Dynamic Multi-Coil Shimming of the Rat Brain at 11.7 Tesla

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INTRODUCTION: The *in vivo* rat model is a work horse in neuroscientific research, preclinical studies and drug development. MR imaging and spectroscopy allow the non-invasive assessment of anatomy, physiology and biochemistry, but excellent magnetic field homogeneity is required for meaningful results. However, the homogenization of magnetic fields in the rat brain, i.e. shimming, is a difficult task due to susceptibility-induced field distortions. After the introduction of multi-coil (MC) shimming for the mouse and the human brain [1,2], here the benefits of dynamically updated MC (DMC) shimming are demonstrated for the rat brain.

METHODS: A DMC/RF system was developed for MR imaging and spectroscopy of the *in vivo* rat brain at 11.7 Tesla (Fig. 1). In essence, 48 individual copper coils (30 turns, diameters 10-13 mm) were mounted to an acrylic former (ID 48 mm). Specific DMC shim fields were synthesized by driving the coils with a set of 48 optimized currents over a dynamic range of ±1 A [1]. A surface RF coil (diameter 14 mm) was integrated in the DMC setup for RF transmission and signal reception. DMC shimming was applied in a slice-specific fashion and compared to static, third order SH shimming achieved with the scanners' built-in SH coil system. The quality of the shimming was assessed as standard deviation of the residual field distribution and through the impact of shimming on the quality of echo-planar images (EPI) of male Sprague-Dawley rats studied *in vivo*. EPI parameters typical for functional MRI of the rat brain at 11.7 Tesla were chosen (FOV 30x30x14 mm^3, matrix 64x64x7, TE 15 ms, single-shot) and identical post-processing was applied to assure comparability. The DMC shim currents for EPI were derived from field maps with 0.5 mm thick slices that were analyzed in groups of 4 to resemble the EPI slice geometry.

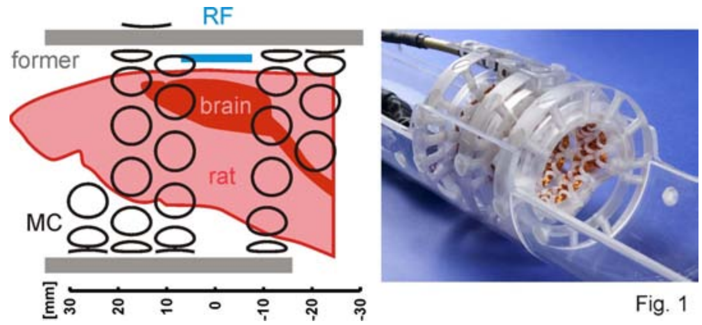

Fig. 1

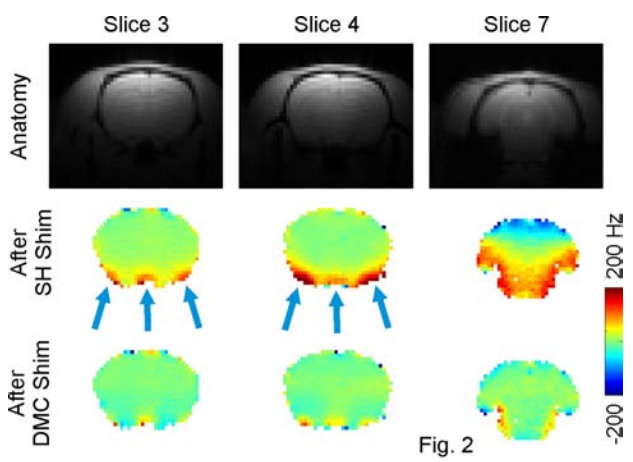

Fig. 2

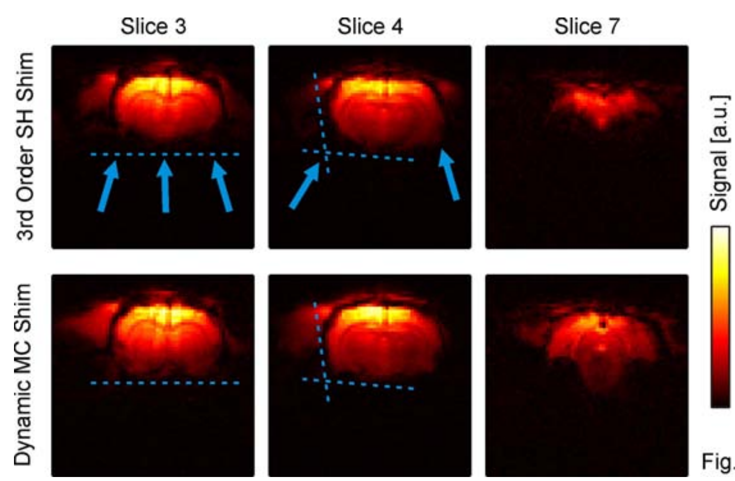

Fig. 3

RESULTS: Third order SH shimming removed the large-scale, shallow field components from the bulk of the brain, but failed to correct for localized terms (Fig. 2, blue arrows). This limitation was further aggravated by the multitude of distortions that exist throughout the rat brain and, therefore, even relatively shallow terms regularly remained after static SH shimming (Fig. 2, SH, slice 7). DMC shimming halved the standard deviation of Larmor frequencies compared to SH shimming. The exact reduction was dependent on the considered anatomical portion of the brain and the details of the covered field imperfections. Shimming with correction fields provided by the MC approach largely eliminated the localized field terms (Fig. 2, DMC) and its dynamic application furthermore alleviated the challenges associated to the large number of artifact areas (Fig. 2, DMC, slice 7). For EPI, field inhomogeneity leads to phase cancellation and spatial misregistration. As such, the brain areas that contained residual field artifacts after SH shimming suffered from signal loss and image deformation (Fig. 3, SH, slices 3/4). By comparison, the brain outline was largely preserved with DMC-shimmed EPI (Fig. 3, DMC, slices 3/4). While peripheral slices were regularly rendered useless with SH shimming due to the limited performance in these areas (Fig. 3, SH, slice 7), DMC shimming allowed meaningful imaging throughout the sensitive area of the RF coil (Fig. 3, DMC, slice 7).

DISCUSSION: DMC shimming has been shown to successfully minimize magnetic field distortions encountered in the rat brain at 11.7 Tesla. Dynamic SH shimming (or "DSU")[3] could be an alternative option. However, the method faces significant technical challenges, e.g. due to the generation of eddy currents, which are negligible for DMC approaches. The selected example focused on the central brain, but other brain areas can be studied by appropriate head positioning. The minimization of signal loss in brain areas that experience strong field artifacts and the improvement of the spatial registration accuracy with DMC shimming are expected to critically benefit a wide range of preclinical and neuroscientific MR research.

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