Cost function guided image based B_0 shimming at 3T for efficient fat suppression in liver and prostate imaging

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Introduction:
With increasing field strength, the off-resonance effects caused by B_0 inhomogeneities become more severe and affect all magnetic resonance (MR) applications. Traditionally, B_0 shimming methods focus either on a local volume of B_0 inhomogeneities, e.g. in MR spectroscopy experiments, or on a global volume of B_0 inhomogeneities such as in abdominal and pelvic imaging. However, some MR applications could benefit from a combination of both shimming approaches. For example, experiments which demand globally constrained B_0 offsets for frequency-selective fat suppression throughout the field of view (FOV), but also require locally optimal B_0 homogeneity in a region of interest (ROI). In general, a more optimal shim solution for a specific MR experiment can be pursued by exploiting the higher order shim coils available at high field MR systems. Previously we have shown for spectroscopic imaging in the human brain at 7T, employing up to 3rd order shim coils, that a tailored cost function can be constructed in such a way to find a balance in the trade-off between global and local B_0 homogeneity [1]. The goal of this work was to show the potential of cost function guided shimming at 3T for efficient fat suppression in liver and prostate. The upper abdomen and pelvis are challenging regions to shim due to the large fat content and air-filled lungs. Also, at 3T only up to 2nd order shim coils are available which limits the degrees of freedom for cost function guided shimming. Experiments and simulations show that a shim solution with a better trade-off between global and local field homogeneity can be found compared to traditional shimming methods that is beneficial for the balance between fat suppression and local geometrical distortions.

Material and Methods:
Prostate:
Data acquisition was done on five healthy volunteers on a Philips 3T whole body MR system using a 6-channel phased array cardiac coil. B_0 field map acquisition was performed using a 3D dual-echo gradient echo sequence with TR/TE/ΔTE =186/4.6/2.3ms, FA=40°, 18 slices and $3.6\times3.6\times4.6mm^3$ spatial resolution. The field map data, ΔB_0, with all the shim values set to zero ('noshim') was processed offline and phase unwrapped [2]. Next, a ROI containing the prostate, $40\times40\times83mm^3$, was manually drawn in the images. In Matlab, a nonlinear minimization algorithm [3] was used to minimize the cost function: $C_{125Hz} = \sigma_{ROI} + \alpha N_{125Hz}$, employing shim fields up to 2nd order constrained by the hardware shim current limits. The algorithm minimizes the standard deviation of ΔB_0 in the ROI, σ_{ROI}, while simultaneously minimizing the number of voxels *outside* the ROI (in %) which deviate more than 125Hz from the mean frequency inside the ROI, N_{125Hz}. In this study the weight factor, α, was set at 1. The 125Hz criterion was chosen from the properties of the frequency-selective fat suppression pulse used in abdomen and pelvic imaging; bandwidth=340Hz, offset w.r.t. water peak frequency=137Hz. Calculated shim terms were ported back to the scanner and used for an additional B_0 field map. This B_0 field map was compared with the B_0 field map after the application of the clinically employed 'autoshim' method (1st order shim coils only), which uses the entire FOV as shim volume, and the MR system's 'pencil beam' method (up to 2nd order shim coils), which uses a user-defined shim volume (same as the prostate ROI) and is based on the FASTMAP method [4].

Liver (simulation only):
B_0 field map acquisition and processing was done on three healthy volunteers using a similar B_0 field map acquisition but with a spatial resolution of $6\times6\times8.5mm^3$ and coronal slices. A mask denoting the liver region was manually drawn in the images. Shimming simulations with the same algorithm as for the prostate were performed using a) the proposed cost function (C_{125Hz}) with the liver as ROI, b) least-squares minimization only on the liver ROI (LSQ_{liver}) and, c) the whole abdomen ($LSQ_{abdomen}$).
For both studies the σ_{ROI} and N_{125Hz} was calculated from the measured and simulated B_0 field maps. Shim value optimization computation time was less than 30s.

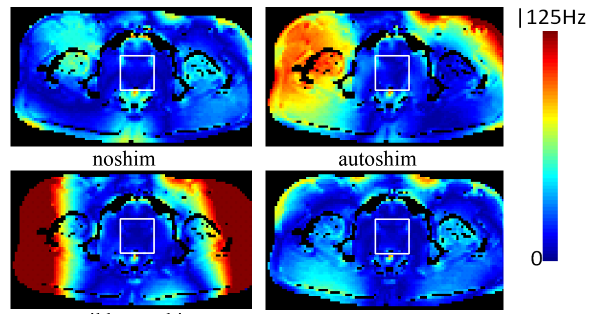

Figure 1 prostate shimming measurements.

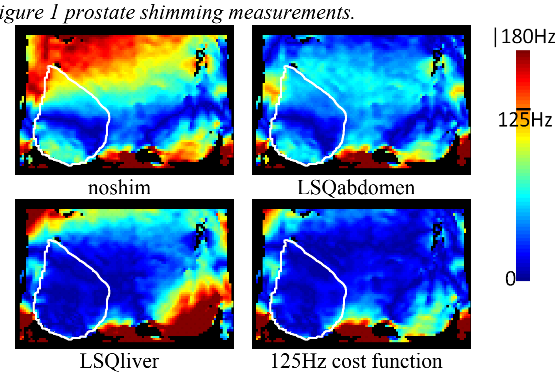

Figure 2 liver shimming simulations.

Results and Discussion:
Tables 1 and 2 show the measured prostate and simulated liver shimming results respectively for the different methods averaged across subjects. Figures 1 and 2 contain for two different subjects the measured and simulated B_0 field maps, where outlined in white the prostate and liver ROI are shown. The simulated and measured 125Hz cost function B_0 field maps agreed very well for the prostate experiment (data not shown). The proposed hybrid shimming approach resulted in a significant reduction of the large frequency offsets outside the ROI in a controlled manner, while maintaining a similar good B_0 homogeneity in the ROI compared to shimming only on the ROI (LSQ_{liver} and pencil beam). The weight factor α can be used to give more weight to efficient global fat suppression or to a better homogeneity in the ROI (data not shown). Finally, the proposed cost function guided shimming opens the possibility to set the properties (bandwidth and/or frequency offset) of the frequency selective fat suppression pulse according to the shimming predictions on an individual basis.

		method			
	Prostate measurements	noshim	Autoshim	Pencil beam	C_{125Hz}
ROI	prostate B_0 std (Hz)	37.4	25.7	19.2	19.9
	Pelvis B_0 std (Hz)	50.2	62.3	131.7	47.4
	Pelvis N_{125Hz} (%)	2.5	6.0	21.2	1.8

Table 1: Prostate shim measurement results averaged across subjects.

		method			
	Liver simulations	noshim	LSQ_{liver}	$LSQ_{abdomen}$	C_{125Hz}
ROI	liver B_0 std (Hz)	62.0	18.6	51.1	22.2
	Abdomen B_0 std (Hz)	56.6	131.7	48.9	69.4
	Abdomen N_{125Hz} (%)	32.1	41.8	11.2	14.3

Table 2: Liver shim simulation results averaged across subjects.

Conclusion

The proposed method allows for optimizing up to second order shim terms on a user-defined region of interest while restraining the field inhomogeneities in the rest of the field of view. The cost function guided shimming method opens the possibility to control frequency selective fat suppression for abdomen and pelvic imaging.

References
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