Feasibility of in-vivo Diffusion Tensor Echo Planar Imaging and Fiber Tracking at 14.1T

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Introduction:

Diffusion tensor imaging (DTI) has shown remarkable results over the last decade mainly for tumor detection and tracking brain recovery processes by assessing tissue microstructures information. Indeed, proton magnetic resonance spectroscopy has also shown interest in studying brain development [1] by looking at metabolic changes. Therefore, the combination of DTI with MRS gives a complete tool of investigation. However, none such multimodal *in vivo* studies in the rodent brain have been published so far. Combination of MRS and DTI is very challenging due to different requirements and the difficulties to find a good tradeoff between scan time, signal-to-noise ratio (SNR), sensitivity and spatial resolution. However, the use of surface coils for transmission and reception offer larger γB_1 allowing high performance spectroscopy acquisition by shortening the pulse length and benefiting of the higher sensitivity as compared to the usual volume coil excitation. Additionally, B_1 inhomogeneities engendered by surface coil allow the use of reduced field of view in the cranial-caudal direction without aliasing and have no impact on DTI reconstruction, as the images are rescaled with respect to the b_0 reference image. Furthermore, adiabatic pulses can attenuate this effect and provide a better coverage of the rodent brain. DTI is also time consuming due to its requirement of a minimum of seven experiments with different gradient orientations. In addition, to increase accuracy of anisotropy measurements, at least 20 non-collinear gradient orientations are required [2], necessitating the use of fast imaging techniques like echo planar imaging (EPI). The aim of this study was to implement a diffusion tensor echo planar imaging (DT-EPI) sequence with whole brain coverage at 14.1T, while using a surface coil as both transmitter and receiver.

Materials and Method:

All MR experiments were performed on a 14.1T/26cm magnet (Varian/Magnex) equipped with 12-cm gradient coils (400mT/m, 120µs) with a quadrature transmit-receive 20-mm surface RF coil. To improve brain coverage, radio frequency adiabatic full passage 180° pulses (AFP180) were used and to cancel the quadratic phase dependence [3], a second AFP180 was applied giving a twice refocused spin echo sequence (fig. 1). Adult Wistar rats were placed supine within an adapted holder and continuously anesthetized under a flow of 1.5-2% isoflurane in oxygen. Body temperature was maintained at 37^{0}C using thermoregulated water circulation. First and second order shims were adjusted using FASTMAP [3]. Diffusion gradients (G_{diff} = 29 G/cm, δ = 3 ms and Δ = 20 ms, giving a *b*-value of 1029 s.mm^{-2}) were positioned around the first AFP 180 pulse to minimize the TE and were applied along 42 spatial directions in order to improve the accuracy of anisotropy measurements: Icosahedral 21 directions sampling scheme as well as the 21 opposite directions to cancel cross terms [4]. A field of view of 23 × 15 mm^2 was sampled on a 128 × 64 cartesian grid. 4 shots interleaved EPI k-space acquisition was used to reduce TE as well as readout time, thus susceptibility artifacts. 8 slices of 0.8 mm thickness were acquired in the axial plane (10 averages) with TE/TR = 40/4000 ms. Nyquist ghosting artifacts were minimized by addition of images acquired with a positive and a negative readout gradient and their respective reference phase scans [5]. Diffusivity values (ADC, $D_{//}$ and $D_{\perp}$) as well as FA was derived from the tensor using a Matlab (Mathworks, Natick, MA) software. Six different ROIs were analyzed: the Corpus Callosum (CC), the Cortex (Cx), the External Capsule (EC), the Cranial Nerves (CN), the Cingulum (Cg) and the Ventricles (Ven). Fiber tracking imaging was performed using the "*MedInria DTI Track*" software [6].

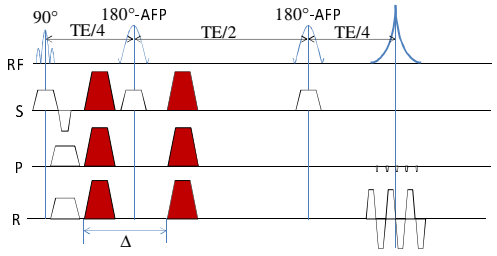

Figure 1: Semi adiabatic double spin echo sequence. White: imaging gradients, red: diffusion gradients.

Results and Discussion:

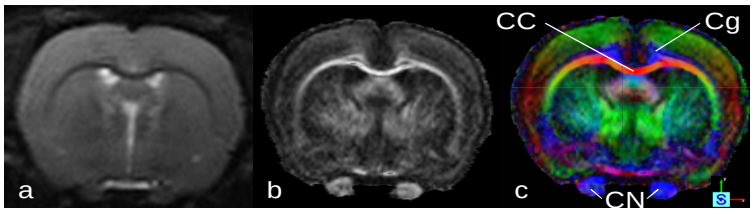

Figure 2: Typical a) b_0 image, b) FA map c) color map of an adult rat brain. Images show a complete coverage of the adult rat brain with a good SNR.

	CC	Cx	EC	CN	Cg	Ven
ADC	7.55	7.34	6.97	9.38	7.25	21.8
$D_{//}$	17.9	9.06	11.6	15.0	13.0	23.3
$D_{\perp}$	2.35	6.48	4.66	6.58	4.37	21.0
FA	0.86	0.21	0.53	0.49	0.61	0.07

Table 1: ADC, $D_{//}$, $D_{\perp}$ and FA values measured in the different ROIs. Diffusivity values are expressed ×10^{-4} mm^2/s.

Images provided evidence for a good coverage of the deeper part of the adult rat brain with an excellent SNR and a high resolution (fig. 2.a). Additionally, Nyquist ghosting artifacts were not visually significant. Mean values of apparent diffusion coefficient (ADC), parallel diffusivity ($D_{//}$), orthogonal diffusivity ($D_{\perp}$) and fractional anisotropy (FA), presented in Table 1, were in excellent agreement with literature [7]. The contrast in the b_0 image allowed a clear differentiation between grey and white matter (fig. 2.a) as well as in the FA maps (fig. 2.b). Direction encoded color maps (fig. 2.c), in agreement with previous study [8], show direction of diffusion in the CC (red - right ↔ left). Cg and CN were identified as well as the radial organization in the cortex or the isotropy in the ventricles with an ADC and a FA close to those of free water. *In-vivo* fiber tracking (FT) in the CC was clearly accomplished (fig. 3). In addition, FT in the CN at the base of the brain demonstrated the coverage of the brain with the proposed pulse sequence (fig. 3).

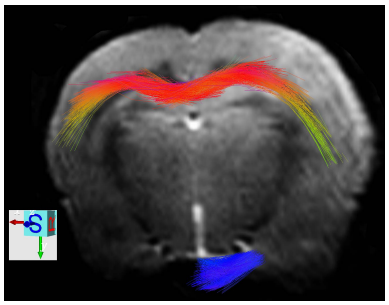

Figure 3: Fiber tracking image of the CC and the CN of an adult rat brain.

We conclude that using a surface coil as transceiver is feasible for *in vivo* DT-EPI at 14.1T with whole brain coverage. The *in vivo* combination of surface coil ^{1}H-MRS with DTI is expected to shed light on the effect of Hypoxia-Ischemia on the developing rat brain.

References: [1] Tkáč I, MRM 2003, [2] Jones DK, MRM 2003, [3] Gruetter R, MRM 2000, [4] Madi S, MRM 2005, [5] van der Zwaag W, in Proceeding ISMRM 2008, [6] P. Fillard, Proceeding ISBI 2006, [7] Bockhorst KH, J Of Neuro Res 2008, [8] Numano T,. MRI 2006.

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