Diffusion-Weighted, Readout-Segmented EPI with Synthesized T2- and T2*-Weighted Images

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Target Audience: Sequence programmers and radiologists.

Purpose: Diffusion-weighted Imaging (DWI) using readout-segmented EPI (rs-EPI) with 2D navigator correction [1] is an alternative to standard single-shot EPI (ss-EPI) that improves image quality by reducing susceptibility artifacts and allowing a higher spatial resolution. This improved image quality raises the possibility that the low b-value image could be used to replace a separate T_2-weighted acquisition and reduce the overall examination time. The EPI readout used by the rs-EPI sequence is much shorter than that of ss-EPI, resulting in a significant reduction in echo time. Whilst this is beneficial for DWI because of the improved SNR, it can be a disadvantage for providing T_2-weighted images because the TE is short compared to the value used in standard clinical, T_2-weighted protocols. The purpose of this study was to implement a prototype of a modified navigator-corrected rs-EPI sequence that provides an additional T_2-weighted image with a flexible, user-defined echo time. The proposed modification achieves this with minimal increase in the overall scan time and without sacrificing the data at short echo time provided by the original sequence. In addition, the additional image can be generated with T_2^*-weighting, making it potentially useful for identifying hemorrhage.

Methods: ***Pulse Sequence:*** In the standard rs-EPI sequence (Fig. 1), data are acquired from two spin echoes. The first is used to acquire imaging data from multiple excitations by sampling a different readout segment at each shot. The second is used to sample a 2D navigator region at the centre of *k*-space to correct the shot-to-shot, motion-induced phase variation. The same acquisition is performed for both high- and low-b-value images, even though navigator correction is only required in the high-b-value case. The new technique replaces the navigator acquisition at low b-value with a second imaging echo, so that an image is now generated for two echo times. For the high-b-value scans, a 2D navigator is acquired as in the original sequence. A variant of the new technique is to omit the second RF refocusing pulse for the low-b-value scans, so that the image from the second echo has T_2^*-weighting.

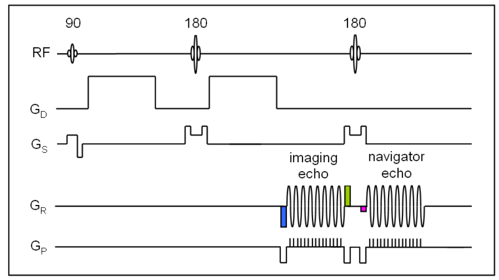

Fig. 1: Pulse diagram for readout-segmented EPI with 2D navigator correction. For b=0 scans in the modified sequence the fixed readout pre-phase gradient (■) for the 2D navigator is replaced by the same variable encoding gradient (■) as for the imaging echo.

Image Calculation: For typical diffusion-weighted, rs-EPI protocols, the first echo time tends to be below the preferred value for clinical T_2-weighted imaging and the second echo time tends to be above this preferred value. An image corresponding to the preferred echo time can be generated by combining the data from the two echoes to generate a synthesized image for an intermediate echo time [2]. A synthesized image with signal S_s was calculated in this study using a weighted geometric mean of the two acquired images given by the following expression:

$$S_S = \sqrt[w+1]{(S_1)^w S_2} \quad \text{with} \quad w = \frac{TE_2 - TE_S}{TE_S - TE_1},$$

where S_1 and S_2 are the signal intensities in the the first and second echoes respectively, with corresponding echo times TE_1 and TE_2, and TE_s is the user-specified echo time for the synthesized image.

Results: Figs. 2 and 3 show images acquired from a healthy subject using the prototype sequence at 3T and 1.5T respectively. The first two images in the top row of Fig. 2 are the standard trace-weighted and low-b-value images. The third image is the additional late-echo image generated by the modified sequence. Synthesized low-b-value images for a range of intermediate echo times are shown in the second row. Fig. 3 shows images acquired with the second RF refocusing pulse omitted to give the late echo a T_2^*-weighted contribution, the level of which can be controlled by the echo time selected for the synthesized image.

Discussion: The technique introduced in this paper promises to extend the clinical utility of diffusion-weighted rs-EPI by providing additional T_2- or T_2^*-weighted images for a user-specified echo time. This is achieved with almost no increase in scan time and without compromising the short echo time requirement for optimal SNR in the diffusion-weighted scans. The combination of high-quality DWI and T_2^*-weighted images is likely to be of particular benefit in acute stroke [3].

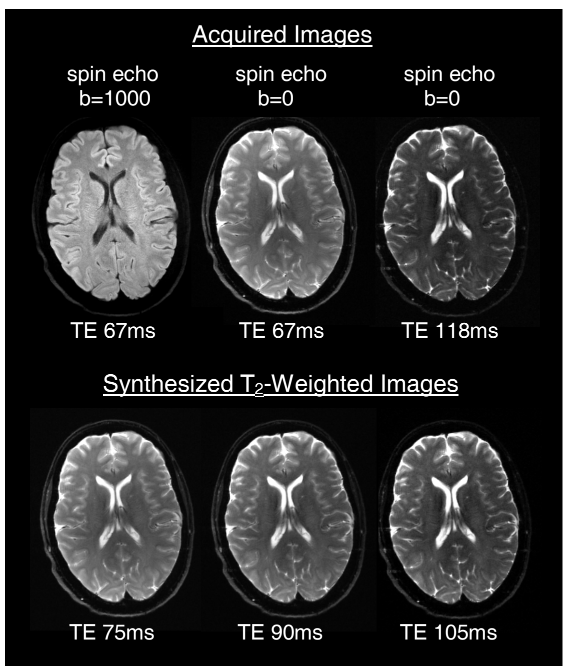

Fig. 2: Data from a modified rs-EPI sequence with two spin echo images at b=0. FOV 220mm, matrix 256x256, TR 5600ms. slice thickness 4mm, 11 readout segments.

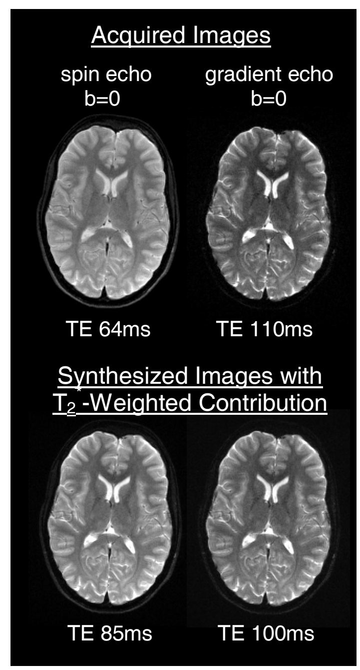

Fig 3: rs-EPI with a spin echo and a gradient echo image at b=0. Matrix 214x214, TR 3000, 9 readout segments.

References: [1] Porter & Heidemann. *MRM* 2009:62;468.
[2] Riederer et al. *Radiol.* 1984:153;203-206.
[3] Schellinger et al. *Stroke* 1999:30;765-768.