High Resolution Spine Diffusion Imaging using 2D-navigated Interleaved EPI with Shot Encoded Parallel-imaging Technique (SEPARATE)

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Target Audience: Researchers and clinicians interested in high resolution spine DWI or DTI

Purpose: Diffusion weighted imaging (DWI) is a useful tool for studying microstructures and diagnosing injury of spinal cords [1]. Using the traditional DWI method, single-shot EPI, is very challenging in scanning the spine because of the large coverage and severe B0 field inhomogeneity, which can induce geometric distortion and limited spatial resolution. In this study, the 2D-navigated interleaved EPI acquisition combined with a proposed reconstruction method, Shot Encoded Parallel-imaging Technique (SEPARATE), was implemented to generate high resolution diffusion-weighted spine images with reduced distortion.

Theory: In multi-shot EPI DWI, while each shot acquires one segment of the full k-space, they cannot be combined directly because of motion-induced phase errors [2,3]. Since the different phase can be regarded as a kind of sensitivity encoding in image domain, it can be used to recover the full k-space data of each shot through convolution. In this report, a GRAPPA-like reconstruction scheme [4], Shot Encoded Parallel-imaging Technique (SEPARATE), is proposed and is illustrated by Fig. 1. The missing data (hollow points) of each shot are interpolated by the acquired data (solid points), and the weighting vectors are calibrated using fully sampled navigator data. Specifically, for each missing data point, its adjacent data of all shots within a kernel (e.g. 3×3 kernel in Fig. 1) are selected for the interpolation (marked with the arrows). Data of all the numbers of signal average (NSA) can also be used in the interpolation to improve matrix inversion conditioning.

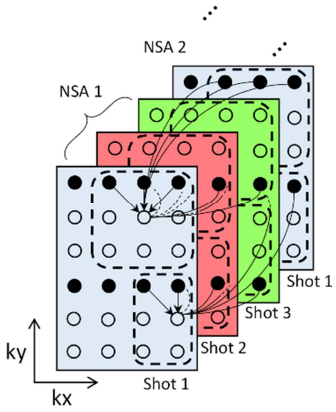

Fig.1 A schematic diagram of the reconstruction process using SEPARATE.

Methods: *In vivo* spine DTI data were acquired on a Philips 3T scanner with PPU triggered 2D-navigated interleaved EPI [5]. The imaging parameters include, shot number=10, b =500s/mm^2, diffusion directions=6, slice thickness=5mm, NSA=2, TR=3 heart beats. Seven healthy volunteers were scanned; four of them were imaged at cervical spine and the other three at lumbar spine. For cervical spine imaging, FOV=250×250mm^2, spatial resolution=1.31×1.31mm^2, TE=62ms; for lumbar spine imaging, spatial resolution=1.39×1.39mm^2, FOV=300×250mm^2, TE=59ms. Single-shot EPI data with resolution of 2×2mm^2 and SENSE=2 were acquired as a comparison. The multi-shot data of each channel were individually reconstructed using SEPARATE, and the reconstructed images of all shots and all channels were combined using the sum-of-squares method.

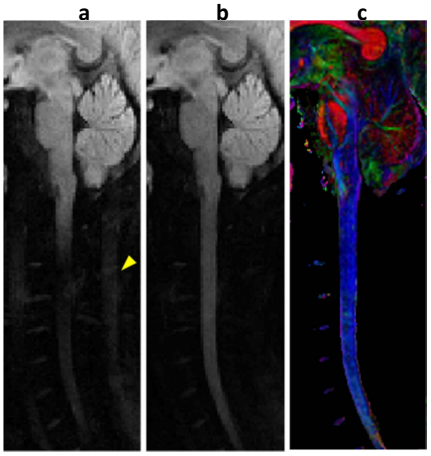

Fig.2 DW images of the cervical spine with direct reconstruction (a) and with SEPARATE (b), and the FA map.

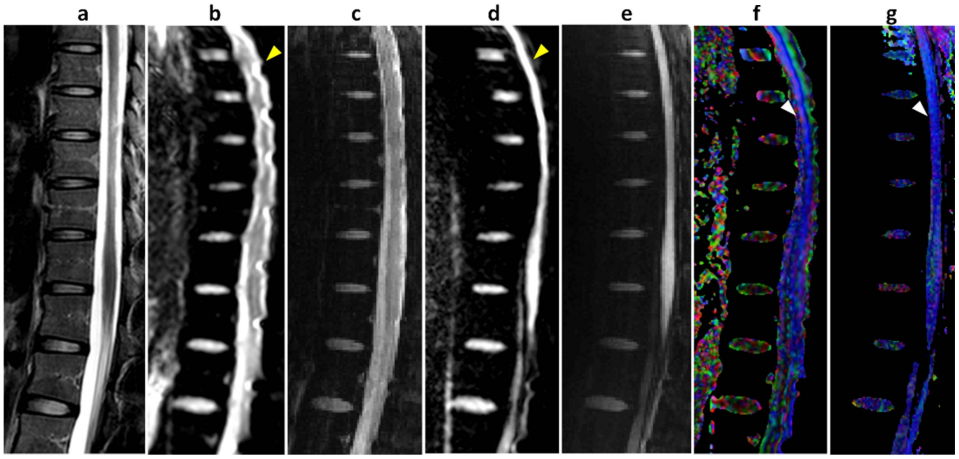

Fig.3 Lumbar spine results. (a) T2-TSE; (b) b=0 image from single-shot EPI DWI; (c) b=0 image from SEPARATE; (d) mean DWI from single-shot; (e) mean DWI from SEPARATE; FA maps from (f) single-shot EPI and from (g) SEPARATE.

Results and Discussion: (1) The reconstructed DTI results in the cervical spine were given in Fig. 2. The ghost artifacts in the diffusion weighted image caused by motion-induced phase errors (yellow arrow in Fig. 2) were suppressed by SAPERATE, and the FA map can be derived from the reconstructed images. (2) The results in the lumbar spine were shown in Fig. 3. Multi-shot scan with SEPARATE yields diffusion weighted images with increased resolution and reduced distortion, compared to the single-shot scan (yellow arrows). The FA map calculated from SEPARATE results reveals the directional delineation more accurately than single-shot (white arrows). Since SEPARATE is a k-space reconstruction method, the image registration between the imaging data and navigator is not needed [5].

Conclusion: A 2D-navigated interleaved EPI with a proposed reconstruction method SEPARATE was implemented here to generate high resolution spine DTI with reduced distortion. The increased spatial resolution and reduced distortion in comparison with single-shot EPI suggests its potential application for the research and the clinical diagnosis in the spine. SEPARATE provides a k-space phase correction approach as an alternative to conventional image domain correction, and it can be easily extended to the imaging on other positions.

References: [1] Thurnher MM et al., Magn Reson Imaging Clin N Am 2009;17(2):225-244. [2] Anderson AW et al., MRM 1994;32(3):379-387.
[3] Miller KL et al., MRM 2003;50(2):343-353. [4] Griswold MA et.al., MRM 2002;47(6):1202-1210. [5] Jeong HK et.al., MRM 2013;69(3):793-802.