Rapid B_0 Shimming with Three Orthogonal Frequency Maps

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Introduction: Image-based shimming methods have been shown to have robust shimming performance in regions with poor homogeneity [1] and in the presence of multiple resonances with comparable amplitudes (e.g., water and lipid) [2]. Typically these methods use the phase difference measured between two or more evolution times to estimate the frequency maps. This generally requires phase unwrapping, which is challenging, but can be performed reliably by using multiple unevenly-spaced evolution times. The shimming methods based on line mapping, such like FASTMAP [3], are faster and provide good results in relatively homogenous tissues, but only if B_0 inhomogeneity is relatively small and the tissue contains only one dominant resonance, typically water. In this work, we improve on the previously reported multi-slice 3D method [1-2] by using three orthogonal slices to more rapidly cover the 3D volume, and by incorporating an iterative decomposition of water and fat with echo asymmetry and least-squares (IDEAL) to estimate frequency [4]. With this orthogonal frequency-map (OFM) technique, 1st and 2nd order shim corrections can be calculated from either the whole sample volume or user-defined ROIs.

Materials and Methods: All experiments were performed with a Siemens 3 T Trio TIM scanner using commercial CP head and phased-array breast coils. The method was tested and calibrated using a spherical saline phantom, with 128x128 matrix over a 200 mm field of view, TE = 3, 3.5 and 4 ms, and TR = 7 ms, resulting in 6-7 s total acquisition time for 3 orthogonal slice groups, including a 1s delay between slice groups for T_1 recovery. The manufacturer's standard 3D shimming was used for comparison. Localized water line widths were measured using the manufacturer's interactive shimming. The same protocol was applied to show improvements in human head and breast tissue where strong lipid resonances are present. The frequency maps were calculated using a previously introduced algorithm [4] with a cut-off 10 % of maximum signal (all studies) and additional user defined ROIs in the human experiments. The model functions for X, Y, Z, Z2, XY, XZ, YZ and X2Y2 shims were fitted into three orthogonal slices simultaneously in a least square sense.

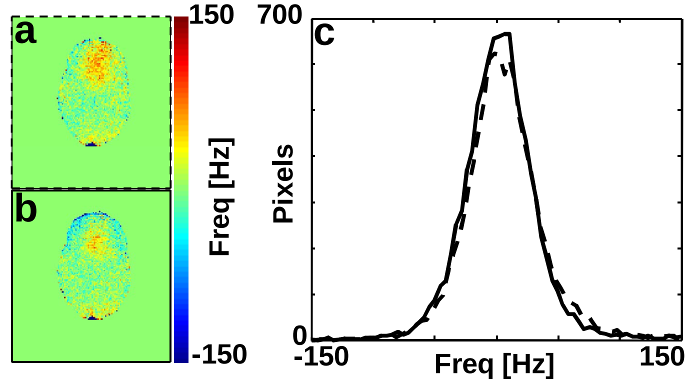
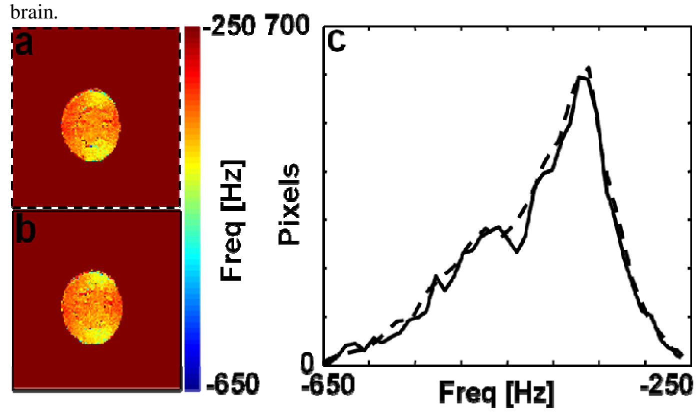


Fig. 1 Frequency maps obtained after standard 3D shimming (a) and using OFM (b). Histograms of frequencies of standard 3D shimming (dashed line) and OFM (continuous) from all 3 orthogonal slices from human brain.



Fg. 2 Frequency maps obtained after standard 3D shimming (a) and using OFM (b). Histograms of the frequencies of standard 3D shimming (dashed line) and OFM (continuous) from all 3 orthogonal slices from human breast.

Results: In the human brain study (n=1), one iteration of the OFM method led to an acceptable shim (33 Hz whole-brain), while two iterations of the standard method gave 45 Hz (**Figure 1**). We were able to obtain smooth frequency maps also in the presence of fat/water interfaces in breast tissue (**Figure 2**). In the breast tissue (n=2), the OFM method converged to 56 Hz after 2 iterations (14 s measurement), compared to 4 steps (≈3 min measurement) with standard 3D shimming. The need for high 2nd order shim currents was greater than the scanner's capacity when large regions-of-interest were selected for optimization; with small ROIs the predicted 2nd order shim currents were achievable. In the current implementation OFM requires 7 s measurement time per iteration, compared to 96s in [1] and ≈30 s for the manufacturer's standard 3D shimming.

Discussion: The results suggest reliable performance of new method in conventionally challenging tissue, such like breast. Phase unwrapping is not needed due to the IDEAL-type frequency mapping, which enhances robustness of the method. The very short measurement times required will be particularly valuable for shimming in body tissues (heart, liver, etc) where motion can make conventional shimming perform poorly. The primary applications for this technique are single-voxel spectroscopy in the body and breast, and in the more challenging regions of the brain such as the temporal lobe and hippocampus. Future work will include optimizing the ROI selection and incorporating the maximum available shim currents into the fitting routine.

References: [1] Hetherington, B et al., MRM 56 (2006) 26-33, [2] Hetherington, B et al., Proc. Intl. Soc. Mag. Reson. Med. 14 (2006), [3] Gruetter, R MRM 29 (1993) 804-811 [4] Yu, H et al., MRM 54 (2005) 1032-1039

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