# Rotating Short-Axis EPI “blades” as veering diffusion gradient directions with composite reconstruction (RSA)

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**Target audience:** MRI Physicists, MRI scientists interested in diffusion imaging, Neuroscientists, Clinicians whose researches focus on brain imaging.

## Purpose

Advanced diffusion weighted imaging (DWI) has been used widely to assess the integrity of white matter (WM) and to measure the directional information of WM fiber tracts. Because the diffusion signals are attenuated MR signals from the diffusion weighting (i.e., b-values/q-values), the imaging signal-to-noise ratio (SNR) is crucial. In particular, approaches using high and/or multiple b-values such as HARDI, CHARMED, NODDI, DSI and HYDI, demand adequate SNR for accurate diffusion estimations. Conventionally, DWI uses single-shot spin-echo EPI sequences (SS-SE-EPI). However, SS EPI suffers from geometric distortion and long echo time (TE), which decreases SNR exponentially. Higher spatial resolution imaging worsens the distortion and SNR as well as increases the scan time. As such, high quality diffusion imaging with a voxel size of 1x1x1mm$^3$ is almost impossible for a common 3T clinical MRI scanner. Herein, we propose a diffusion sequence and reconstruction method that is faster than SS-SE-EPI sequence with reduced geometric distortion and higher SNR. The new sequence, Rotating Short-Axis EPI “blades” as veering diffusion gradient directions with composite reconstruction (RSA), uses short-axis EPI blades to reduce EPI echo spacing and hence reduces geometric distortion.[1] It also shortens TE and hence increases signals. Because only one short-axis blade is acquired per DW direction, the scan time is reduced.

## Methods

***RSA:*** Only one short-axis EPI “blade” that covers the central part of k-space was acquired per DW direction (Fig. 1(a)). The EPI blade rotates along with switching the DW directions as shown in Fig. 1. However, the orientations of EPI blades are independent of the DW directions as shown in Fig. 2. Thus, an arbitrary DW direction encoding scheme could be used in RSA diffusion imaging.

***Composite Reconstruction:*** For each DW direction, the k-space short-axis EPI blades were first re-centered to remove the phase shift in the image space and realigned to remove EPI Nyquist ghosts. The k-space blades (Fig. 2(a)) were subsequently fast Fourier Transformed (FFT) to the image space and yielded low-resolution DW images (Fig. 2(b)). After correcting the phase errors of the k-space blades across the DW directions[2], the low-resolution diffusion images were FFT back to the k-space to form the composite k-space data shown in Fig. 3(a). The collective composite k-space data was first corrected for sampling density and then FFT to the image space as shown in Fig. 3(b). The high-resolution reconstructed DW images (Fig. 2(c)) were obtain by training the low-resolution images (Fig. 2(b)) using the composite image in Fig. 3(b).[3]

***Image Acquisition:*** RSA-EPI diffusion imaging was performed on a healthy volunteer at a 3.0T Philips Achieva INTERA scanner with an 8-channel head coil. In addition, diffusion weighted SS-SE-EPI was performed on the same subject. Both sequences have TR>900ms, five slices, 61 DW directions[4] and b-value = 1000s/mm$^2$ with a diffusion gradient strength of ~60mT/m. Other MR imaging parameters are listed in Table 1. The fast imaging factor is defined as the reduction factor of the k-space whereas the total scan time reported by the scanner accounts for preparation, DW gradients and EPI readout sections.

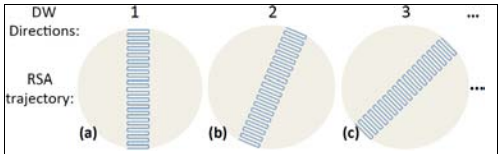

**Fig. 1** k-space trajectories of rotating short-axis EPI blades. (a) 0°, (b) 15°, (c) 30°, and so on.

Table 1. MR parameters for EPI and RSA sequences

| Sequence | Fast imaging factor | FOV$_x$XFOV$_y$ (mm) | Matrix size (nx x ny) | Voxel size (mm) | TE (ms) | Relative Scan time |
|---|---|---|---|---|---|---|
| EPI | No | 256x256 | 256x256 | 1x1x1 | 290 | 100 % |
| EPI | SENSE: 2 | 256x128 | 256x128 | 1x1x1 | 164 | 77 % |
| RSA | 2 | 256x256 | 128x256 | 2x1x1 | 205 | 85 % |
| RSA | 4 | 256x256 | 64x256 | 4x1x1 | 156 | 76 % |
| RSA | 8 | 256x256 | 32x256 | 8x1x1 | 122 | 69 % |

x: frequence encoding direction, y: phase encoding direction

## Results

For high-resolution DWI studies with voxel size of 1x1x1mm$^3$, EPI without and with SENSE parallel imaging had minimal signal shown in Fig. 2(d) & (e), respectively. SENSE factor of 2 is the highest SENSE reduction number recommended by the manufacture for an 8CH head coil. RSA sequences were faster (~70%) than EPI with full k-space sampling (Table 1). The reconstructed RSA images with fast imaging factor of 8 in Fig. 2(c) not only had higher SNR efficiency (SNR/scan time) but also restored the high spatial resolution after the composite reconstruction. DTI measures including mean diffusivity (MD), fractional anisotropy (FA), colormap of major eigenvectors, and major eigenvectors at the genu and splenium of the corpus callosum are shown in Fig. 4 (a-e), respectively. These maps showed high imaging quality with minimum geometric distortion and high imaging resolution. The major eigenvectors appeared to accurately estimate underlying fiber orientations.

## Discussion and Conclusions

In this pilot study, we have shown that the RSA diffusion sequence with composite reconstruction has higher SNR efficiency than conventional SS EPI sequences with/without parallel imaging. A higher signal is achieved by decreased TE and larger voxel size along the frequency encoding direction. High spatial resolution is restored by composite reconstruction. The new approach makes high spatial resolution at 1x1x1mm$^3$ voxel size possible at common 3T clinical MRI scanners without significant geometric distortion. In addition, composite reconstruction requires two criteria to work best: sparsity of the image object and slow changes of image intensity. Therefore, it is suitable for diffusion imaging where only WM is significantly visible and for high angular resolution diffusion imaging. Although DTI results were presented, the RSA approach yields DW images just like conventional EPI and is independent and capable for any diffusion data processing algorithms.

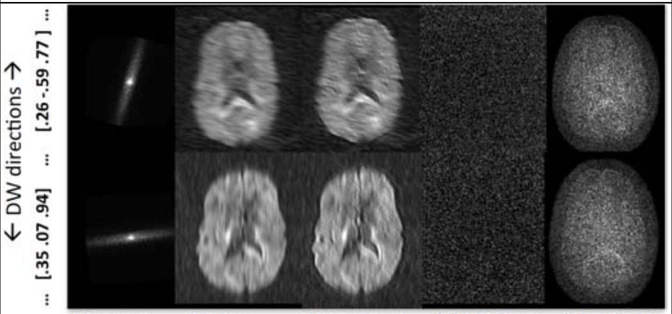

**Fig. 2** (a) k-space blade (b) Low resolution image (c) Composite reconstructed image (d) EPI image: full k-space acquisition (e) EPI image: Full k-space with SENSE 2

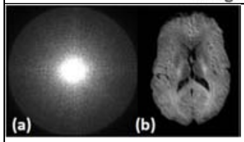

**Fig. 3** (a) Composite k-space data. (b) Composite image.

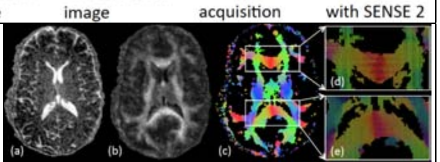

**Fig. 4** (left) DTI measures: (a) MD, (b) FA, (c) major eigenvector colormap, and (d, e) color coded major eigenvectors.

**References:** 1. Skare et al. MRM 2006;55:1298-1307. 2. Pipe et al. MRM 2002;47:42-52. 3. Mistretta CA et al. MRM 2006;55(1):30-40. 4. Cook et al. JMRI 2007;25(5):1051-1058.