A Simple Approach of Combined Passive and Active Shimming for *In Vivo* MR Spectroscopy at High Magnetic Field

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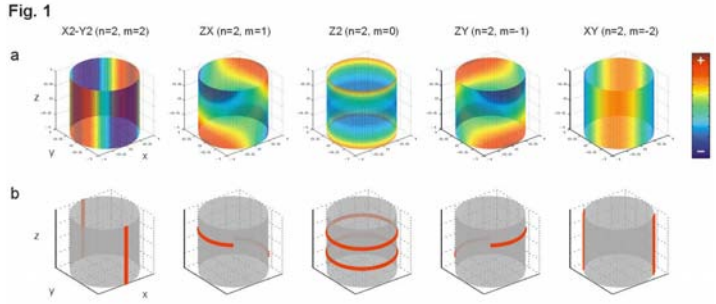
High magnetic fields increase the sensitivity and spectral dispersion in MR spectroscopy. However, spectral peaks are broadened *in vivo* at higher field strength due to stronger susceptibility-induced effects. Strategies to minimize the spectral linewidth by optimal shimming are therefore of critical importance. In our current 7T MR system, the shim requirements exceeded the dynamic range of the second order active shim capabilities up to 10 times, which was overcome by a combined passive and active shim approach. Thereby, simple ferro-shim geometries were theoretically derived and applied for shimming of regions in the visual cortex of the macaque monkey.

METHODS: Simple ferro-shim geometries were developed by quantitative field calculations [1] to approximate the five second order spherical harmonics (Fig.1a) when placed into the scanner B_0 field. A cylindric geometry was used as basic design block and the passive shim fields were numerically optimized for a cube volume with a side length of 27% of the cylinder diameter. Experimentally, μ-metal sheets were mounted on a plastic tube (diameter 25 cm) to surround the monkey head and the RF coils. First and second order active shimming was achieved with FASTMAP [2]. Measurements were performed on a vertical 7T/60cm Bruker Biospec system, temporarily equipped with a Siemens AC44 head gradient insert.

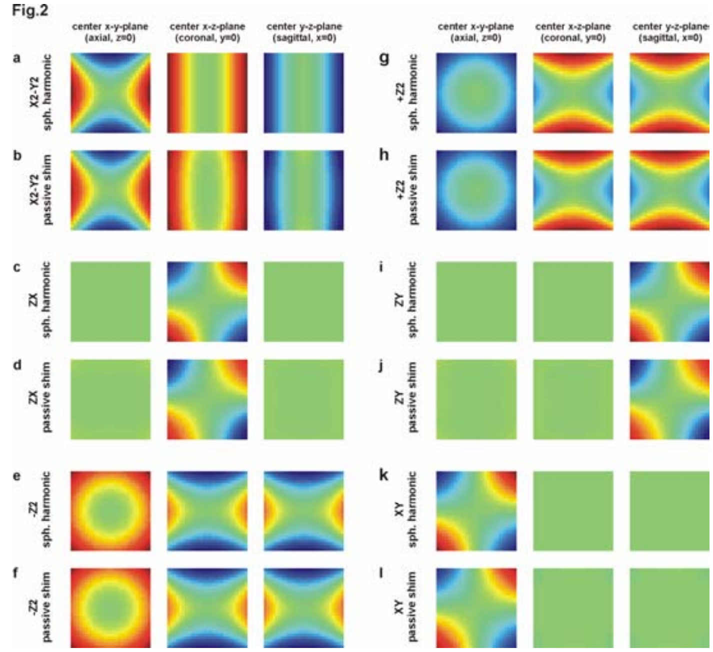
Fig. 1



RESULTS: High accuracy approximations of all five second order shim fields were derived from simple geometries of only two pieces of ferro-shim per shim term (Fig.1b/red, X2-Y2/XY: 2 vertical lines, ZX/ZY: 2 quarters of a loop, ±Z2: 2 loops as proposed in [3]). The optimal ratio of the vertical length vs. the horizontal distance for X2-Y2/XY shimming was found to be 1.21, and the optimal ratios of the vertical distance vs. the loop diameter for the generation of the ZX/ZY, +Z2 and –Z2 shim fields were determined to be 0.34, 0.24 and 0.85, respectively. The shim fields after optimization are visualized in figure 2b,d,f,h,j,l for the three central sections of the optimized FOV compared to sections of the second order spherical harmonic target fields (Fig.2a,c,e,g,i,k).

The passive shimming was first verified on a water phantom (data not shown) and then applied in the monkey *in vivo*. Crude passive shimming required the adjustment of the ferro-shimming for a particular setup and brain region once. In subsequent sessions simple mounting of the shim tube was enough to reproducibly reduce the shim requirements to the dynamic range of the active shimming device. No artifacts like B_0 eddy currents or spikes were observed in MRS or fMRI applications using STEAM or EPI. With the combination of strong passive and high accuracy active shimming MRS linewidths of 12-14 Hz for water and 10.5-12.5 Hz for the Cr+PCr resonance at 3 ppm were reproducibly achieved in the primary visual cortex (V1) of the macaque monkey (reported in a separate abstract this meeting).

Fig.2



DISCUSSION: It was demonstrated that even strong limitations of the active shim power can be overcome by a combination of strong passive and high accuracy active shimming. The numerically optimized vertical loop distances for ±Z2 shimming matched the analytical results on a sphere [3]. However, the cylinder geometry used as basic design block in this study was considered a preferable approach. Mounting of 2 pieces for X2-Y2, XY, ZX and ZY shimming minimized the experimental effort compared to 11 pieces for ZX/ZY or 17 pieces for X2-Y2/XY shimming [3]. The optimized volume with a side length of 6.8 cm (27% the tube diameter) covered large parts of the monkey brain and the decrease in accuracy for bigger FOVs was moderate and depending on the shim term (data not shown). Since the optimized shim region scales with the shim tube diameter, the presented approach is easily applicable to all subject sizes from rodents up to a human setup. The results might be of high practical relevance for high field MR setups of limited shim power and/or shimming of body regions which inherently require very high shim fields.

[1] Med Phys 31, 579 (2004), [2] J Magn Reson 96, 323 (1992), [3] Magn Reson Med 1, 44 (1984)