The Benefit of Reduced FOV Diffusion Imaging with and without SENSE

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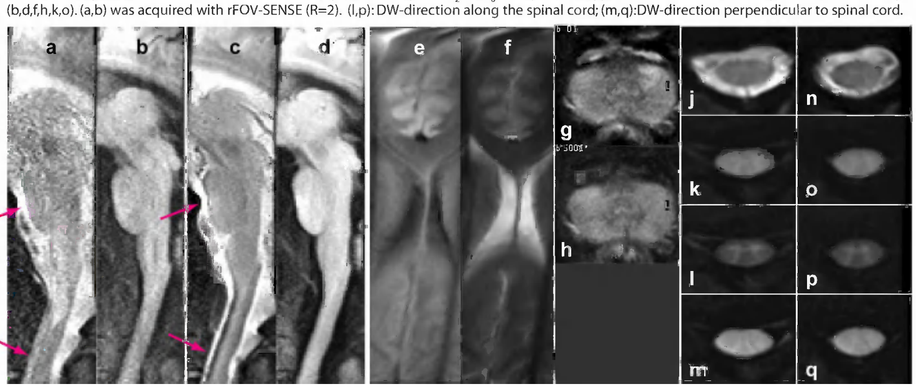
Introduction: Among diffusion weighted (DW) techniques single-shot spin echo EPI (SS-SE-EPI) achieves relatively high SNR and is fairly robust against physiological motion. However, high resolution acquisition with this technique is complicated by strong susceptibility effects, due to its long readout train. Recently it has been shown, that single-shot spin echo EPI using a reduced Field-Of-View (rFOV) in phase encoding direction is well suited for spinal cord DW imaging without the occurrence of susceptibility artefacts [1,2,3].
In this work we evaluate the applicability of the previously proposed rFOV approach [3] in different anatomical regions at 3T and 7T. In addition, the combination of this technique with sensitivity encoding (SENSE) is evaluated, enabling further EPI readout shortening. In simulations the SNR performance of 3T-rFOV+SENSE (R=2) of the brainstem and 1.5T-rFOV were evaluated. In both cases similar susceptibility artefacts can be expected.

Methods: rFOV: SS-SE-EPI with diffusion weighting in 6 directions was performed in different anatomical regions on healthy volunteers (n≥3) using the following parameter configurations:

Region	MR-system	coil	NSA and DW [s/mm^2]	TR	TE	FOV_{phase}	z	Res [mm^2]
Spinal cord	3T Philips Achieva	3-element coil-array	6/12 for b=0/b=750	3.0 s	43 ms	30 mm	5 mm	0.6^2
Brainstem	3T Philips Achieva	8-element head coil	6/12 for b=0/b=750	3.0 s	45 ms	38 mm	5 mm	0.87^2
Prostate	3T Philips Achieva	cardiac coil array	6/12 for b=0/b=500	3.0 s	58 ms	45 mm	4 mm	0.7^2
Corpus callosum	7T Philips Achieva	T/R-head-coil	6/12 for b=0/b=750	3.5 s	62 ms	35 mm	5 mm	0.7 x 0.8

Figure 1: In-vivo rFOV DW SS-EPI acquisition in the different anatomical regions: brainstem (sagittal)(a-d), corpus callosum (transvere)(e,f), prostate (transverse) (g,h), spinal cord (2 transverse slices) (j-q), showing the T_2W (b_0) images (a,c,e,g,j,n) and the corresponding isotropic DW images (b,d,f,h,k,o). (a,b) was acquired with rFOV-SENSE (R=2). (l,p): DW-direction along the spinal cord; (m,q): DW-direction perpendicular to spinal cord.



For all imaging regions the echo train length T_{train} (and echo time TE) was set minimal constrained by the scanner's gradient system and was further shortened by partial-Fourier = 0.6 to minimize susceptibility effects. For the same reason the size of the FOV in phase direction (FOV_{phase}) was set minimal while still covering the entire region of interest.

rFOV+SENSE: To evaluated the combination of rFOV with SENSE, g-factor maps for different FOV sizes using SENSE (R=2) in AP direction were obtained from phantom scans. From these data the relative SNR was estimated with respect to the FOV_{phase} at $B_0 = 3$ T and $B_0 = 1.5$ T. The simulations were performed for the imaging parameters in the brainstem mention above. T_2 (white matter) was set to 72 ms and 69 ms for 1.5 T and 3.0 T respectively [4]. Thus, relative SNR could be estimated as $SNR \propto B_0 \sqrt{T_{train}} \cdot e^{-TE/T_2} / g$, where g is the maximum g-factor measured in the region of the brainstem. In-vivo DW images were acquired in sagittal orientation on a 3T Philips Achieva MR system using the same parameters as used for the simulations. The FOV_{phase} reduction was achieved as in [3].

Figure 2: maximum and mean geomerty factor in an FOV centered on the brainstem against the FOV size

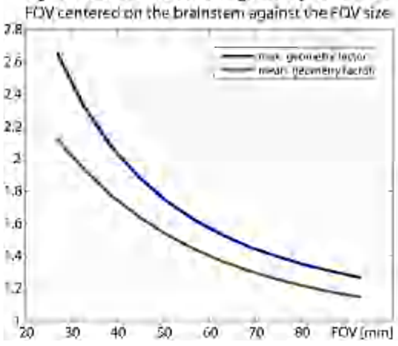
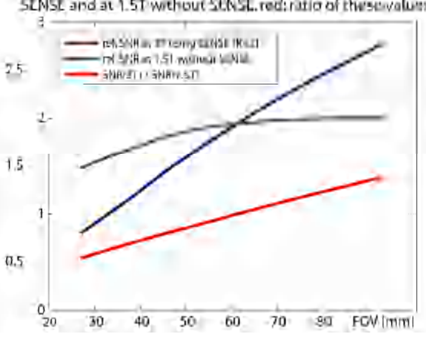


Figure 3: relative SNR at 3T using 2-fold undersampled SENSE and at 1.5T without SENSE. red: ratio of these values



Results: rFOV: The images acquired in the different anatomical regions using rFOV without SENSE showed little (fig.1c-f) or no (fig.1 g-q) susceptibility distortions, with unprecedented resolution (fig. 1 j-q) revealing fine anatomical details even on the DW images. Also 7T SS-EPI images of the central part of the brain could be obtained without severe susceptibility artefacts (fig 1. e,f).

rFOV+SENSE: Susceptibility artefacts in the brainstem (fig 1c,d) were reduced by the combination of rFOV+SENSE (R=2) (fig.1 a,b). Due to the drastically increasing g-factors for smaller FOVs (figure 2) a gain in SNR at 3T using SENSE (R=2) as compared to 1.5 T without SENSE is to be expected only for FOVs > 60 mm (figure 3). Thus theoretical SNR loss by a factor of $g_{FOV=38mm} \cdot \sqrt{2}$ is reflected by the noise amplification visible in these images (fig. 1 a,b).

Conclusion: The feasibility of DW-SS-SE-EPI in different anatomical regions on 3T and 7T by the use of a reduced FOV approach [3] was shown. For a combination of rFOV+SENSE for brainstem DW imaging, simulations based on measured sensitivity maps predicted a drastic loss of SNR, which was confirmed by in-vivo measurements. To diminish susceptibility effects in this and similar cases, we suggest rFOV acquisition on lower fields (1.5 T) without SENSE. However, a combination of rFOV+SENSE may be promising for DW imaging in cases where lower g-factors can be expected.

References:
1: Wheeler-Kingshott NeuroImage16, 93–102 (2002), **2:** Jeong MRM 54:1575–1579 (2005),
3: Wilm ISMRM 2006:850, **4:** Stanisz MRM 54:507–512 (2005)