A 3D radial FSE-based SPLICE sequence for MR diffusion imaging

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Introduction: MR diffusion imaging plays a valuable role in the diagnosis of certain diseases, such as ischemia and stroke, and for tumor assessment. Currently the gold standard is the single-shot diffusion-weighted EPI sequence (DW EPI) due to its simplicity and short acquisition time. However, there are drawbacks to DW EPI, including its sensitivity to B0 inhomogeneity, resulting in artifacts and distortions caused by local susceptibility or chemical shift effects. These problems can be avoided with spin-echo based sequences (FSE or RARE), but the strong diffusion-sensitization gradients can cause the CPMG condition to be violated, causing incoherent phases between spin echoes and stimulated echoes, resulting in signal loss and artifacts. To overcome these artifacts, the SPLICE (split acquisition of fast spin-echo signals for diffusion imaging) technique was developed, in which an artifact-free diffusion-weighted image is obtained by combining two images, each created from one of two echoes in the echo train [1]. Currently, the implementation of SPLICE has been limited to 2D Cartesian and PROPELLER [2] based sequences. In this work, we present a preliminary development of a 3D FSE-based radial sequence with SPLICE for MR diffusion imaging.

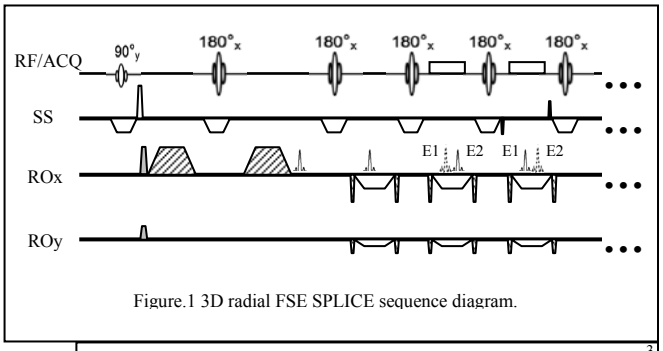

Figure.1 3D radial FSE SPLICE sequence diagram.

Methods: The 3D radial FSE SPLICE sequence is shown Fig.1. The sequence uses a hybrid 3D radial scheme (stack of stars), in which the radial acquisition is performed in-plane and phase encoding is applied along the slice direction. The slice encodings are centric-ordered and are performed in a single spin-echo train generated from each RF excitation, so that the number of slices equals the echo train length. With this strategy, the effective echo time is independent of the number of echoes in the echo train unlike 2D radial FSE sequences. A pair of diffusion gradients is inserted on either side of the first 180° refocusing pulse. SPLICE was implemented by applying an imbalanced readout pre-phasing gradient with a gradient moment of a quarter of the readout gradient, from which two echoes are generated within each readout window. Each echo family is a mixture of spin echoes and stimulated echoes with consistent phases.

The sequence was first tested on a phantom, in which a saline-filled bottle was imaged with a head coil at a 1.5T Siemens Sonata MRI system. The key scan parameters were: FOV = 300x300 mm^2, Slice thickness = 5 mm, matrix = 256x256x32, TR=300ms, echo spacing = 7ms, bandwidth=781Hz/pixel, effective TE=70ms. To generate an ADC map, two b values of 14s/mm^2 and 351s/mm^2 were used. In the in-vivo experiment, a healthy subject was imaged in the brain with the same scan parameters except TR = 1000ms. For comparison a standard DW EPI sequence was also used to obtain brain ADC maps with the following key parameters: echo spacing=0.64ms; TE=66ms; BW=1736Hz/Px. Other parameters were similar to those above.

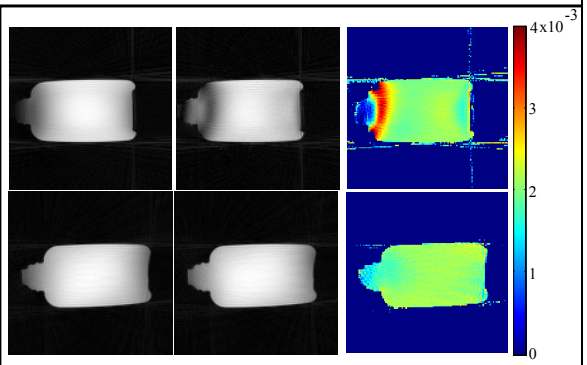

Figure.2 In the phantom experiment with the 3D radial FSE-based sequence, two scans were performed without (first row) and with (second row) the SPLICE technique. The first and the second columns are the diffusion images acquired with b=14s/(mm^2) and b=351s/(mm^2), respectively. The third column shows the ADC maps. The color scale on right is in units of mm^2/s

Results and Discussion:
The phantom experiment results are shown in Fig. 2. Artifacts can be clearly observed in high b value image without SPLICE, resulting in high values in the ADC map. A homogenous ADC map is obtained when the diffusion images were acquired with the SPLICE technique. Figure 3 shows the in-vivo diffusion experiments in the brain. In the EPI images, artifacts caused by magnetic susceptibility variations are observed. The artifacts are removed in the 3D radial FSE SPLICE sequence. It should be noted that the signal-to-noise ratio (SNR) of the SPLICE images is somewhat lower than that of images acquired with EPI. The lower SNR is due to a combination of shorter TR and from the fact that in SPLICE, signal from the two echo images are combined after separate magnitude reconstruction.

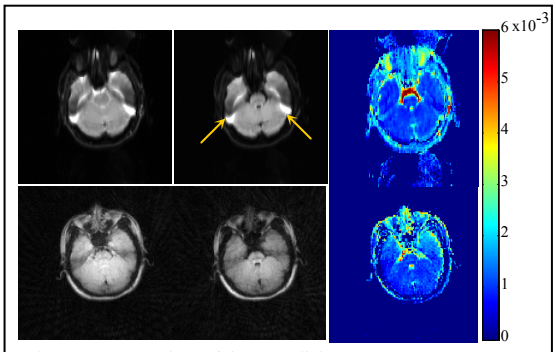

Figure.3 A comparison of the 3D radial FSE SPLICE sequence (the second row) with DW EPI (the first row) in the brain. The first and the second columns are the diffusion images acquired with b=14s/(mm^2) and b=351s/(mm^2), respectively. The third column shows the ADC maps. The color scale on right in units of mm^2/s.

Conclusion: We present the preliminary work of a hybrid 3D radial FSE SPLICE sequence which combines the radial acquisition scheme and the SPLICE technique. The sequence was tested in phantom and in-vivo experiments and the results showed that improved ADC maps can be obtained.

Acknowledgements: This work is supported by NIH R01-CA125226.

References: [1] Schick F, Magn Reson Med, 38:538-644 (1997). [2] Deng J et.al., Magn Reson Med, 59:947–953 (2008).