

## Population Variability of Susceptibility-Induced $B_0$ Field in Bilateral Breast MRI

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**Introduction:** Susceptibility-induced off-resonance field can lead to significant EPI image distortion and fat suppression errors in high field MRI. In breast, such field is known to have dominant anterior-posterior gradient due to the half-spherical shape of the breast. Quantitative population studies on the susceptibility-induced field in bilateral breast could help guide shimming strategies in high-field breast imaging which is gaining popularity as a modality to diagnose cancer. In this work we apply an anatomy-based  $B_0$  calculation method to obtain 3D bilateral breast  $B_0$  maps in thirteen volunteers, and calculate linear and higher order harmonic components. We found that, in addition to strong anterior-posterior gradient, there is statistically significant linear gradient in the left-right direction. We predict that whole-body 2<sup>nd</sup> and 3<sup>rd</sup> order shimming would not be very effective in removing nonlinear residual  $B_0$  fields in 3D bilateral breast imaging.

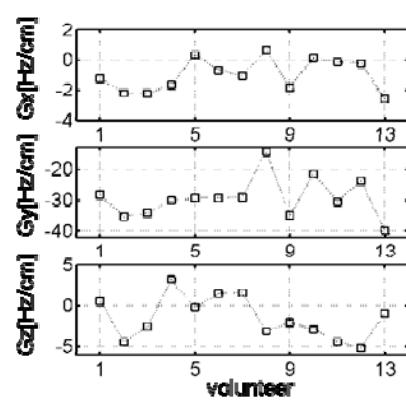
**Theory:** Diamagnetic tissue voxels in the main magnetic field of MRI contribute dipolar magnetic fields in the imaging volume to disturb the  $B_0$  field homogeneity. Such disturbance, on the order of a few ppm, can be calculated by direct summation of dipolar fields in the spatial domain [1] or summation in the Fourier domain [2,3]. Recently, a 2D Fourier method was proposed [4] as a tradeoff between computational speed and memory requirement in  $B_0$  calculation. In this work, we applied this method to calculate susceptibility-induced  $B_0$  maps in axial slices of bilateral breast.

**Method:** Thirteen healthy volunteers, one of whom had silicone breast implants, were scanned for a 3D anatomical image in the upper torso. The subjects were scanned in the feet-first prone position in a single breath-held session lasting 17 seconds. The image was segmented offline in air/lung/tissue and each segment was assigned susceptibility of 0/–2.25/–9 ppm, respectively. Slice-by-slice Fourier method [4] was used to calculate dipolar  $B_0$  maps on nine axial slices covering both breasts. The results were compared with  $B_0$  maps obtained by Dixon's fat-water separation-based  $B_0$  mapping (IDEAL). Good agreement was observed for all volunteers except for the one with implants. Subsequent analysis was applied only to anatomy-based calculated  $B_0$  maps for reasons of chemical composition independence, and reduced motional/respiratory artifacts involved in breath-held scans. For each volunteer, the nine-slice  $B_0$  map was first fitted with linear gradient fields. The second order shim values were subsequently obtained by fitting the residual  $B_0$  map with eight spherical harmonic functions representing linear and 2<sup>nd</sup> order field variation. The third order shim values were obtained similarly, fitting the 2<sup>nd</sup>-order-shimmed residual field map. All calculations were performed in Matlab (Mathworks, MA) on a laptop with 2 GB memory.

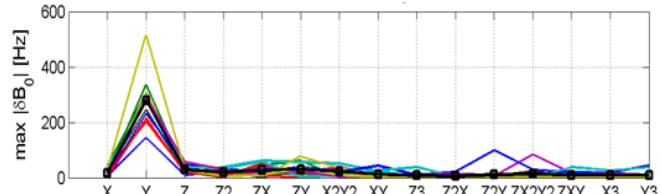
**Results:** Figure 1 shows the result of simulated linear shimming. Here, subject's right, posterior, inferior directions define positive  $G_x$ ,  $G_y$ ,  $G_z$ , respectively. The *t*-test for the null hypothesis yielded  $p < 0.01$  for  $G_x$  and  $G_y$ , and  $p = 0.07$  for  $G_z$ . Strong negative  $G_y$  observed in most volunteers is in agreement with results in [5]. Small but statistically significant, negative  $G_x$  is observed and is consistent with a diamagnetic heart on the left adding positive  $B_0$  field on the left breast. High order shimming was also considered; figure 2 shows off-resonance field strengths contributed by each of the 15 harmonics used for field map decomposition. On the average, nonlinear residual  $B_0$  field does not seem to be dominated by any single harmonic component. Figure 3 shows improvement in  $B_0$  homogeneity as a function of the shim order. On the average, the incremental reduction of the standard deviation of  $B_0$  was 39% (first order), 4.5% (second), and 3.0% (third).

**Discussion:** Harmonic analysis of susceptibility-induced static field distribution in bilateral breast revealed dominant anterior-posterior field gradient as reported earlier. We found experimentally that using  $G_y \approx -30$  Hz/cm as a starting value for automatic shimming improved the chance of higher quality final shimming *in vivo*. Our simulation shows that the second and third order shimming is likely relatively inefficient in reducing localized  $B_0$  inhomogeneity. Figure 3(b) suggests the need for a fourth order shim coil, or, alternatively, localized lower-order coils to address such field. The local coil method, as demonstrated in [1], could be a cost-effective way to do higher-order  $B_0$  shimming in breast, and is a subject of future investigation.

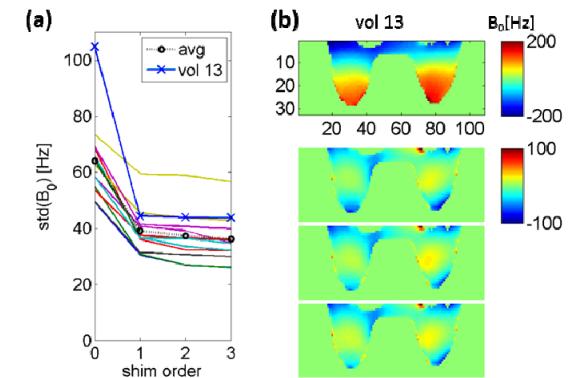
**Acknowledgement:** This work was supported by the NIH grant 1R01CA154433-01A1. **References:** [1] Lee S-K et al., Proc. ISMRM 19:715 (2011) [2] Salomir R et al., Concepts Magn Reson 19B:26 (2003) [3] Jordan CD et al. Proc. ISMRM 19:1034 (2011) [4] Lee S-K et al. submitted to Annual Meeting of ISMRM (2012) [5] Maril N et al. MRM 54:1139 (2005)



**Figure 1.** Susceptibility-induced  $B_0$  field gradient calculated from anatomical images in 13 volunteers. The population mean ( $\pm$ standard deviation) of the shim gradients, in [Hz/cm], are:  $-1.0 (\pm 1.1)$ , ( $G_x$ );  $-29 (\pm 6.5)$ , ( $G_y$ );  $-1.4 (\pm 2.6)$ , ( $G_z$ ).



**Figure 2.** Off-resonance field amplitudes from harmonic components up to the third order. Thirteen volunteers are shown in different colors; black line with markers indicates the average.



**Figure 3.** (a) Standard deviation of residual  $B_0$  field after three-dimensional simulated shimming. (b) Example of shimmed  $B_0$  maps in an axial slice. The four images correspond to un shimmed and shimmed maps up to the 3<sup>rd</sup> order (shim order increasing from the top to the bottom, identical scale in the last 3 images).