3D MR Imaging with the Dynamic Multi-Coil Technique: DYNAMITE MRI

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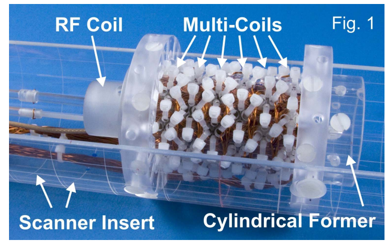
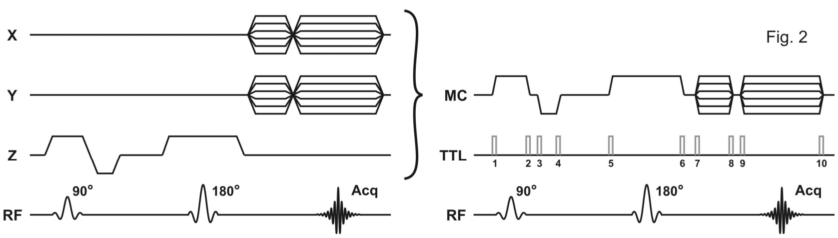
INTRODUCTION: To date, spatial encoding for MRI is based on linear X, Y and Z field gradients generated by dedicated X, Y and Z wire patterns. The multi-coil (MC) technique enables the generation of a multitude of magnetic field shapes relevant to biomedical MR [1]. The benefits of the Dynamic Multi-Coil Technique (DYNAMITE) for the magnetic field shimming in rodent [2,3] and human [4] brain have been shown recently as well as proof-of-principle of radial [1,5] and algebraic [6] MRI. Here the potential of DYNAMITE MRI is explored further and the first 3-dimensional multi-slice MRI implementation is presented in which all gradient fields are purely MC-based. The obtained image fidelity is shown to be virtually identical to a conventional MRI system with dedicated X, Y and Z gradient coils. Comparable image quality is a milestone towards the establishment of fully functional and purely MC-based MRI (and shim) systems.



METHODS: The goal of the study was to establish 3-dimensional DYNAMITE MRI at an image quality that is comparable to what is achieved with conventional gradient coils. To this end, multi-slice radial MRI was acquired with the scanners' gradient system at 9.4 Tesla and reconstructed by filtered back-projection (96 angle steps, 11 slices, FOV 12×12×11 mm^3, TE 12 ms, BW 36 kHz). For the generation of DYNAMITE fields, a MC setup was used that had been designed for field shimming in the mouse brain [2] and applied for the first DYNAMITE MRI implementations [5,6] (Fig. 1). In essence, 48 individual, localized coils were arranged in 6 rows of 8 coils (diameter 13 mm, 30 turns) on a cylindrical surface. Conventional MR sequences differentiate between X, Y and Z gradient schemes (Fig. 2, left). Instead, all fields in this study were provided by the MC setup with DYNAMITE and played out serially by TTL trigger signals (Fig. 2, right). A 30 kHz/cm (7 G/cm) amplitude was chosen for all gradient fields for slice-selection and radial encoding based on the available ±1 A dynamic range per coil. A set of 48 DYNAMITE currents was calculated ahead of time in a slice-specific fashion for every gradient field. To this end, the targeted field gradient for a given slice (Fig. 3, left, dark gray, 1mm) was optimized over a slab that was tripled in thickness (right, dark + light gray = red box, 3 mm) at a four-fold refined spatial grid (0.25 mm vs. 1 mm). As such, intra-slice field components were considered and the larger scale behavior was taken into account. The latter was particularly relevant for the slice-selection gradients to differentiate the volume of the slice itself from its surroundings. In other words, a true regional copy of the original large-scale X, Y or Z gradient fields was synthesized with DYNAMITE for the considered 1067 (96·11 + 11) field scenarios that were applied in a total of 10560 (96·11·10) events. The average error in every field optimization ROI was ≤1%.



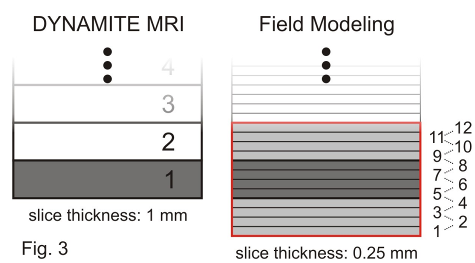
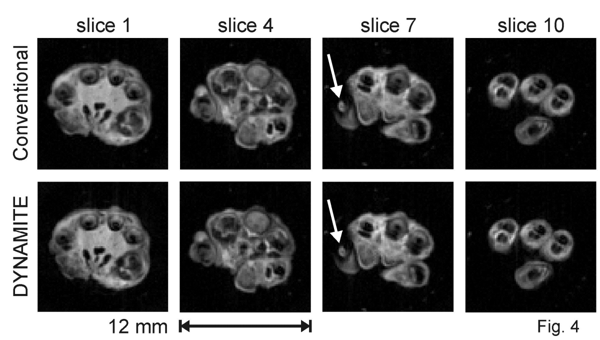


Fig. 3

RESULTS: DYNAMITE allowed the artifact-free acquisition of multi-slice MRI. Images from a foot of a rat look virtually identical to reference images that were acquired at identical parameter settings with the scanner's built-in X, Y and Z gradient coils (Fig. 4, selected slices throughout the FOV). The similarity confirms the accuracy at which DYNAMITE resembles conventional gradient fields for both slice-selection and radial (in-plane) encoding. Note that even partial volume effects within individual slices share the identical appearance (e.g. white arrow). This suggests that the achieved spatial accuracy is significantly better than the slice thickness of 1 mm.



DISCUSSION: The demonstration of image fidelity comparable to standard technology is a necessity for a novel method and an important hurdle to take. In this study, a fully functional MRI system based on DYNAMITE rather than conventional gradient coils has been presented. Radial MRI was applied, but other MR sequences are possible. For instance, phase encoding gradients for Fourier reconstruction pose a subset of the field shapes employed here. Identical sequence timing was used for DYNAMITE and conventional gradient encoding to ensure comparable image contrast. However, MC switching times of the applied MC setup of 10 µs bear the potential for echo time reductions or the realization of faster MRI techniques (e.g. EPI). The gradient amplitudes in this study were limited by the 1 A amplifier range. MC field amplitudes can be significantly increased when stronger, readily available amplifiers are applied, coils with more turns are used or field accuracy is traded for efficiency [5,7]. With the gains for shimming in both performance and efficiency [2-4,7], the MC technology has the potential to replace spherical harmonic coil systems for specific applications.

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[1] J Magn Res 204:281-289 (2010); [2] Magn Res Med 66:893-900 (2011); [3] Proc ISMRM (2013), p. 667; [4] J Magn Res 212:280-288 (2011); [5] Proc ISMRM (2013), p. 2590; [6] Proc ISMRM (2013), p. 2545; [7] J Magn Res 236:95-104 (2013).