Spiral MRI on rat brain and rat heart at 7 Tesla

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INTRODUCTION: Although quite similar in many aspects, the spiral imaging technique features several advantages over Echo Planar Imaging (EPI). Especially, *(i)* higher acquisition speed, due to a more efficient use of the gradient hardware (the two in-plane channels operate simultaneously, applying waveforms optimized to fully exploit the amplifiers), *(ii)* very short minimum echo time (TE), with a trajectory starting from the k-space centre and *(iii)* good flow properties, due to gradient moment nulling. Two experiments performed at 7 T on rats are presented here. They take advantage of these remarkable features and demonstrate the feasibility of spiral MR imaging for small animal studies at high B0 fields.

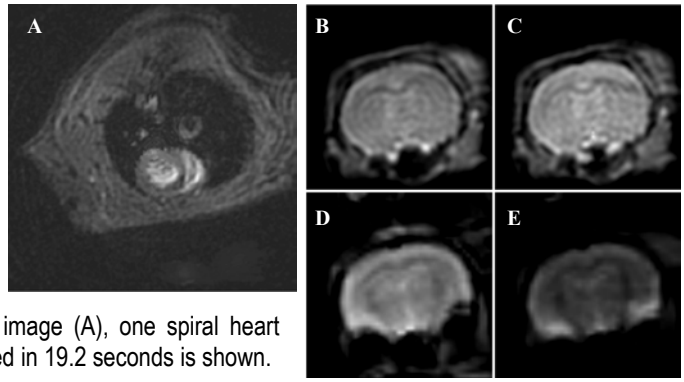
PURPOSE: The purpose of this study is to show the potential of the spiral k-space scanning method for functional MRI and cardiovascular animal applications at high field. An image comparison is performed in order to assess the image quality obtained with spiral and with EPI acquisitions, both very prone to B0 in-homogeneity artifacts.

METHODS: A spiral imaging method has been implemented in the *ParaVision*® environment (Bruker BioSpin MRI GmbH, Ettlingen, Germany). It allows the two-dimensional trajectory to be measured and processed [1]. The spiral-acquired data are reconstructed with a conventional regridding algorithm using a Kaiser-Bessel function as convolution kernel [2]. The MRI experiments were performed on a 7 T, 16 cm diameter bore, *PharmaScan*® (Bruker BioSpin MRI GmbH, Ettlingen, Germany) equipped with a B-GA9S gradient coil (Gmax = 366 mT/m, slew rate max = 3424 T/m/sec). Birdcage resonators of 38 mm and 60 mm diameters were used respectively for the brain and for the heart experiments. Rats were anesthetized with isoflurane at 1-2.5 %.

For brain experiments, first and second order shims were adjusted with FASTMAP over a voxel of $(7.8\text{mm})^3$ positioned at the front lobe of the rat brain, where the five imaged slices were located. For more flexibility, all single and multi-shot trajectories were calibrated directly on the animal. A spatial resolution of 469 μm was chosen, corresponding to a 3 cm FOV and a matrix size of 64x64. With acquisition bandwidths of 450 kHz and 250 kHz respectively, the spiral acquisition duration was 12.1 ms while the EPI one was 17.2 ms. For the selected FOV (3 cm) the upper limit of the EPI bandwidth was 250 kHz because of gradient hardware constraint applies on the EPI readout channel, while a 450 kHz bandwidth was possible for the spiral protocol. The images were acquired using the shortest TE achievable for the desired spatial resolution (EPI) and slice thickness (spiral, EPI). Minimum TEs of 1.1 ms and 6.7 ms were found for gradient echo (GE) spiral and EPI techniques, respectively. Performing the same experiments with a spin echo (SE) preparation scheme leads to TEs of 5.4 ms and 16.3 ms, respectively.

For heart experiments, a global first order shim was performed. The heart slice of interest was first localized with a T_2^* weighted sequence (FLASH, TR/TE: 52/2 ms). Because of the beating motions preventing proper *in vivo* trajectory measurement, the trajectories were measured on a completely homogeneous phantom (water solution with $CuSO_4$ 1 g/l) prior to acquire *in vivo* images. A sixteen-shot spiral scan was used for cardiac acquisitions with a TR/TE of 10/1.6 ms allowing 15 frames to be measured for covering the whole cardiac cycle (350 bpm). Each shot was synchronized with the rat ECG and breathing signals. All movie frames were acquired for each shot. Eight scans were averaged, resulting in a total scan time of 19.2 seconds for the whole cardiac cycle. The chosen spatial resolution was 625 μm corresponding to a FOV of 6 cm and a matrix size of 96x96.

RESULTS: A comparison is shown between single-shot GE (B) and SE (C) rat brain spiral images and single-shot GE (D) and SE (E) EPI images. All brain experiments were performed with saturation slices in order to suppress the brain surrounding tissues located outside the FOV. Because of shorter TE and shorter gradient application duration, spiral images suffer from fewer B0 in-homogeneity artefacts and thus provide a better level of details than EPI images. On image (A), one spiral heart image taken from a cardio cycle movie acquired in 19.2 seconds is shown.



CONCLUSIONS: Constant improvements in MRI hardware allow on one side to shorten the "spiral" readout gradient duration – gradient amplifiers and actively shielded coils, increased sampling rates (digital receiver allowing acquisition bandwidths up to 1 MHz) – and on another side to decrease the residual B0 in-homogeneities – gradient-integrated shim coils allowing very good shim performances. Both factors concur to make possible new *in vivo* applications of spiral MRI on small animals and at high B0 fields. As shown by our preliminary results at 7 T, spiral MRI can be a good alternative to EPI especially for fMRI, perfusion, cardiovascular or diffusion applications. To our knowledge this is the first described study demonstrating the spiral technique for rat imaging with good spatial resolution at high field.

REFERENCES: [1] Y. Zhang *et al.* Magn Reson Med. 1998; 39: 999-1004. [2] J.I. Jackson *et al.* IEEE Trans. Med. Im. 1991, 10: 473-478.