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 T1 measurement. This increases the accuracy of T1 and contrast media concentration measurements obtained with a clinically employed T1-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 T2-weighted (2D turbo spin echo, TR/TE = 5647/120 ms) and T1-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 T1 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 T1-weighted image was used to measure phantom signal intensities as a function of T1.

Results: The circumferential phantom compartments (vertical compartments are not visible in this projection; they are on the backside) and their appearance on the T2- and T1-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 T1.

Because the circumferential compartments are visible on both the inner and outer sides of the breast in an axial scan, estimated M₀ values in the phantom compartments can indicate spatial variation in coil sensitivity (here, lower on the outer side of the breast). The signal-vs.-T₁ graph shows that the lower bound of the T₁-sensitive range of the clinical T₁-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 T₁ the signal is attenuated. However, this effect might be varying spatially.

Based on the known T₁’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 T₁-measurement, and obtained T₁’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 T₁ 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 T₁ 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.