Patient-specific calibration for breast MRI: breast-coil insertable reference phantom

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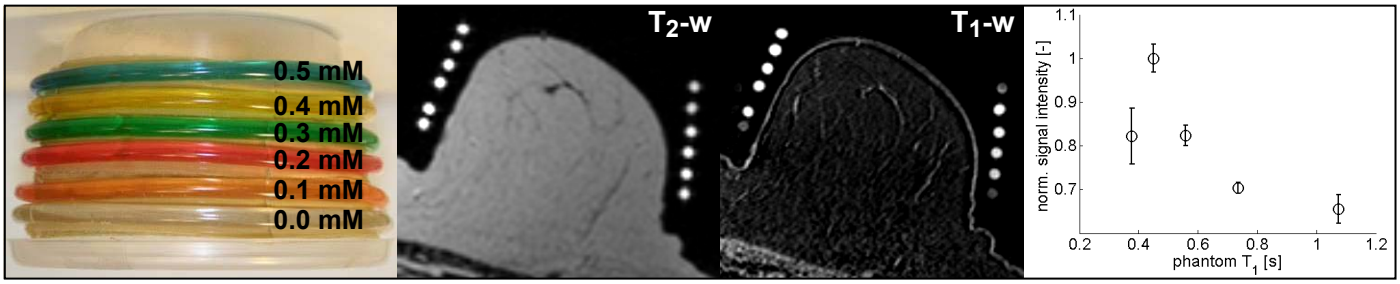
Introduction: The routine use of a calibration phantom that fits easily into a breast coil could provide the basis for standardization and patient-specific calibration of breast MRI. Here, we use a phantom to correct the variable flip angles in a T_1 measurement. This increases the accuracy of T_1 and contrast media concentration measurements obtained with a clinically employed T_1-weighted dynamic contrast-enhanced protocol.

Methods: A unique phantom was designed, with a comfortable breast-coil insert mounted with color-coded circumferential and vertical tubes filled with distilled water solutions containing Gd-DTPA (0.0, 0.1, 0.2, 0.3, 0.4, 0.5 mM, Omniscan). The geometry of the phantom was adjusted so that multiple phantom compartments were present in many slices, irrespective of slice orientation.

A healthy volunteer (no contrast media injected, University of Chicago Institutional Review Board approval) was scanned in a standard bilateral breast coil at 1.5 T with one breast placed in the phantom cup. Clinical T_2-weighted (2D turbo spin echo, TR/TE = 5647/120 ms) and T_1-weighted (fat-suppressed ultrafast gradient echo, flip angle (FA) = 12°, TR/TE = 12.6/3.7 ms) images were acquired. A variable flip angle protocol was used for T_1 measurement (3D FSPGRE, nominal FA's = 3, 5, 10, 15, 20, 30°, TR/TE = 5.0/1.5 ms, NA = 3).

The clinical images were evaluated by an experienced breast radiologist to assess image quality in the presence of the phantom. In addition, the clinical T_1-weighted image was used to measure phantom signal intensities as a function of T_1. Based on theoretical T_1 values in the phantom, the true flip angles were estimated and these values were used to calculate accurate T_1's for breast tissue.

Results: The circumferential phantom compartments (vertical compartments are not visible in this projection; they are on the backside) and their appearance on the T_2- and T_1-weighted MR images are displayed in the figure below. In the graph, the measured phantom signal intensities are plotted as a function of the theoretical T_1.



Because the circumferential compartments are visible on both the inner and outer sides of the breast in an axial scan, estimated M_0 values in the phantom compartments can indicate spatial variation in coil sensitivity (here, lower on the outer side of the breast). The signal-vs.-T_1 graph shows that the lower bound of the T_1-sensitive range of the clinical T_1-weighted scan is about 0.40 s, which corresponds to a concentration level larger than 0.4 mM Gd-DTPA in distilled water. For shorter T_1 the signal is attenuated. However, this effect might be varying spatially.

Based on the known T_1's of the phantom compartments, the true flip angles were estimated at 3.2° (107%), 5.8° (116%), 7.2° (72%), 10.1° (67%), 14.6° (73%), and 22.9° (76%). We used these flip angles to fit the data from the variable flip angle T_1-measurement, and obtained T_1's of 1.08 s and 0.48 s for parenchyma and fat (without correction: 0.73 s and 0.36 s), respectively. With a precontrast T_1 of 1.08 s, the upper bound on the concentration level in parenchyma would be about 0.36 mM.

Discussion: The quality of the breast images acquired with the phantom in place was found to be normal. Analysis of data from the phantom compartments resulted in significant corrections to the flip angles, and therefore increased the accuracy of T_1 measurements. The volunteer noticed mild heat dissipation in the phantom cup during a fast spin echo sequence with a large acceleration factor (SAR level: high). Heating may be due in part to currents induced in the phantom. In this case, use of air-bubble free agar instead of a liquid solution could minimize heating.

Conclusion: Our preliminary results demonstrate that this new breast phantom can assist in quantitative measurements of contrast media concentration as a function of time after injection, and therefore may increase sensitivity and specificity of MRI. We plan routine clinical use of the calibration phantom.