Comparison of two alternative approaches for diffusion-weighted Readout-Segmented (RS)-EPI

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Introduction: Readout-segmented (RS)-EPI is a technique that has been used for reducing distortion in diffusion-weighted imaging (DWI) [1], whereby multiple EPI segments are used to fill up *k*-space (Fig. 1). Two alternatives have been described for filling *k*-space in RS-EPI: one recently demonstrated to reduce scan time by filling *k*-space with full readout segments (Fig. 1a) [2], and the other which minimizes the echo time (TE) through the use of partial readout segments (Fig. 1b) [3]. In first example, only three segments are acquired (requiring a full echo), with partial Fourier reconstruction performed in the k_x direction (labeled 'RS-EPI-X'). In the second example, five partial readout segments are used to fill up *k*-space, with partial Fourier encoding performed in k_y (labeled 'RS-EPI-Y').

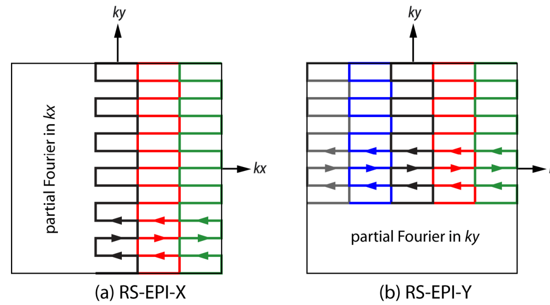

Fig. 1. The two alternative approaches for RS-EPI (a) fully sampled segments in the k_y direction, i.e. a full echo acquired with partial Fourier encoding in k_x (b) partially sampled segments in the k_y direction, i.e. minimizing the TE, which therefore requires partial Fourier reconstruction in the k_y direction.

Here we explore whether one gains from reducing the number of segments at the expense of a longer TE (RS-EPI-X), or from having a larger number of segments at the minimum TE (RS-EPI-Y). We performed an SNR comparison for the two approaches, comparing the SNR for both single- [4] and twice refocused [5] diffusion preparation, the latter which is commonly used to reduce the effects of eddy currents in diffusion imaging.

Materials & Methods: GRAPPA-accelerated DW RS-EPI-X and RS-EPI-Y images were acquired on a healthy volunteer on a 1.5T whole-body GE system using an 8-channel head coil. Both single-refocused (1 x 180) and twice- refocused (2 x 180) DW preparation schemes were tested, together with two matrix sizes: (192 x 192, blind width = 48, number of overscans = 24) and 288 x 288 (blind width = 64, number of overscans = 32). The TE and maximum number of slices are reported in Table 1. Other parameters were: acceleration factor R = 3, NEX = 3, slice thickness = 5 mm, FOV = 24 cm, b = 1000 s/mm^2, and TR = 3s. For SNR measurements, noise maps generated from three repeated b = 0 scans, and the SNR normalized for scan time efficiency ($\eta = SNR / \sqrt{\text{scan time/slice}}$) was calculated over 20 slices. For the post-processing stage, the ghost calibration [6] and GRAPPA weights [7-8] were calculated from the central segment of first b = 0 scan and applied to each volume, followed by ramp sampling correction, POCS reconstruction [9-10], and sum-of-squares over coils.

Blind width x final resolution	RS-EPI-X (1 x 180 / 2 x 180)		RS-EPI-Y (1 x 180 / 2 x 180)		$\eta Y / \eta X$ (1 x 180 / 2 x 180)
	TE (ms)	Max. # slices	TE (ms)	Max. # slices	
48 x 192	67/90	24/20	55/70	29/25	1.0/1.1
64 x 288	83/128	17/13	55/70	24/20	1.1/1.6

Table 1: Echo time (TE) and maximum number of slices achievable in a TR = 3s for RS-EPI-X and RS-EPI-Y. The SNR ratio (RS-EPI-Y/RS-EPI-X) is also shown.

Results: Table 1 shows the normalized SNR ratio ($\eta Y / \eta X$).There was no significant difference in normalized SNR for all cases except for the matrix size of 288 x 288 with the 2 x 180 diffusion preparation scheme. Human brain data showing scan time matched b = 0 and isotropic DW images for the matrix size of 288 x 288 and two diffusion preparation schemes are shown in Fig. 2. The effect of the SNR reduction for RS-EPI-X for 2 x 180 is particularly pronounced in isotropic DWI images. Note that the longer TE of the RS-EPI-X scheme resulted in b = 0 images with greater T2-weighting.

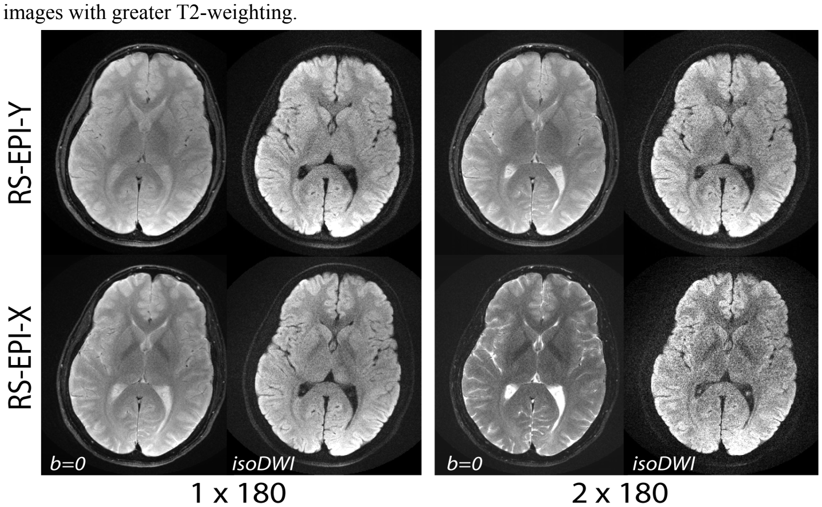

Fig. 2. Scan-time matched RS-EPI-X and RS-EPI-Y b = 0 and isotropic DW images of a healthy volunteer, acquired with 1 x 180 and 2 x 180 at a matrix size of 288 x 288.

Discussion: Here we explored the SNR difference between two alternative RS-EPI techniques. While fewer segments are required for RS-EPI-X, the combination of the longer echo train and resulting reduction in the number of slices that can be acquired per TR reduces its scan time efficiency more than originally expected. The scan time efficiency was similar for all but one case tested here: the case of RS-EPI-Y with a 2 x 180 and 288 x 288 matrix size was a factor of 1.6 times more efficient – clearly evident in the isotropic DW images of Fig. 2. This is due to the excessively long TE brought about by the longer echo train for 2 x 180 RS-EPI-X. While it is reasonable to assume that the need to only acquire 3 segments (instead of 5) in RS-EPI-X (in this particular example) implies that one can scan faster, for most clinical purposes one needs to average several times to keep the SNR for DW RS-EPI at a reasonable level, so the scan time advantage of RS-EPI-X can be misleading. At our institution we use 2 x 180 DW preparation for the acquisition of reliable FA maps, and often acquire these with matrix sizes of 288 x 288 – thus RS-EPI-Y would be the best choice of implementation. Furthermore, as one moves to higher matrix sizes one can expect that RS-EPI-Y will become even more efficient, as the TE does not increase with matrix size.

References: [1] Porter D *et al*. ISMRM 2008;3262. [2] Frost R *et al*. ISMRM 2010; 1625. [3] Holdsworth SJ *et al*. ISMRM 2008;4. [4] Stejskal EO. J. Chem. Phys. 1965;43(10):3597–3603. [5] Reese TG *et al*. MRM 2003;49:177–82. [6] Nordell A *et al*. ISMRM 2007:1833. [7] Griswold M *et al*. MRM 2002;47:1202-1210. [8] Qu P. *et al* JMR 2005;174(1):60-67. [9] Haacke EM *et al*. JMR 1991;92:126–45.[10] Liang ZP et. al. MRM 1992;4:67–185.

Acknowledgements: This work was supported in part by the NIH (5R01EB002711, 5R01EB008706, 3R01EB008706, 5R01EB006526, 5R21EB006860, 2P41RR009784), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, Oak Foundation, and the Swedish Research Council (K2007-53P-20322-01-4).