

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 2nd and 3rd 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 2nd order field variation. The third order shim values were obtained similarly, fitting the 2nd-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)

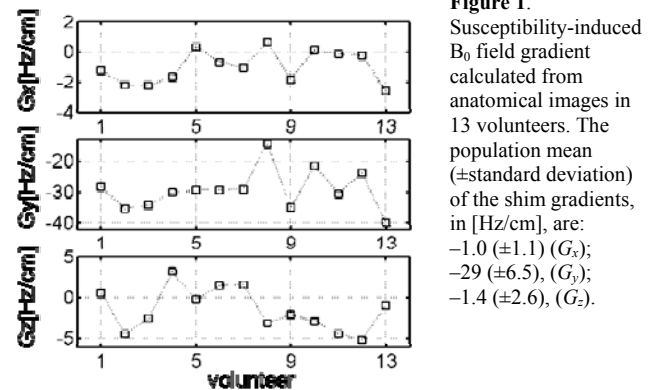


Figure 1. Susceptibility-induced B_0 field gradient calculated from anatomical images in 13 volunteers. The population mean (\pm standard deviation) of the shim gradients, in [Hz/cm], are: $-1.0 (\pm 1.1)$ (G_x); $-29 (\pm 6.5)$, (G_y); $-1.4 (\pm 2.6)$, (G_z).

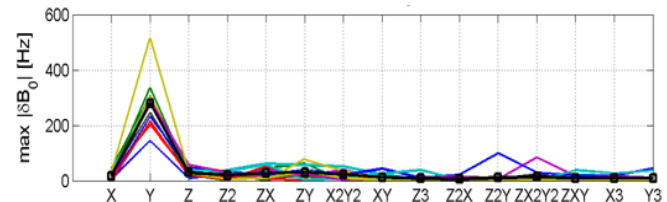


Figure 2. Off-resonance field amplitudes from harmonic components up to the third order. Thirteen volunteers are shown in different colors; black line with markers indicates the average.

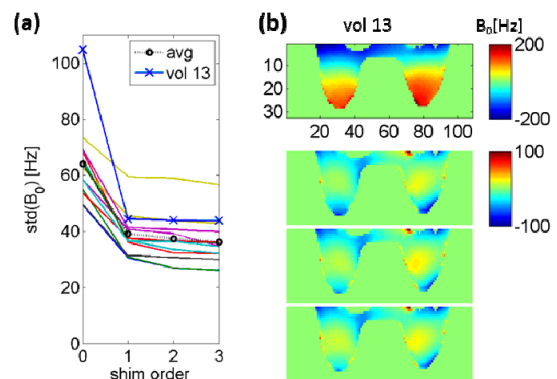


Figure 3. (a) Standard deviation of residual B_0 field after three-dimensional simulated shimming. **(b)** Example of shimmed B_0 maps in an axial slice. The four images correspond to unshimmed and shimmed maps up to the 3rd order (shim order increasing from the top to the bottom, identical scale in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