Dynamic Multi-Coil Technique (DYNAMITE) Shimmed EPI 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 essential for meaningful results. The homogenization of magnetic fields in the rat brain, i.e. shimming, is a difficult task due to a multitude of susceptibility-induced field distortions. Conventional shimming with spherical harmonic (SH) functions performs satisfactorily in limited areas in which field distortions are shallow, e.g. in cortex. The inability of SH shimming to homogenize magnetic fields throughout the brain is a long-standing problem that limits the study of various subcortical structures or the brain as a whole. Based on the recently introduced multi-coil (MC) concept for magnetic field modeling [1] and the Dynamic Multi-Coil Technique (DYNAMITE) for magnetic field shimming of the rat brain [2], here the benefits of DYNAMITE shimming for echo-planar imaging (EPI) of the rat brain at 11.7 Tesla are presented.

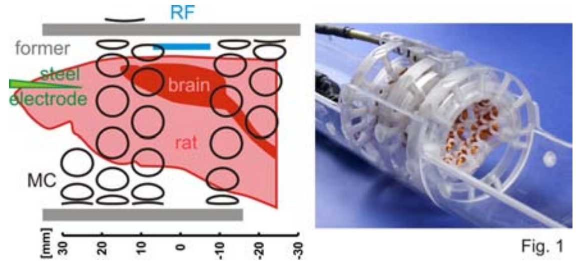

Fig. 1

METHODS: Single-shot EPI was performed on male Sprague-Dawley rats at 11.7 Tesla (FOV 26×26×10 mm^3, matrix 64×64×5, TE 15 ms) with an integrated MC/RF system presented recently (Fig. 1, [2]). In essence, 48 individual copper coils (30 turns, diameters 10-13 mm) were mounted to an acrylic former (ID 48 mm). Specific DYNAMITE shim fields were synthesized by driving the coils with a set of 48 optimized currents over a ±1 A range. A surface RF coil (diameter 14 mm) was integrated in the MC setup for RF transmission and signal reception. After the first reports of improved slice-shimming with DYNAMITE [2], here the shim performance was studied for a larger population (n = 12). More importantly, the impact of magnetic field homogeneity on primary output measures, namely the signal strength with EPI and the portion of usable EPI voxels (defined as signal >10% of max.) were studied.

Table 1: Regular Brain Shim

uncorrected	136 ± 20 Hz
static SH 1st	69 ± 8 Hz
static SH 2nd	61 ± 11 Hz
static SH 3rd	52 ± 7 Hz
static SH 4th	44 ± 8 Hz
static SH 5th	38 ± 7 Hz
dynamic SH 1st	42 ± 4 Hz
dynamic SH 2nd	33 ± 4 Hz
dynamic SH 3rd	27 ± 3 Hz
dynamic SH 4th	22 ± 3 Hz
DYNAMITE shim	17 ± 3 Hz

RESULTS & DISCUSSION: DYNAMITE shimming with the MC/RF setup reduced the residual B_0 field spread after correction to a third compared to current shim technology that employs static zero through third order SH shapes (Table 1, average standard deviation ± SD of the analysis). The EPI signal over the rat brain increased by 31% and a 24% gain in usable EPI voxels could be realized in the *in vivo* rat brain.

DYNAMITE shimming has been shown to minimize magnetic field distortions encountered in the rat brain *in vivo*. Magnetic field shimming in the rat brain particularly benefits from the dynamic application of (any) correction fields due to the multiplicity of terms throughout the brain and second SH order dynamic shimming has been presented before [3]. DYNAMITE shimming with the presented MC/RF setup improves the field homogeneity by an additional factor of two, while avoiding the technical difficulties that bore-size SH coil systems face with respect to eddy currents and B_0 fluctuations. DYNAMITE is not limited to the slice orientation chosen here and other geometries have been realized already, e.g. coronal slicing for functional MRI of cortical layer structures (data not shown). The developed MC/RF setup allows the inclusion of extra-cranial (EEG) or intracranial electrodes for electrophysiological recording and additional hardware for forepaw or whisker stimulation. The ability of the presented approach to compensate even extreme field artifacts can be appreciated when a non-magnetic (e.g. tungsten) electrode for whisker stimulation is replaced by a model made of steel (Fig. 1, green). The field distortion induced in the brain spans a frequency range of several thousand Hertz (Fig. 2). Note the identical geometry to the regular brain shimming scenario described above, i.e. four field map slices resemble the geometry of every EPI slice. Significant field imperfections remain within EPI slices throughout the brain with second order SH shimming (Fig. 3, left) and lead to major EPI artifacts (Fig. 3, right). While not perfect, DYNAMITE shimming is capable of removing large part of both the electrode- and the anatomy-induced field terms (Fig. 4, left) and allows meaningful EPI (Fig. 4, right). In summary, improved DYNAMITE-provided field homogeneity along with the achievable large brain coverage of the method is expected to be crucial when signal pathways, cortical circuitry, the brain's default network or multi-modal integration are studied. Along with the efficiency gains of MC-based shimming demonstrated recently [4], DYNAMITE shimming has the potential to replace conventional SH shim systems in small bore animal scanners.

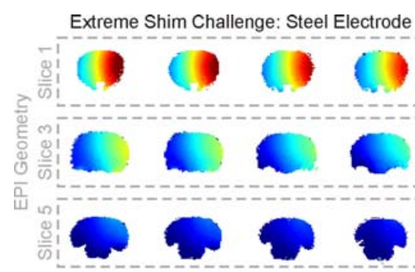

Fig. 2

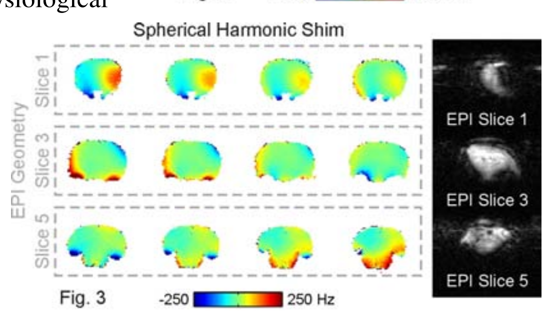

Fig. 3

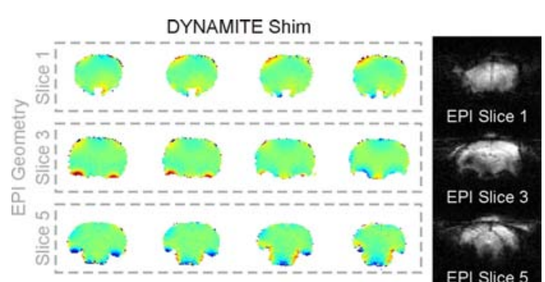

Fig. 4

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[1] JMR 204:281-289 (2010); [2] Proc ISMRM (2012), p667; [3] MRM 49:409-416 (2003)