Spatial Selection Through Multi-Coil Magnetic Field Shaping

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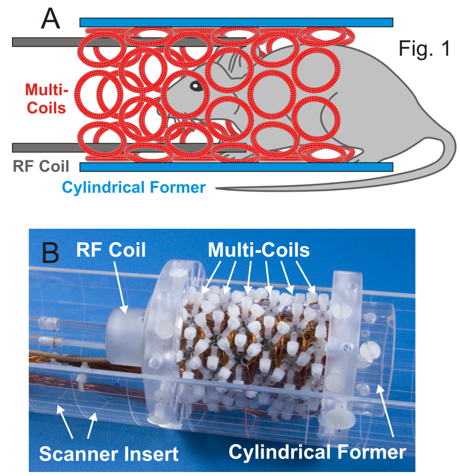
INTRODUCTION: The spatial selection of planar slices in MR is typically achieved through frequency-selective radio-frequency (RF) pulses in the presence of linear magnetic field gradients. 2D RF pulses allow the selection of more complex spatial patterns [1]. The downsides of 2D RF schemes include the limited achievable bandwidth, demanding gradient switching and long RF pulses which ultimately limits their application at high magnetic B_0 field due to SAR concerns.

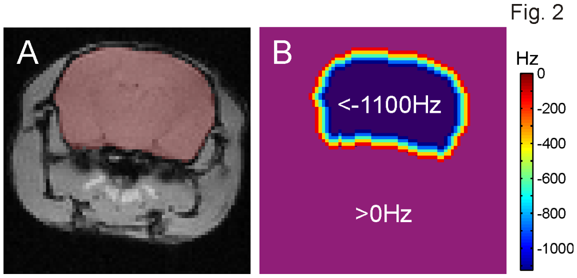
After the introduction of the multi-coil (MC) concept for magnetic field modeling in MR [2], and its application to shimming [3], here we show that the selection of non-trivial spatial patterns like the brain of a mouse can be achieved by applying an appropriate, complex magnetic field distribution during a single frequency-selective RF pulse.

Fig. 1



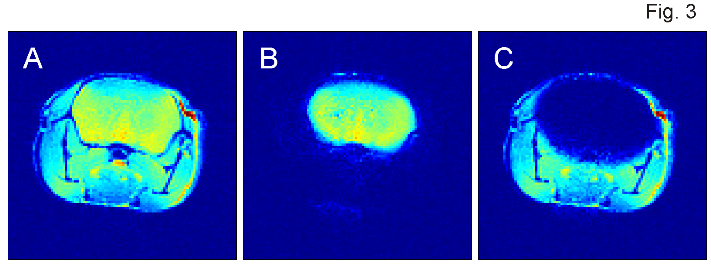
METHODS: The MC setup for magnetic field synthesis consisted of 48 coils (30 turns, diameter 13 mm) that were distributed in 6 rings of 8 coils each (Fig. 1A). The coils were made of copper wire and mounted on the inside of an acrylic former with an inner diameter of 35 mm (Fig. 1B). A costum Bolinger RF antenna was placed inside the MC setup to surround the mouse head and was used for the application of a spin-echo RF scheme and for image signal reception. For spatial selection of the mouse brain in 2-dimensional slices, the brain was extracted from anatomical reference images (Fig. 2A) and band-like gradient patterns were created to resemble the outline of the brain (Fig. 2B). A set of 48 optimized coil currents in the -1..1 A range was then derived to best approximate the desired magnetic field distribution in Fig. 2B based on calibration field maps [2] and custom-built amplifier electronics was used to apply the coil currents and the corresponding magnetic field shapes in as little as 10 µs [3]. The zero cut-off frequency between the brain and the rest of the field-of-view allowed the selection of the brain or everything but the brain with simple, frequency-selective RF pulses covering the negative or positive frequency ranges only, respectively. Note that the spatial selection fields were only applied during the spin inversion with adiabatic full passage RF pulses which were chosen based on their sharp cut-off frequency. Experiments were carried out on a 9.4 Tesla animal system and all imaging, field measurements, data analysis and hardware handling were done with custom-made software and methods.

Fig. 2



RESULTS: Figure 3A shows a section through the head of a mouse. The combination of simple, frequency-selective RF pulses and magnetic field gradients that were shaped as described in Fig. 2B allowed the selective excitation of the brain (Fig. 3B) or everything but the brain (Fig. 3C) with reasonable accuracy.

Fig. 3



DISCUSSION: The presented method allowed the selection of the mouse brain with simple, frequency-selective RF pulses in the presence of static, spatially specific magnetic encoding fields. As for all localization methods that are based on magnetic field gradients, chemical shift displacement is a concern. However, the presented method provides, unlike conventional linear magnetic field gradients, a handle on the orientation pattern and the shape of the chemical shift artifact. Potential applications of the presented method include brain selection and/or outer volume suppression for MR imaging, spectroscopy or spectroscopic imaging. Due to the small number of RF pulses and the low concomitant power deposition, spatial selection and outer volume suppression with the presented method has the potential to provide a low-SAR alternative to 2D RF localization schemes or multi-slice outer-volume-suppression. Future extensions will focus on the improvement of the spatial selection, the limitation of the chemical shift artifact and an extension from 2-dimensional slices to 3-dimensional volumes. No obstacles are expected for the translation of the method to the human brain. In fact, the shape of the human brain is simpler than the mouse brain and simulations have shown that the required field shapes can be generated more easily.

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[1] J Magn Reson 1989, 81:43-56, [2] J Magn Reson 2010, 204:281-289; [3] Proc. ISMRM (2010), 1535; [4] Proc. ISMRM (2010), 1532.