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In vivo high resolution rat spinal cord diffusion weighted imaging at 9.4T: a new approach based on adiabatic refocusing pulses and reduced FOV multislice EPI

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Introduction

The spinal cord (SC) is affected in a large number of neurological diseases such as multiple sclerosis, SC traumatic injury and tumours. The use of rodent animal models for further understanding pathological mechanisms and exploring therapeutic approaches based on in vivo MR studies is limited compared to the brain because of challenging experimental difficulties. The main problems are the SC structure, magnetic field heterogeneity due to surrounding bony structures, and physiological motion such as breathing, cardiac beating, and cerebrospinal fluid pulsation. Various strategies have been proposed to overcome the challenges posed by this particular structure. A high spatial resolution can be reached by selecting a reduced region of interest containing mainly the SC such as ZOned Oblique Multislice (ZOOM) diffusion weighted EPI [1] and 2D interleaved multislice reduced FOV single-shot diffusion-weighted EPI (2D ss-rFOV) [2]. These sequences consist of multiple slice selective conventional RF pulses which might be very sensitive to the B_1 and B_0 inhomogeneities observed at very high magnetic field. As a result, the profiles of the Volume of interest (VOI) along the different spatial axes and the saturation of the outer volume signals are not optimal. It's mandatory to get a good spatial selectivity before reducing the FOV in order to avoid any aliasing artefacts. The adiabatic RF pulses are less sensitive to these effects with a better selection profile. Traditionally, a pair of identical Adiabatic Full Passage (AFP) pulses is applied for the refocusing of the transverse magnetisation because of the nonlinear position dependent phase induced by each pulse at the expense of increased power deposition and TE. It was shown that a significant phase refocusing can be achieved by applying single AFP pulses along different spatial axes. The phase variation across an MRI [3] or MRSI [4] voxel is negligible provided that the phase is sufficiently spatially resolved. In this work, a new approach based on a combination of conventional and adiabatic spatially selective RF pulses which makes use of narrowed selected VOI and shortened TE is described and preliminary results of the rat lumbar SC Diffusion Weighted Imaging (DWI) were presented.

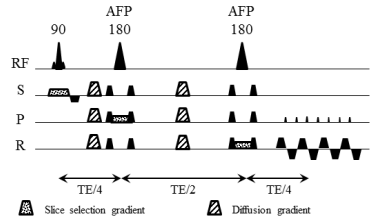

Fig.1 The pulse sequence of the developed sequence. The VOI is selected using a combination of one non-adiabatic and two adiabatic RF pulses applied in three orthogonal spatial axes. Standard EPI readout is employed for the spatial encoding of the signal.

Materials and Methods

Pulse sequence: The developed sequence is based on the selection of the VOI by applying slice selective RF pulses in three orthogonal spatial axes. As a result, only a narrow cross section of the volume is both excited and refocused. The pulse sequence is shown in Fig.1 and consists of a slice selective non-adiabatic excitation RF pulse followed by a first AFP RF pulse applied along the phase encoding axis and a second AFP RF pulse along the readout axis. Pairs of gradient crushers are surrounding the adiabatic RF pulses in order to suppress residual unwanted signals originating from outside the selected VOI. For the spatial encoding of the signal, a standard EPI readout is employed. In order to avoid any aliasing artefacts, the encoded FOV is larger than the selected volume of interest (VOI). The positions of the VOI and the FOV can be adjusted independently (Fig. 2). For DWI, one diffusion gradient is applied before the first AFP pulse and the other one before the second AFP pulse.

Acquisition and Application: Experiments were performed on anesthetized Dark Agouti rats on a 9.4T Agilent scanner (Agilent Technologies, Santa Clara, CA, USA) using transmit volume coil (Rapid Biomedical, Ø=72 mm) and two elements receive array coil (Rapid Biomedical). A global manual shimming was performed after the adjustment of the animal position based on fast localization imaging. The VOI was set at the lumbar level. Eight slices of 1 mm thickness and in-plane extend of 7x7 mm^2 were selected using a sinc RF pulse and two Hyperbolic Secant AFP pulses, respectively. A FOV of 14.4x14.4 mm^2 was encoded using 6 shots EPI with an isotropic in-plane spatial resolution of 150um. The acquisition parameters were TE/TR=32/1500ms and NEX=15. For the DWI, a diffusion gradients were applied separately in x and z axes (b=0s/mm^2, bx=bz=500 s/mm^2). In order to reduce artefacts arising from movements the acquisition was synchronised with the respiration.

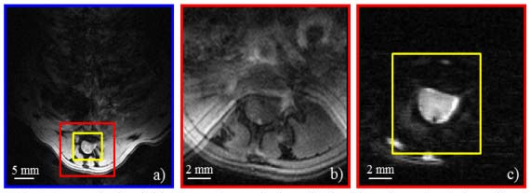

Fig.2 Anatomical axial images of rat spinal cord. The blue, the red and the yellow rectangles delineate the full FOV, the reduced FOV and the selected VOI, respectively. The images **a** and **b** are acquired using a standard gradient echo sequence. The image **c** is acquired using standard EPI and the VOI is selected using a combination of one non-adiabatic and two adiabatic RF pulses.

Results

Fig.2a and Fig.2b depict the images corresponding to a full FOV and a reduced FOV obtained using gradient echo imaging sequence. Fig.2c depicts the images obtained using the developed sequence and based on a narrowed selected VOI and the reduced encoded FOV. Fig.3 depicts some selected DWI slices corresponding to b=0, bx=500s/mm2, and bz=500s/mm2 obtained with the developed sequence.

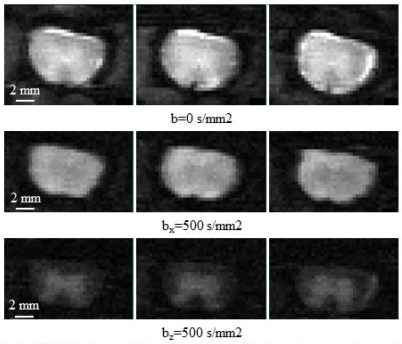

Fig.3 Diffusion weighted images of rat lumbar spinal cord acquired using adiabatic refocusing RF pulses and a reduced EPI encoded FOV. The row on the top depicts images without any diffusion gradients. The second and the third row depict DWI along x and z axes, respectively. The SNR of the DWI along z axis is lower because of a shorter acquisition time.

Discussion

A good spatial selectivity and saturation of the outer volume signals saturation were obtained. Compared to the previously reported works [1,2], a better suppression of the unwanted signals originating from outside the selected VOI should be obtained due to the combined effects of the accumulated nonlinear phases and the crushers surrounding the adiabatic RF pulses. Some artefacts are still present on some images because of the pulsing blood in the arteries surrounding the SC. The presence of relatively high subcutaneous lipids in the bottom of the VOI could be explained by the chemical shift displacement errors (CSDE) in the anterior-posterior direction. Because of gradient performance limitations, multi-shots EPI acquisition was needed in order to reach the desired spatial resolution and to reduce the TE. An efficient use of the gradient system, a shortened TE, and a reduced sensitivity to movement and flow effects can be obtained by combining the described spatial selection scheme with spiral encoding of the K space. Gradient modulated adiabatic RF pulses such as FOCI can be applied in order to improve the spatial selectivity, to reduce the CSDE and to overcome RF power limitations.

Conclusion

This work presents the development of a new approach based on adiabatic refocusing pulses and reduced FOV multislice EPI and its validation on in vivo high spatial resolution structural and DWI of the spinal cord at very high field. The adopted spatial selection and acquisition schemes can be combined with other preparation approaches like ASL and CEST in order to get high spatial resolution imaging of other small structures of the CNS like the spinal cord and the optic nerve.

References: [1] Wheeler-Kingshott et al. MRM 2002 ; [2] Jeong MRM 2005 ; [3] Park MRM 2006 ; [4] Sacolick MRM 2007