Multi-slice localized parallel excitation for DWI with a reduced FOV in the spinal cord

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Introduction

Due to a fast scanning speed, echo-planar imaging (EPI) offers major advantages over conventional MR acquisition techniques [1]. However, EPI applications are often limited in clinical practice, as they require relatively long read-out durations and therefore are highly sensitive to B_0 inhomogeneities, leading to geometric distortions in the MR images. The distortion artifacts can become particularly severe in DWI of the abdomen, pelvis or spinal cord.

For a reduction of distortions, the use of inner volume imaging (IVI) has been suggested [2, 3]. In this method, 2D pulses excite arbitrarily-defined regions of interest (ROIs) and therefore the FOV is reduced substantially in the PE direction, resulting in significant shortening of the EPI echo train and thus minimizing distortions. Nonetheless, 2D pulses have long durations and as a result appear to be sensitive to relaxation and B_0 deviations. In the technique of parallel excitation (PEX), multiple RF coils are used for parallel RF transmission allowing shortening of the 2D pulses and making them applicable to in vivo MRI protocols [4, 5]. In previous studies, localized PEX was demonstrated for zoomed multi-slice DWI in the brain and exploited in phantoms using parallel transmission [6-8].

In this work, the use of accelerated 2D PEX is investigated for multi-slice DWI with a reduced FOV in the spinal cord. This study also describes the initial experience obtained with PEX in humans on a 3T MRI system with parallel transmission.

Methods

The experiments were carried out on a human 3T MR scanner (Siemens Magnetom Trio) equipped with an 8-channel TxArray extension and an 8-channel transceive array shown in Fig. 1 (Rapid Biomedical GmbH, Rimpar, Germany, [9]). To ensure SAR-safe operation for imaging in vivo with parallel transmission, models of the coil and scanned volunteer were simulated as described in [9], resulting in 10 cm^3 averaged SAR values. The calculated RF power limits were applied and informed consent was obtained from the volunteer before scanning, which was performed in accordance with protocols approved by the IRB.

PEX was applied to the imaging scheme presented in [2]. In this method, a set of limited slice profiles confined to an ROI is excited by 2D pulses (Fig. 2). The implemented IVI sequence is shown in Fig. 3. The profiles are limited in the PE direction of the subsequent EPI read-out (RO) and extend across the object along frequency encoding (FE), which is accomplished by playing out one of the excitation gradients on the slice axes (Fig. 3). The slices are later refocused in the slice direction and thus the imaging plane is the FE-PE plane. In this manner, a multi-slice SE-EPI method was applied for imaging slices limited in the PE dimension.

The excitation trajectories were EPI with an undersampling factor of 2 and defined on a grid size of 192 (slice) × 8 (PE) over a field of excitation (FOE) of 38.4 (slice) × 19.2 (PE) cm^2, resulting in a thickness of 4 mm for the profiles. The 2D pulses were calculated with the help of a small tip-angle algorithm combined with a conjugate gradient optimization using axial single-slice B_1-sensitivities at the scanner isocenter [11]. The pulse duration was 8.16 ms.

A special workflow was developed for scanning on the MRI system with parallel transmission. The following calibrations were necessary to be performed in vivo before the sequence from Fig. 3 was tested: 1) RF shimming for homogenization of refocusing; 2) acquisition of B_1-sensitivities of the coil elements for 2D pulse calculation [11]; 3) B_0 shimming locally over the excitation ROI; 4) adjustment of the flip angles for the excitation and refocusing pulses; 5) calibration of the delay between RF and gradient shapes for suppression of Nyquist ghosts of the limited profiles caused by imperfections of the gradient system.

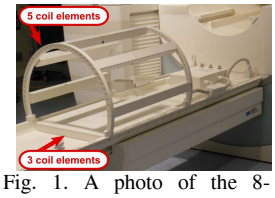

Fig. 1. A photo of the 8-channel transmit array used.

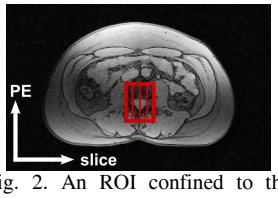

Fig. 2. An ROI confined to the spinal cord and cut into slices.

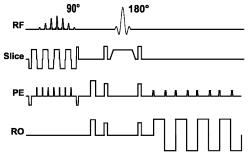

Fig. 3. The sequence diagram for imaging of profiles in Fig. 2. The 2D selective pulse in each TR corresponds to a new slice. Diffusion-weighting was based on double refocusing as described in [10] (only one refocusing pulse is shown in the diagram for simplicity).

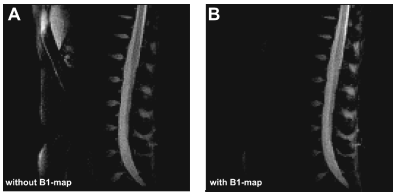

Fig 4. Sagittal FLASH images of a limited slice excited by accelerated 2D 30° pulses calculated without (A) and with (B) the use of single-slice central axial B_1-sensitivities, respectively. The data were obtained on the 3T MR scanner with parallel transmission.

Results and Discussion

Comparison of the limited slice profiles excited in the spinal cord by accelerated 2D pulses calculated with and without the use of the B_1 data is shown in Fig. 4. The used excitation flip angle was 30°. As can be seen in Fig. 4A, undersampling of the excitation trajectory results in excitation of a Nyquist replicate of the main slice profile at the periphery of the defined FOE. The use of the B_1 data during calculation of the 2D pulse and application of fat suppression allowed the excited replicate to be diminished to a negligible level (Fig. 4B).

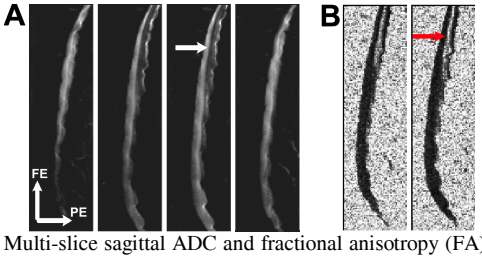

Fig. 5. Multi-slice sagittal ADC and fractional anisotropy (FA) maps of an ROI confined to the spinal cord and acquired on the MR scanner with parallel transmit. The imaging parameters: slice thickness = 4 mm, FOV = 25.5 (FE) × 7.17 (PE) cm^2, matrix = 192 (FE) × 54 (PE), TE = 93 ms, TR = 10 s and excitation flip angle 90°. The *b*-values used for diffusion-weighting were 0 and 500 s/mm^2.

The resulting multi-slice ADC and fractional anisotropy (FA) maps with a restricted FOV acquired in the spinal cord using DWI with parallel transmission are presented in Fig. 5A and B. As can be seen, the presented approach allowed images with acceptable quality to be obtained and the FOV could be reduced in the PE direction by a factor of 3.6. Thus, the minimum TE value was shortened to 93 ms minimizing distortions in the spinal cord. A fiber structure can be identified in the obtained images as indicated by arrows in Fig. 5.

In contrast to previous IVI-MRI applications of PEX [5, 12], the method developed combines multi-slice imaging with the use of 2D selection. In former studies, either single-slice 2D PEX or multi-slice 3D PEX were demonstrated for IVI, which is due to the fact that multidimensional pulses were designed primarily for excitation of ROIs with complicated geometry. Furthermore, in similar studies reported previously [7, 8], rather low limits were employed for RF power supervision, restraining the tests of the presented method in human subjects substantially. The system architecture applied in this work allowed for significantly higher RF power limits and thus enabled tests of the IVI methods that require RF pulses with high flip angles such as DWI. Nonetheless, the RF power limits used led to relatively long TR (≈10 s) for the EPI-based scans from Fig. 5. This limitation is not intrinsic to the described method and is solely due to the available RF monitoring hardware.

Conclusions and Outlook

Localized 2D PEX was demonstrated experimentally for multi-slice zoomed DWI in the spinal cord on a 3T MRI system with parallel transmission. The presented method has certain advantages such as shorter excitation duration. However, several technological challenges must be overcome before the technique described can be used in clinical practice. An example of problematic aspects is insufficient fat suppression on MRI systems with parallel transmission, which could be improved with spectrally-selective 2D pulses. Another solution could be application of PEX to imaging concepts with intrinsic fat suppression such as that presented by Saritas in [3].

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