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: $\Delta f = (\varphi 2-\varphi 1)/(2*pi*(TE2-TE1))$. 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.

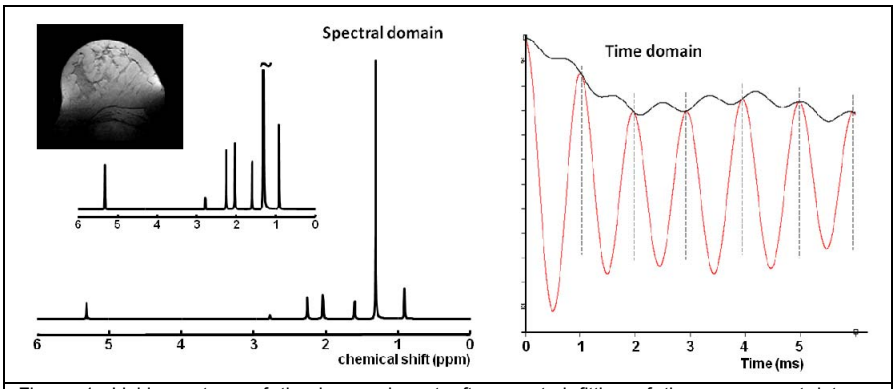

Figure 1. Lipid spectrum of the human breast after spectral fitting of the seven most intense resonances. The time domain evolution for the full lipid spectrum shows a complex behavior, which is dependent on the relative intensities of all lipid peaks.

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 CH3 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 an 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 CH3 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 CH3 lipid resonance, shows large bias fields of up to 100 Hz.

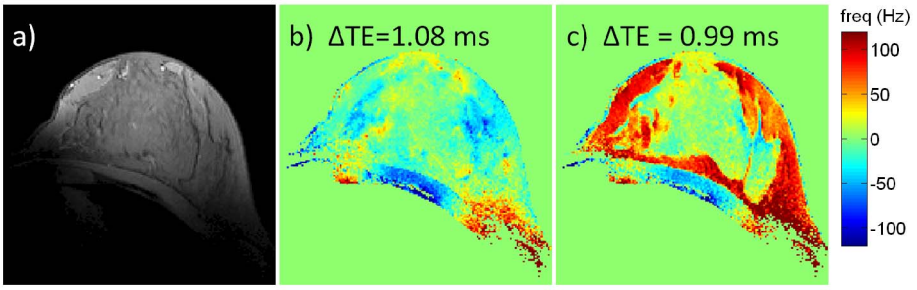

Figure 2: B_0 field map of the human breast (a), acquired with optimized in-phase echo times, based on a lipid spectrum (b), and acquired with default in phase echo time difference, based on only the CH_3 lipid resonance at 1.3 ppm.

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