Feasibility of High Resolution Mouse Brain Spiral Imaging at Very High Field (11.75T) for Perfusion Studies

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Introduction: Transgenic mouse models of central nervous system (CNS) diseases (e.g. stroke, neuronal pathologies...) are increasingly developed and studied with MRI. Multimodal approaches, including structural, functional and anatomic imaging are usually used, leading to long acquisition times despite the gain in sensitivity obtained with the use of very high field strengths (B_0 > 7T). Therefore, improvements of the MR sequences are required to obtain high spatial resolution images (~200µm) in reasonable scan times. High temporal resolution is usually achieved with fast imaging such as EPI. However, with the increasing fields, single-shot EPI may not be applicable due to the increase of image distortions or strong susceptibility artifacts. The replacement of single shot EPI by multi-shot EPI can partially overcome these limitations but lead to increased scan times. Gradients systems available on small animal scanners are usually highly performing in terms of strength and switching time. In this context, spiral imaging could be a good alternative to EPI as it offers theoretically similar acquisition speed performance with less sensitivity to susceptibility artifacts. Moreover, spiral imaging is less sensitive to motion, which could be an important issue when long protocols are run or when specific area of CNS (e.g. spinal cord) are investigated. However, the successful application of high resolution spiral imaging for mouse CNS investigation at very high field can be challenging for several reasons: significant B_0 inhomogeneities and potential gradients imperfections. This work presents the investigation of spiral imaging feasibility at very high field (11.75T) for high resolution mouse CNS imaging. Several resolutions and spiral design parameters were tested. Resulting images were compared to EPI images and both imaging techniques were applied in a brain perfusion study perfomed with a presaturated FAIR-ASL technique [1].

Methods: Experiments were performed on an 11.75T vertical MR system (Bruker, AV 500WB, transmitter/receiver volume coil:∅ 3cm, length 5cm, G_{max}=1T/m, slew rate SR_{max} =900kT/m/s) on anaesthetized mice (C57BL/6j, 10 weeks, weight 25±1g).
MR parameters: Spin-echo sequences were used with a bandwidth of 400 kHz, a FOV of 2.5cmx2.5cm and a slice thickness of 1mm. Spatial resolutions of the images were 400µm^2/pixel (corrseponding to a 64x64 Cartesian matrix) and 200 µm^2/pixel (corresponding to a 128x128 Cartesian matrix). A first order shimming was performed. Reference gradient echo images of same resolutions were acquired. Specific parameters of spiral and EPI are reported in the table below.
Spiral imaging data were acquired using an Archimedean spiral k-space sampling trajectory [2] with 4 and 8 interleaves depending on the required spatial resolution (table). Gradient amplitude and slew rate were 0.9*G_{max}, and 0.9*SR_{max} respectively. True k-space trajectories were calibrated prior to the *in vivo* experiments on a phantom using the technique described in [3] and for the different investigated resolutions. Data reconstruction, based on a gridding algorithm [4] was realized using in-house-developed software running under Matlab. The convolution kernel (Kaiser-Bessel) used to resample spiral grid into cartesien grid had a width of 4 samples and a Beta of 18.5547. Finally, the density compensation function was calculated using Voronoi diagram library available on Matlab software.

	spiral			EPI		
Matrix size	# of interleaves	Acquisition duration	Echo time	# of shots	Acquisition duration	Echo time
64x64	4	2.15 ms	3.6ms	1	10.25ms	6.4ms
	8	1.18 ms				
128x128	4	5.78 ms		2	20.50ms	8.9ms
	8	3.02 ms				

presat-FAIR experiments were performed with both EPI (2shots, mtx=128x128) and spiral (8 interleaves, mtx=128x128). A single inversion time (TI=1.7s) and a recovery time τ=3.4s after the presaturation were used [5]. M_b^0 (equilibrium magnetization) was acquired for perfusion signal normalization in full relaxation conditions. Perfusion related images (ΔM_b) were obtained by subtracting control images (selective inversion) from the labeled images (global inversion). ΔM_b data were averaged for 10 min (corresponding to 40 averages for EPI based sequences and 5 averages for spiral based sequences).

Results:

Figure 1 shows typical images obtained with EPI and spiral for the different resolutions. Strong B_0 inhomogeneities effects, arising from interface areas, are shown on EPI and spiral images for both resolutions (red arrows). These artifacts tend to decrease with the increasing number of spiral interleaves (decreased acquisition duration). Distortions are more pronounced for EPI (phase-encoding direction, A/P) and 4 interleaves spiral (blue arrows). They are clearly reduced for 8 interleaves spiral. Green arrow shows chemical shift artefact due to non-fully suppressed fat signal. Figure 2 below shows control and label images obtained with the presat-FAIR experiments along with the resulting normalized perfusion related image ($\Delta M_b/M_b^0$). Typical perfusion contrasts were obtained perfusion signal (fig 2).

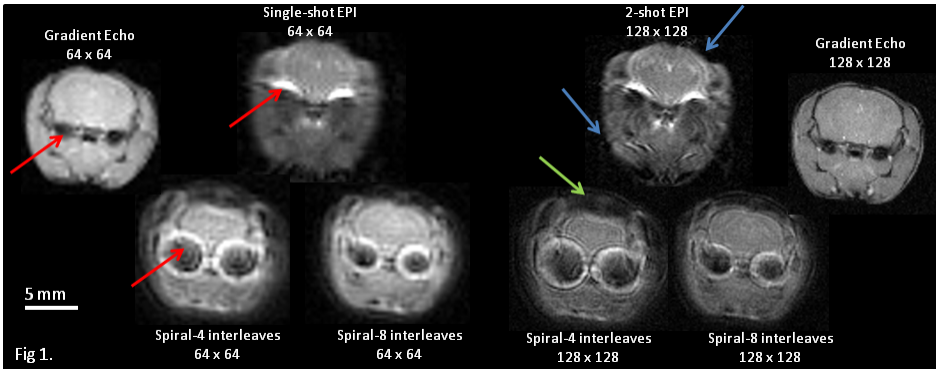

Fig 1.

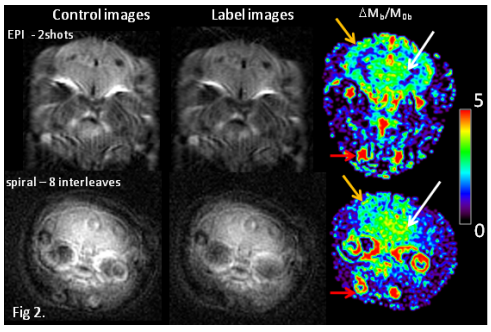

Fig 2.

for both techniques, although more homogenous (particularly in the cortex) with EPI. High perfusion was then observed in thalamus (white arrows) and in cortex (orange arrows). The signal of big vessel can also be seen (red arrows). Similar sensitivities were obtained for spiral and EPI techniques.

Discussion: This work presents the investigation of spiral techniques for high resolution mouse CNS imaging. Preliminary results obtained show that spiral imaging is feasible at very high field (11.75T) although further adjustments are required to improve the image quality. In particular, there is a real need to optimize the B_0 field homogeneity and the fat signal suppression to reduce off-resonance artifacts (fig 1 red arrows). Additionally, a variable density k-space sampling (oversampling of the k-space center) would help for the image quality. In this study, best results were obtained for 8 interleaves acquired in 8 repetitions. However, the acquisition duration is short enough (3.02ms) relative to average brain T_2 value (~25-30ms) to allow acquiring interleaves in a multi-echos train scheme (e.g. TSE).
Further studies will be necessary to evaluate the advantage of spiral for presat-FAIR experiments. However, the perfusion contrast obtained in this work suggests that spiral can be used. Despite the reduced number of averages due to the number of interleaves, the signal-to-noise ratio remained sufficient to provide reliable

Reference: [1] Pell et al., MRM (1999) [2] Glover MRM 1999; [3] Zhang MRM 1998; [4] Jackson IEEE 1991 ; [5] Duhamel et al., MRM (2008)