Slice Acceleration without Parallel Imaging for Diffusion-Weighted Echo-Planar Imaging of the Cervical Spinal Cord

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Introduction

Multi-band acquisitions [1] offer a promising approach to accelerate diffusion-weighted acquisitions. Several slices are excited, refocused, and acquired simultaneously but separated during image reconstruction using parallel imaging algorithms. With slice-gradient blips, e.g. like in blipped-CAIPI [2], the performance of multi-band acquisitions can be further improved. A coil with an appropriate geometry that allows for parallel imaging in the slice direction is mandatory; however, while such coils are widely available for the human head, most standard neck coils are not compatible with multi-band acquisitions. In this study, it is demonstrated that slice acceleration can also be achieved without appropriate coil geometries by using 2D-selective RF excitations to restrict the excitation to the spinal cord in combination with slice-gradient blips to induce different shifts in the image for the different slices excited. The feasibility of this approach is demonstrated in phantoms and the human cervical spinal cord in vivo.

Methods

Figures 1 and 2 show the basic spin-echo echo-planar pulse sequences and geometric setups, respectively, that were used in the present study. The spin-echo refocusing is performed with multi-band RF pulses (Fig. 1). The initial RF excitation of a conventional EPI sequence is replaced by a 2D-selective RF (2DRF) excitation [3,4] based on a fly-back blipped-planar trajectory (Fig. 1). The 2DRF envelope is designed to excite several rectangular regions-of-interest (ROIs) at different spinal cord locations simultaneously (Fig. 2). Two different setups for the 2DRF excitation were implemented. In the first ("tilted") setup, the blip direction of the 2DRF trajectory is tilted with respect to the imaging readout and phase-encoding direction such that the side excitations appear between the refocusing RF pulse bands (Fig. 1a and 2a). The 2DRF envelope is chosen to excite several rectangular regions covering the spinal cord at different levels (Fig. 2a). In the second setup ("non-tilted"), the 2DRF blip direction coincides with the slice direction. The 2DRF parameters were chosen such that the side excitations of the main excitation, a single rectangular shape, cover the other desired spinal cord ROIs (Fig. 1b and 2b). For both setups, additional blip gradient pulses were applied in the slice direction along the echo train (Fig. 1c) to induce spatial shifts in the phase-encoding direction that differ between the simultaneously excited ROIs to separate them in the image [2,5].

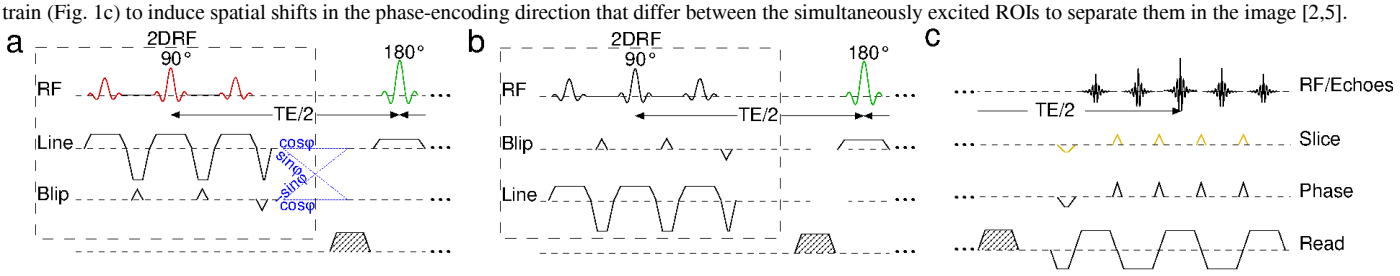

Fig. 1: Basic pulse sequences used for (a) the "tilted" and (b) the "non-tilted" 2DRF setup and (c) the echo-planar readout. Coloured RF envelopes indicate the coverage of multiple ROIs or bands. The slice-gradient blips in (c) are used to separate the different slices excited and refocused in the image.

Experiments were performed on a 3 T whole-body MR system (Magnetom TIM Trio, Siemens Healthcare). Phantoms and healthy volunteers were investigated with a wrist coil and the standard neck coil, respectively. 2DRF envelopes were calculated using the low-flip-angle approximation [4] and were designed to excite rectangular profile(s) of 5×25 mm^2 with a resolution (line×blip) of 2.5×10 mm^2 and 10×2.5 mm^2 for the tilted and non-tilted setup, respectively, yielding pulse durations of 9.7 and 16.8 ms, respectively. Three rectangular target ROIs with a distance of 40 mm in the slice direction were chosen and refocused with a three-band RF pulse. Echo-planar images were acquired with an in-plane resolution of 1.0×1.0 mm^2 covering a field-of-view of 90 mm in the phase-encoding direction. The slice-gradient blips applied induced shifts in the image of 30 mm per 40 mm slice distance such that the three refocused ROIs did not overlap in the image. Diffusion weighting was performed with a *b* value of 500 s mm^{-2} and using six different directions. With a TR of 4.5 s and 16 averages, the total acquisition time was 8.5 min. For comparison, slice-selective (FOV 192 mm) and non-accelerated inner-FOV measurements [6] were performed.

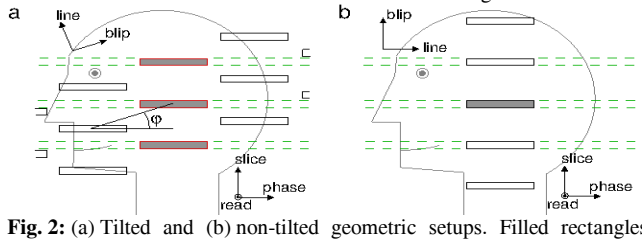

Fig. 2: (a) Tilted and (b) non-tilted geometric setups. Filled rectangles represent the desired excitation profile, unfilled the side excitations that appear as copies of the main excitation in the blip direction.

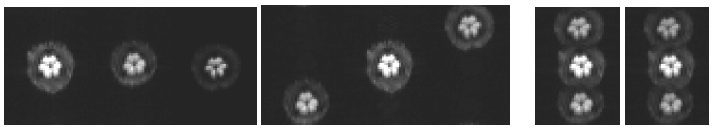

Fig. 3: Three slices of a cucumber acquired without and with slice-gradient blips, respectively, in three images (left) and accelerated in a single image with the tilted and the non-tilted setup, respectively (right).

Results and Discussion

The basic principles are demonstrated in Fig. 3. With the slice-gradient blips the different slices appear shifted in the phase-encoding direction such that they can be acquired in a single image with an appropriate field-of-view. Colour-coded FA maps obtained in a healthy volunteer are shown in Fig. 4 and 5. Compared to a conventional slice-selective measurement (cf. Fig. 5) a smaller, inner FOV is sufficient which significantly shortens the echo time (by about 40 ms) and the acquisition time per slice (by about 180 ms). Compared to a single-slice inner-FOV measurements with 2DRF excitations [6] (cf. Fig. 5), the echo time is slightly increased (by about 18 ms) due to the larger FOV to host three spinal cord sections but the acquisition time per slice is reduced from about 117 ms to about 52 ms.

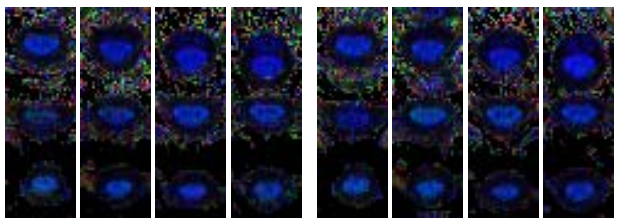

Fig. 4: Colour-coded FA maps of 12 slices acquired in four images with the tilted (left) and the non-tilted setup (right).

In conclusion, the presented method could help to perform slice acceleration even when no coil supporting full multi-band acquisitions is available. Thus, it could help to speed up diffusion-weighted measurements, in particular in the human spinal cord.

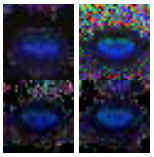

Fig. 5: Colour-coded FA maps of one section acquired with a slice-selective excitation, a single-band 2DRF excitations, and slice-accelerated acquisitions with the tilted and the non-tilted setup (from upper left to lower right).

References

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