Multi-Slice Parallel Excitation Reduced FOV Imaging for Rodent EPI Applications

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Introduction

Echo-planar imaging (EPI) offers major advantages over conventional MR imaging, including reduced imaging time and the ability to image rapid physiologic processes [1]. However, signal decay and off-resonance effects limit the possible duration of the EPI echo train, requiring high resolution EPI to combine k-space signals from several sequential excitations. Multiple shot techniques suffer from increased scan times and susceptibility to artifacts arising from inconsistencies between k-space data collected in different shots. Particularly in diffusion-weighted imaging (DWI) applications, even a subtle motion, e.g. brain pulsation, gives rise to significant phase errors between shots and results in artifacts in reconstructed images. Sophisticated navigator-based approaches have been developed to enable multi-shot DW-EPI in vivo [2], which nonetheless often lack stability and robustness required for routine applications.

The recently introduced technique of Parallel Excitation (PEX) [3-5] has allowed for a shortening of multidimensional RF pulses, making the Inner Volume Imaging (IVI) concept, where only specifically selected regions of interest (ROI) are excited, applicable for realistic MRI protocols [6]. Generally, spatially selective excitation (SSE) allows for a reduction of the field of view (FOV) in the phase encoding (PE) direction, thus shortening the echo train length and enabling single-shot EPI with high resolution.

In this study the application of 2D spatially selective pulses combined with a reduced FOV in PE direction for rodent multi slice DWI is examined.

Materials and Methods

The experiments in this study were carried out on a 9.4 T Bruker BioSpec animal system (Avance III) with 8 transmit and receive channels in combination with an 8-channel transceive volume-array coil, with coil elements arranged in 45º steps around the B0 axes.

In order to keep the magnetization from saturation in SSE with multiple repetitions, the following multi-slice IVI method was implemented. The ROI is defined on a sagittal scan and divided into parallel bands (Fig. 1A-C). For each band, a set of 2D pulses and gradients is calculated and exported to the scanner (Fig. 1D). In every slice the excitation pulse corresponding to a different band is played out (Fig. 2B) and thus a new strip segment extending across the whole phantom in the frequency encoding (FE) direction is excited in the slice-phase encoding plane (Fig 2A, B). The strip is later refocused in the slice direction (Fig. 2A, B). In order to achieve this, one of the gradient waveforms of the selective excitation is played out on the same axes as the slice gradient of the refocusing pulse (Fig. 2B) and the frequency offset of the latter is adjusted to the band shift from the iso-center in the slice direction. The imaging plane is the FE-PE plane which is perpendicular to the one the ROI was defined in (Fig. 2A, B). Thus a multi-slice SSE-EPI method was implemented for imaging the layers limited in the PE direction (Fig. 1, 2).

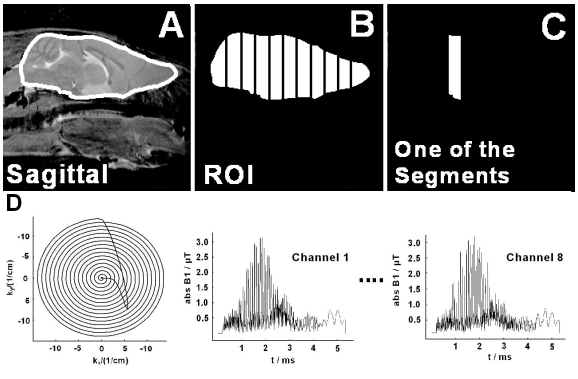

Fig. 1 Definition of the multiple layers limited in PE. A. Definition of an arbitrarily shaped ROI for imaging. B. Cutting the defined ROI into bands (width of every band is equal to the slice thickness in the EPI scan. C-D. Designing the k-space trajectory (spiral) and RF-shapes for every segment.

The 2D pulses were calculated with the help of a small-tip angle algorithm combined with conjugate gradient optimization. B0- and B1-maps of the central sagittal slice were taken into account in the pulse design. The pulses had a resolution of 64×64 with a field of excitation (FOX) of 3.2cm×3.2cm and were accelerated by a factor of 1.3 (pulse duration was 17 ms). For DW-EPI the acquisition matrix was 128×128 with FOV of 3.2cm×3.2cm; full FOV version required 4 shots. 6 slices were scanned.

The measured object was a piece of rope with a ribbon tightly tied around it and positioned into a cylindrical tube filled with water. The phantom geometry thus restricted the diffusion inside the piece of rope to the preferred diffusion along the fiber direction in the rope.

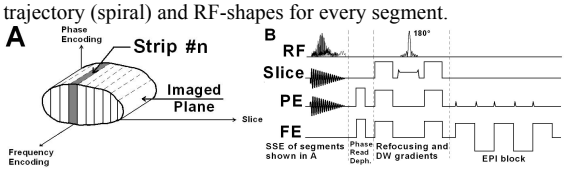

Fig. 2. Principle of the experiment. A. The scheme showing the strips excited. B. The corresponding sequence diagram. The 2D selective pulse in every TR corresponds to a new strip from A.

Results and Discussion

A slice selected out of axial multi slice ADC map in the aforementioned phantom acquired with the conventional and the presented methods are shown in Fig. 3.

The standard ADC map (Fig. 3A) obtained in 4 shots is compared with the PEX counterparts collected with the same FOV (Fig. 3B) and a FOV reduced by a factor of 4 in PE direction (Fig. 3C). The smaller FOV allowed for a single shot scan with the same TE and resolution (Fig. 3D). As can be seen from Fig. 3D the reduced FOV combined with single shot EPI acquisition produced acceptable images.

High homogeneity in FE direction probably results from an effective B1 shim of the RF field along this direction, which would not hold for significantly accelerated pulses, producing artifacts caused by B1 variations of the 8-channel coil in the axial slice. B0 and B1 calibration data were also collected only in the central sagittal slice acquired for definition of ROI. Further improvements could be possible with optimized k-space trajectories and RF pulses based on multi-slice B0 and B1-maps perpendicular to the imaging plane, as well as with different imaging volume or coil geometries, aligning the direction of non-selective excitation with the direction of largest B1 field homogeneity.

The apparent decrease of SNR in the single-shot reduced FOV version is related to a smaller object producing the MR signal and the scan time reduction by a factor of 4. This, however, can be seen as an advantage, as the SNR loss can be compensated for by averaging in the magnitude domain, where phase inconsistencies between shots will not result in image artifacts.

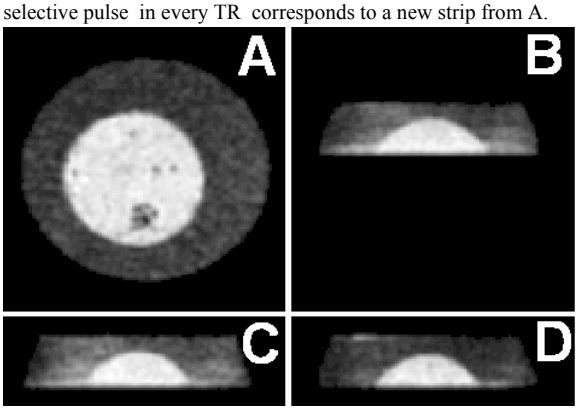

Fig. 3. Resulting ADC maps. A. Conventional scan with number of shots (NS) = 4. B. PEX-scan with full FOV in PE (3.2 cm) and NS=4. C. PEX scan with reduced FOV in PE (0.8cm) and NS=4. D. PEX scan with reduced FOV (0.8 cm) and NS=1.

Conclusions

Parallel excitation in combination with the multi-slice inner volume imaging technique developed in this study was experimentally demonstrated in phantoms and gives advantage to novel applications for single shot EPI. Rodent DWI is a clear example showing the main principle of this technique and its potential for future in vivo studies.

References

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