).

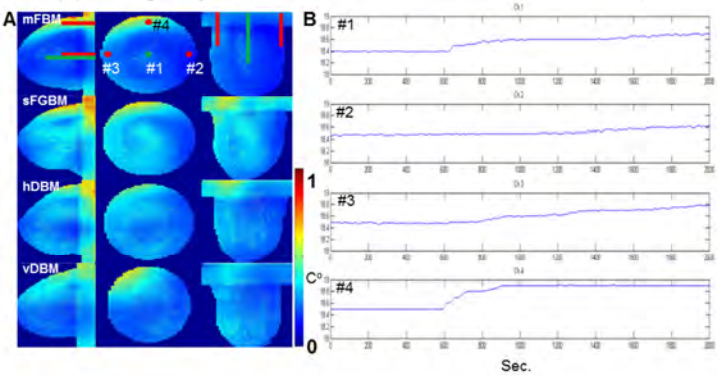

Figure 4 Calculated SAR maps in the breast models (A). Location of the four probes inserted in the breast phantom (red bar – 30mm depth, green bar – 50mm depth). Temperature change measured during RF heating at four locations in the breast phantom (B). Note the SAR map was normalized with highest peak SAR calculated (sFGBM - 1.75 W/Kg/10g tissue).