Bias in Breast $B_0$ mapping: shimming lipid rich parts of the body at 7T
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Introduction:
Field mapping is being widely applied for magnetic field ($B_0$) homogenization (shimming) for a range of MR sequences (EPI, MRS etc), since it allows for either a user defined or an automatically segmented region of interest for which the $B_0$ magnetic field is to be optimized. However, the acquisition of a reliable $B_0$ field map in lipid rich environment as the human breast is complicated by highly concentrated lipids.

In short, for $B_0$ field mapping, a dual-echo gradient echo scan is performed. Here, the phase difference between the two images is directly proportional to the frequency offset in the magnetic field: $\Delta f = (\phi_2-\phi_1)/(2\pi(T\text{E}_2-T\text{E}_1))$. However, if multiple resonances are present in the tissue of interest (e.g. water and lipids), the phase evolution of the signal is no longer linear with the frequency offset and shows a complex pattern dependent on the relative intensities of the spectral components (figure 1). The resulting phase offsets establish themselves as large artificial field offsets in a $B_0$ field map. Lipid suppression is one way of reducing these artifacts, however this will lengthen the required scan-time for the shim calibration, but more importantly this approach leads to severe SNR reduction in fatty tissue, and therefore a severely limited precision in the acquired field correction. Therefore, in lipid-rich parts of the body, a method is preferred where the $B_0$ field can be accurately mapped in lipids as well as in other tissue types [1]. As an alternative, a multi point Dixon method may be applied, but considering the many resonances of lipids, many echo times are required, hence increasing the scan time significantly.

For accurate $B_0$ mapping where only two gradient echo images are acquired at different echo times, the lipid signal should have a similar phase so that no bias is introduced. To this end, the frequency difference between water (4.7 ppm) and the CH$3$ lipid resonance (1.3 ppm) is normally used to calculate two in-phase echo times. However, since any lipid spectrum contains multiple resonances, up to 10 in the human breast [2]. This leads to deviations from the expected phase evolution and severe bias in the $B_0$ map. Therefore, a method is required that takes into account the multiple lipid resonances in calculated the optimal echo times for unbiased $B_0$ field mapping in lipid rich tissue. In this work we investigate which in-phase echo times are applicable for $B_0$ field mapping in the human breast at 7T.

Methods:
All MR measurements were performed on a whole body 7 Tesla MR (Philips, Cleveland, USA) with a custom build breast coil [3]. Semi-LASER localized single voxel measurements of the lipids were acquired to estimate the intensity of the lipid peaks[3]. Spectral fitting and simulation of the temporal phase evolution of the MR signal in the human breast were performed. Simulations were performed with a combination of water and the major lipid resonances (CH$3$ at 1.3 ppm) and with an extended lipid spectrum containing the seven most intense lipid resonances in the human breast. In vivo $B_0$ field maps were acquired in the human breast, with an echo time difference of 0.99 ms (in-phase echo times for water and the CH$3$ resonance) and with optimized echo times obtained from the simulations including more spectral components of the lipid tissue (figure 1).

Results:
Phase evolution over time of the full spectrum shows a complex behavior rather than a simple beating pattern of two resonances (Figure 2). The first four in-phase echo times are 1.035, 1.987, 2.936, 3.945 for lipids in the human breast at 7T. $B_0$ mapping performed with optimized echo times shows an unbiased estimation of the magnetic field where the field map with default in-phase echo times, assuming only the CH$3$ lipid resonance, shows large bias fields of up to 100 Hz.

Conclusion:
For accurate $B_0$ field mapping in lipid rich tissue, it is essential to determine all major spectral components. With optimized echo times, the $B_0$ field homogeneity can also be optimized in lipid rich tissue using fast $B_0$ mapping.

References:
(1) Siero ISMRM 2010  
(2) Dimitrov MRM 2011  
(3) Klomp NMR Biomed 2010