Development of a rapid, automated shim approach for cardiac MR in mice in vivo

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Introduction: Homogenizing (i.e. shimming) the static magnetic field is crucial for any MR experiment in order to maximise resolution and signal-to-noise. Adjusting the three linear and typically up to 14 higher order shims manually is laborious and subjective. Moreover, this process is particularly challenging in cardiac MR where various tissues (i.e. heart and skeletal muscle, bone, lungs and flowing blood) are in close vicinity within the chest, each having different magnetic susceptibilities and relative motions. Auto-shim methods such as FASTMAP (1) or FASTERMAP (2), are clinically and experimentally well established in brain tissue, but inevitably fail in the heart due to the ill-defined phase of the MR-signal, particularly inside the ventricles. Based on a technique, previously applied to human brain (3), we propose a novel approach for the application to mouse hearts *in vivo*, that is able to homogenize the B_0-field in an arbitrarily shaped, but connected region of interest.

Methods: All experiments were carried out on a vertical bore 11.7 T MR-system (*Bruker, Germany*), using quadrature-driven ^{1}H-imaging coils (id 28 mm or 40 mm; *Rapid Biomedical, Germany*), optimized for cardiac MR in mice. Starting from 0 on all axes, the linear, five 2nd order and six available 3rd order shims were adjusted either manually using a PRESS sequence (voxel size: $(10\ mm)^3$, TE/TR=9/1000 ms) or automatically over the left-ventricular myocardium, using a 3D segmented GE-sequence (TE/TR= 1.4/4 ms), repeated twice with different echo times (ΔTE=0.8 ms). Both sequences were double-gated with steady-state maintenance (4). MR-data were reconstructed off-line in *idl*, phase maps were generated and unwrapped (5). Fieldmaps and required correction shim currents were calculated using the method proposed by Wen et al (6). The method was applied to a compartmental phantom, containing water with different Gd-concentrations to vary T_1-relaxation times, and a sponge to increase susceptibility differences across the sample. It was also applied to three mice *in vivo*.

Results: Fig. 1a illustrates the compartmental phantom. Fig. 1b shows the fieldmap of the residual B_0-imhomogeneities inside a ring simulating the myocardium of a heart after shimming a 15 mm cubed voxel manually. The duration of the manual shim procedure was approximately 10 minutes. The displayed maps cover a volume of approximately ±7.5 mm. Fig. 1c shows the fieldmap after automatic adjustment (time: 5 minutes). The standard deviation of the residual fields was: (b) 39 Hz and (c) 23 Hz, respectively. Figure 2 shows a stack of axial 3D-MR images across a mouse thorax *in vivo* (Fig. 2a), and the fieldmap of the residual B_0-imhomogeneities inside the left ventricular myocardium after shimming a 10 mm cubed voxel manually (time: 10 minutes, Fig. 2b) or automatically (time: 7 minutes, Fig. 2c). The displayed maps cover the left ventricle over a range of about ±2.5 mm. The standard deviation of the residual fields in the heart was: (b) 184 Hz and (c) 115 Hz, respectively. The overall reproducibility of the fieldmaps in mouse hearts *in vivo* was 9 ± 12 Hz (n=3).

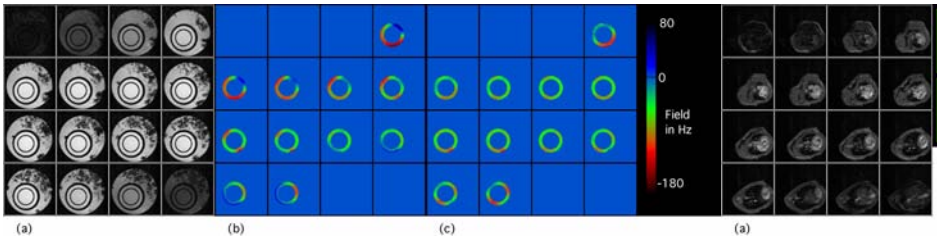

Figure 1.

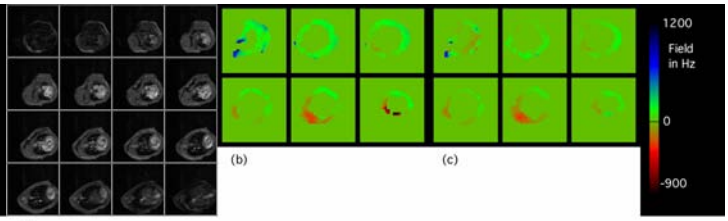

Figure 2.

Discussion: A new method for automatic shimming of hearts in mice is reported, which is faster and provides higher spatial resolution than the chemical shift imaging based technique reported previously (7). The main advantage of our auto-shim approach is that it allows for optimization of the field over an arbitrarily shaped region of interest. Although mainly limited by weak high-order shims, initial experiments in phantoms and mice show the superiority of this approach over manual shimming. Finally, the development of the auto-shim approach represents an important step towards automating experimental cardiac MR and improving its user friendliness.

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