B0 Shimming in 3 T Bilateral Breast Imaging with Local Shim Coils

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Introduction: B_0 variation in 3T breast exams is significant and can significantly degrade the performance of EPI based acquisitions in, for example, diffusion weighted imaging. The within-breast B_0 variability, due to the half sphere breast shape [1], is of limited extent, and can be addressed by the use of susceptibility pads [2]. The between-breast variability, due to the asymmetry in the anatomy (with the diamagnetic heart situated mostly on the left, and lung tissue mainly on the right) can be of larger extent, and cannot be easily corrected by the shims available in a typical clinical scanner. While dual-band excitation pulses [3] can mitigate such between-breast B_0 variability, they extend the echo time undesirably. Here we propose local shim coil-based B_0 asymmetry correction in axial breast imaging, in analogy with the local shim coil method demonstrated in brain [4].

Theory: At 3 T, a diamagnetic sphere with magnetic susceptibility of $-|\chi|$ ppm contributes $\delta B_0 = +|\chi|$ Tesla on the equator just outside the sphere. This field drops with the distance r from the center as $1/r^3$. In a crude model where a heart is approximated as a sphere with $\chi = -9$ ppm, and the lungs as spheres with $\chi = -2.25$ ppm, the average B_0 difference between the left and right breast is on the order of 100 Hz (higher on the left). The geometry of this crude model, together with an axial profile of the B_0 field is displayed in Fig. 1a. A pair of Helmholtz-like coils, placed superior and inferior to one of the breasts, creates a relatively homogeneous B_0 field in the region between the pair of coils, and is shown here to compensate for this right/left B_0 field difference seen *in vivo*.

Method: A pair of 10-turn copper coils of roughly rectangular shape were wound on planar foam supports measuring 12 cm × 16 cm and placed on the right-breast side in the housing of an 8 channel 3T GE breast coil as depicted in Fig. 1b. In order to minimize RF distortion, an inductor with $L \sim 0.3$ mH was connected in series with the coil. The coil pair carried up to $I_{coil} = 200$ mA DC and was found to generate no measureable heat outside the coil housing. The shim coils had no measurable impact on the SNR of the images. B_0 maps were obtained with a 3-point Dixon method (TR/TE/fov/slice/bandwidth = 7 ms/1.4, 3.0, 3.8 ms/36 cm/5 mm/125 kHz) [5]. For in vivo scans, baseline B_0 maps with $I_{coil} = 0$ in bilateral breast were obtained following the scanner's automatic bilateral linear shim algorithm. This shim procedure relies on the placement of small shim ROI's over each breast, followed by shimming over each ROI by using B_0 data in three orthogonal planes, and resulting in the prescription of an average center frequency and shim values for the two breasts. The value of the current in the local shim coil was then determined according to the calibration plot (Fig. 2a) and B_0 mapping was repeated following a new automatic linear shim.

Results: B_1 maps on a silicone breast phantom with $I_{coil} = 0$ and $I_{coil} = 184$ mA showed that the shim coil had no impact on the B_1 profile within the measurement error (< 5%). Figure 2b shows the B_0 field contributed by the shim coil on a phantom in the central axial plane. Figure 3 shows the B_0 maps with and without the local shim coil on. Note the significant improvement seen across the bilateral shim region obtained with the local shim (Fig 3b).

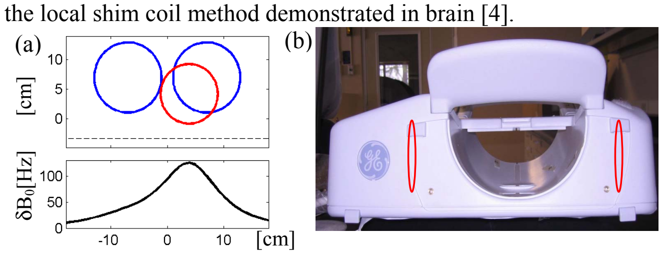

Figure 1. (a) Geometry of the model and B_0 profile in an axial slice (along dashed line) (b) Picture of the modified breast coil, with the approximate location of the pair of shim coils indicated in red.

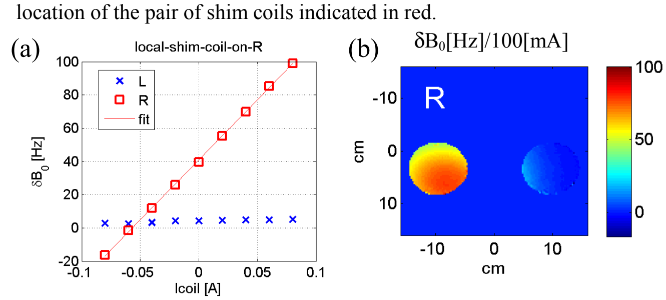

Figure 2. B_0 field measured in a two-sphere phantom contributed by the local shim coil. (a) Fields at the center of the spheres vs current. (b) Map of coil-contributed field δB_0 in the axial plane per $I_{coil} = 100$ mA.

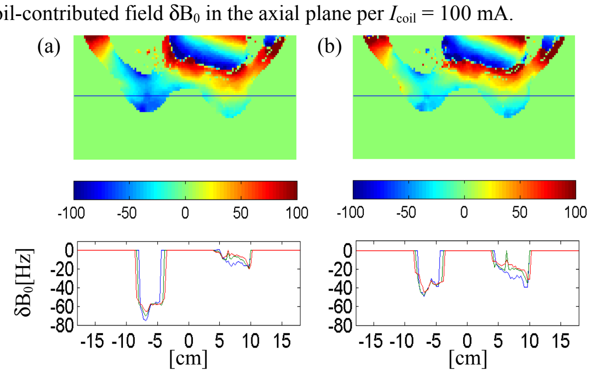

Figure 3. In vivo measurement of bilateral breast B_0 map. (a) $I_{coil} = 0$. (b) $I_{coil} = 57$ mA. The line plots at the bottom show δB_0 profiles along three adjacent rows in the image matrix around the horizontal line indicated in each map.

Discussion: The introduction of a local shim coil for B_0 correction is based on the assumption that the inherent anatomical asymmetry seen *in vivo* has a significant impact on the B_0 distribution in axial breast exams. While the base of the heart tends to be centrally located, the apex is usually directed towards the left anterior direction. Significant variability exists, however, in the heart volume and position in the chest [6]. Consequently, it is possible for varying levels of B_0 correction (i.e. current in the shim coil) to be needed in order to accommodate the anatomical diversity seen in general population. The level of correction needed for each individual subject, however, can be easily determined at the end of the prescan. The difference in the center frequencies seen in the right and left breasts and the calibration curve for the shim coil (Fig 2a) enables one to determine the correction current which maximizes B_0 homogeneity for each person scanned. In the current implementation, the shim coil does not cover extended breast region including axilla. More refined and expanded shim coils can be designed to allow better coverage. This work presents a first step towards a breast-specific high order shim system which would help improve the image quality and diagnostic power of non-contrast breast imaging for cancer screening.

References: [1] Maril N et al, MRM 54:1139 (2005) [2] Lee GC et al, JMRI 32:684 (2010) [3] Han M et al, Proc 17th ISMRM, p 580 (2009) [4] Juchem C et al, MRM 62:1 (2009) [5] Reeder S et al, MRM 51:35 (2004) [6] Hoekema R et al, Computers in Cardiology 1996, p. 717

Support: This work was partly supported by the NIH grant 5R01EB005307-2.