Readout-Segmented EPI with Simultaneous, Multi-Slice Acceleration for the Rapid Acquisition of High-Resolution, Diffusion-Weighted Images of the Breast

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Target audience: Sequence programmers; radiologists and clinicians with an interest in MRI of the breast.

Purpose: Readout-segmented, Echo-Planar Imaging (rs-EPI) with 2D navigator correction[1] is in widespread clinical use for obtaining high-quality, diffusion-weighted (DW) images in a variety of examinations. Clinical studies evaluating breast DWI have shown that this technique provides an improved diagnostic performance compared to standard, single-shot EPI (ss-EPI)[2-4]. In rs-EPI, *k*-space is segmented in the readout direction to substantially reduce the echo spacing and echo-train duration, resulting in reduced distortion and T_2^* blurring respectively. However, the acquisition time increases with the number of readout segments, limiting the clinical application in some cases. The blipped-CAIPIRINHA technique[5] has been introduced as a robust method for reducing scan time in ss-EPI by simultaneous multi-slice (SMS) acceleration and the method has also been extended to rs-EPI in the brain[6-8]. In this study, we demonstrate the application of SMS rs-EPI using blipped-CAIPIRINHA to diffusion-weighted imaging (DWI) of the breast, providing a substantial reduction in scan time or increase in slice coverage or resolution compared to standard rs-EPI, whilst maintaining image quality.

Methods: The blipped-CAIPIRINHA SMS scheme[5] and corresponding split slice GRAPPA reconstruction[9] were used to generate a non-product version of a commercial rs-EPI sequence (RESOLVE, Siemens Healthcare). To optimize the acquisition and reconstruction workflow, reference data for Nyquist ghost phase correction were obtained from a SMS acquisition of the central readout segment similar to that used for SMS ss-EPI[10]; the phase correction and subsequent regridding for the sinusoidal readout-gradient waveform were then applied directly to the imaging data before using split slice GRAPPA to extract the data from individual slices. DW breast images were acquired from healthy volunteers using a commercial 3T scanner (MAGNETOM Skyra, Siemens Healthcare), equipped with an 18-channel Breast coil. Conventional and non-product SMS rs-EPI were acquired with the same slice thickness and coverage using the following parameters: FOV = 340x136 mm^2, matrix size = 274x110, TE = 55 ms, in-plane GRAPPA[11] factor = 2, b = 50 s/mm^2 with 1 average, b = 800 s/mm^2 with 4 averages, diffusion mode = 4-Scan Trace, 28 slices with 5 mm thickness, 20% slice gap; the conventional scan had TR = 5540 ms with total scan time of 5:51 min and the SMS scan had TR = 2250 ms with total scan time of 2:35 min. An additional SMS rs-EPI acquisition was also performed with a larger number of thinner slices for optimized slice coverage and improved resolution in the slice direction; imaging parameters were as follows: 40 slices with 3.5 mm thickness, b = 50 s/mm^2 with 2 averages, b = 800 s/mm^2 with 6 averages, TR = 3240 ms with total scan time of 5:38 min. Both SMS acquisitions were performed with a slice acceleration factor of 2 and a phase-encoding shift factor of FOV/2 was used to improve the g-factor performance[12].

Results: Figs 1A and 1B respectively show conventional and SMS rs-EPI images of the breast with the same number of slices. The two acquisitions show comparable image quality, although the shorter TR in the SMS case (Fig.1B) results in a consequent drop in signal intensity for tissue with longer T_1 values. Fig. 1C shows SMS rs-EPI images with a larger number of thinner slices and an acquisition time similar to that of the conventional acquisition; these images provide an increased level of structural detail due to the higher resolution in the slice direction (see arrows in Fig. 1C). Corresponding ADC maps (not shown) provide similar ADC values in glandular tissue for SMS rs-EPI and conventional rs-EPI (SMS 1847±177 x10^{-6} mm²/s, conventional 1862±205 x10^{-6} mm²/s).

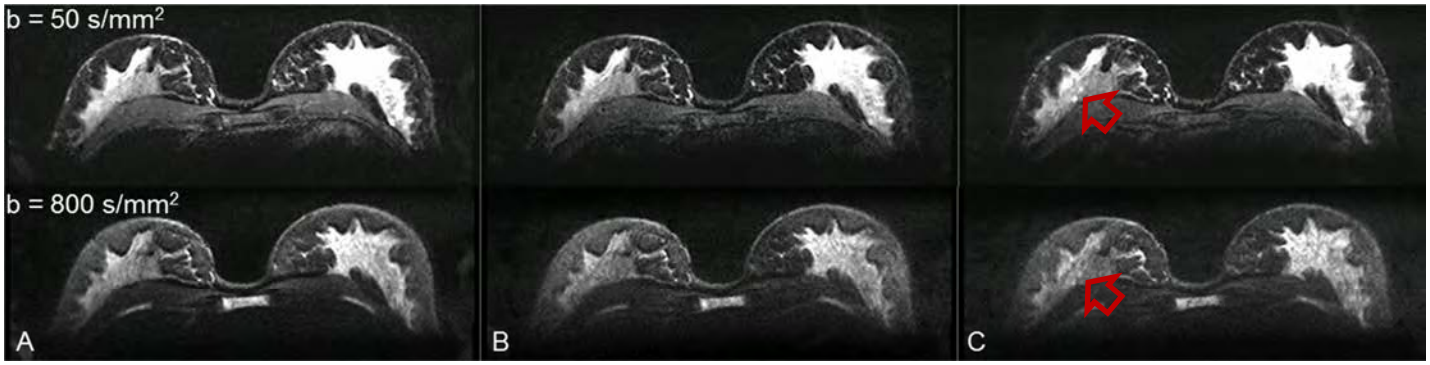

Fig. 1: (A) Conventional rs-EPI, 28 slices, thickness 5 mm, TR 5540 ms, scan time 5:51 min. (B) SMS rs-EPI, 28 slices, thickness 5 mm, TR 2250 ms, scan time 2:35 min. (C) SMS rs-EPI, 40 slices, thickness 3.5 mm, TR 3240 ms, scan time 5:38 min (similar slice position to that of A and B).

Discussion and Conclusion: We have demonstrated that SMS acceleration can be combined with in-plane GRAPPA to substantially reduce scan times in DW rs-EPI studies of the breast at 3T, whilst maintaining a high level of image quality. Alternatively, the application of the SMS method to rs-EPI can be used to increase slice coverage and reduce slice thickness without increasing the overall scan time compared to standard rs-EPI protocols. Readout-segmented EPI is emerging as an important clinical technique for providing high-resolution, DW images of the breast with a low level of distortion and susceptibility artifact and the introduction of SMS acceleration promises to enhance the clinical benefits provided by the technique.

References: **1**. Porter MRM 2009. **2**. Bogner Radiology 2012. **3**. Wisner JMRI 2014. **4**. Kim Korean J Radiol. 2014. **5**. Setsompop MRM 2012. **6**. Frost ISMRM 2012. **7**. Holdsworth ISMRM 2013. **8**. Frost MRM 2014. **9**. Cauley. MRM 2014. **10**. Setsompop. NeuroImage 2012. **11**. Griswold MRM 2002. **12**. Breuer MRM 2005.