Purpose: 3T MRI is increasingly used because of its intrinsic SNR benefits compared to 1.5T MRI. However, there are increased transmit RF field (B1⁺) inhomoogeneities at 3T, which can lead to SNR loss, image shading, errors in quantitative parameters, and other drawbacks. In breast MRI in particular, the phenomenon of left-right B1⁺-asymmetry in the breast has been observed [1-3]. (Fig. 1) This abstract presents simulations of several different methods for compensating left-right B1⁺-asymmetries in the breast region by means of 1) 2-channel RF shimming (IQ-phase/amplitude adjustments); 2) dielectric-absorptive shimming; or 3) a combination of 1) and 2). Both approaches are adaptable to a wide range of MR systems, and are especially relevant to scanners that do not have full parallel transmit capabilities. The methods can be combined in different ways to yield a simple, practical, and inexpensive procedure without SAR penalty for ensuring uniform contrast and quantitative parameter estimates, and ultimately, more accurate detection and therapeutic monitoring of breast cancer.

Methods: Experimental B1⁺ mapping was performed on a 3T GE Discovery MR750 scanner using the built-in transmit-only body RF coil. Coil and human body were modeled in a commercial simulation package, and various proposed shimming methods were evaluated.

Modeling: A commercial FDTD solver (SEMCAD X, SPEAG, Zürich) was used for modeling and simulation purposes. The receive coil was modeled as a 16-leg highpass birdcage type with primary coil diameter of 62 cm, tuned to 128 MHz. Four independent excitation ports located at 45 (I), 135 (Q), -45 (Q̄), and -135 (Ī) degrees with respect to the central coronal plane, respectively, were implemented with pairwise independently adjustable amplitudes and phases, giving rise to the flexibility of analyzing both two- and four-port transmit configurations, both of which are commonly used in practice. Modeling of the human body was performed using a member of the Virtual Family (Ella, female, 26 years, IT’IS Foundation, Zürich). To allow clearer visualization of B1⁺ over a larger breast region, additional mammary tissue was added to the Ella model, with the electric properties of fat (εr = 5.64, σ = 0.03 at 128 MHz) and skin (εr = 65.44, σ = 0.52 at 128 MHz).

RF shimming: Improving B1⁺-homogeneity by means of independent adjustment of the I- and Q-phases alone was attempted in a first step, followed by full RF shimming (both amplitude and phase of I and Q). For this purpose, B1⁺ field characteristics from each port were calculated and superimposed according to their relative phases/amplitudes, allowing for a fine-tuning of the inhomogeneities arising from patient loading.

Dielectric-absorptive shimming: Disks of dielectric-absorptive material were inserted in proximity to the breast with the higher B1⁺ amplitude (Fig. 2) in order to divert the field lines for generating a more uniform field distribution across the cross section of the breast. Materials of different electrical properties and dimensions, located at several distances to the breast, were studied.

Results: Experimental B1⁺ maps of 30 breast patients were used to identify an average B1⁺ amplitude ratio between left and right breast of 1.32. Simulations of coil characteristics yielded at a Q-factor of 216.3 and 37.5 for the unloaded and loaded cases, respectively. Left-right asymmetry was identified as a consequence of a shift in coil resonance after patient loading. With no alterations in "standard" circularly polarized (CP: IQ-phase difference = 90 deg) coil drive, the simulated 2-port B1⁺ map is shown in Fig. 3a. Phase-only RF shimming yielded an optimal result for a phase delay of 130 degrees between I- and Q feeds (Fig. 3b). Full RF shimming with modest additional amplitude shimming is shown in Fig. 3c; this produced moderate additional improvement in B1⁺ symmetry. Dielectric-absorptive shimming results (Fig. 3d-f) are shown for a disk of 60 mm height, at distances of 10 mm and 30 mm from the breast surface, and conductivities of σ = 2 S/m and 5 S/m, respectively. Additional experiments have shown that the most influential parameters are disk distance and conductivity, with only a minor dependence on disk geometry. Fig. 3g depicts the combination of both IQ phase- and dielectric-absorptive shimming yielding the most uniform B1⁺ field distribution throughout the breast cross-section. It can be seen that the simulations reproduce the experimentally measured L/R B1⁺ ratio reasonably accurately, and that both RF and dielectric-absorptive shimming are effective at decreasing this asymmetry, with the combination of both methods leading to the most effective flattening of this asymmetry.

Discussion: IQ phase adjustment is readily implementable on many modern systems today and hence a straightforward and effective method, given the negligible additional improvement afforded by full shimming. Dielectric-absorptive shimming is easily accomplished by mounting an appropriate material on the breast coil. Compared to similar approaches using high-dielectric materials with low conductivity, the requirements on disk geometry and position are simpler, accounting for an easily implementable and cost-effective method if some increase in signal loss can be tolerated. Compared to more complex and cost-intensive parallel transmit methods, the presented approach does not lead to concerns about increased SAR in the patient. Results shown are by simulation only, and consider a single anatomical model, and therefore may not accurately predict optimal parameters for real experiments across a wide range of body sizes/shapes. Glandular tissue has not been modeled but is assumed to add localized heterogeneity to the B1⁺ map (Fig. 1) due to its higher losses.

Conclusion: Inhomogeneities in B1⁺ in breast MR at 3T have been studied and improved using RF- and dielectric-absorptive shimming, offering a cost-effective solution to this field distortion problem using easily implementable methods.


Acknowledgement: Research support from NSERC, NIH P41 EB015891, the Lucas Foundation and GE Healthcare.