An EPIK Navigation Towards High-Resolution Diffusion-Weighted Imaging

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Synopsis:

Interleaved Echo Planar Imaging (IEPI) can be used to produce high-resolution Diffusion-Weighted Images (DWI). However, DW makes the images particularly sensitive to patient motion, resulting in severe artefacts. These problems can be overcome by acquiring a 2D navigator echo after each interleave. Such an approach is not efficient, since the navigator does not contribute signal to the image. We propose the use of a self-navigated sequence based on IEPI which enables the simultaneous acquisition of the navigator and the readout and also offers the advantage of using a Cartesian grid. Also demonstrated is its ability to identify fine tract splits.

Introduction:

A multi-shot approach is required to obtain high resolution DWI. Since diffusion pulse sequences are inherently very sensitive to motion, any movement of the subject during the application of the diffusion gradients will result in considerable phase errors between segments of K-space acquired over different shots. These phase errors can, however, be successfully corrected by separately acquiring a low spatial resolution image for each interleave (2D navigator echoes) as shown by Butts [1].

By altering the way in which K-space is covered, so that the centre will be more densely sampled, the readout echo and the navigator information required to perform the phase corrections can be acquired simultaneously. This should result in an increase in the signal-to-noise ratio (SNR), as the extra lines acquired for the navigator will also be used in the reconstruction of the images.

Other self-navigated sequences have previously been presented, but were either based on the Propeller method [2] or used spiral trajectories [3], thus requiring regridding to the Cartesian grid. We propose the use of a scheme of covering K-space which is based on IEPI with the consequent advantage of already using a Cartesian grid. This scheme is termed Echo Planar Imaging with Keyhole (EPIK) and was first introduced by Zaitsev for fMRI [4] - Fig. 1.

Methods:

Data were acquired on a 3.0 T Varian Inova scanner. To minimise eddy currents, a doubly-refocused spin-echo sequence was used [5]. Each set of images contained 9 contiguous slices (2.5 mm thickness). The other acquisition parameters were: TE= 106 ms, TR= 1.6 s, bandwidth of 200 kHz. The field of view was set to 240×240 mm^2, with a matrix size of 128×128, which resulted in a final, true, resolution of 1.875×1.875 mm^2 in-plane. K-space was covered over four shots and the keyhole covered a fraction of one-sixteenth of K-space. Each dataset consisted of one non-DW and nineteen DWI (b-value 650 s/mm^2). The gradients were uniformly distributed over a sphere in b-space, using the optimized scheme proposed by Jones [6]. In order to obtain enough SNR, eight datasets were acquired. This took approx. 54 minutes. Acquiring several datasets is essential also to be able to satisfactorily compensate for the motion-induced phase errors. The refocusing method introduced by Miller [7] was adapted to EPIK and used to perform the phase corrections. While using the refocusing method, it is crucial to ensure a smooth modulation of the K-space phase [7]. This was achieved by synchronising the acquisition with the cardiac cycle so that, for a given image, all interleaves would be acquired at roughly the same stage. Peripheral gating was used such that triggering occurred on every cardiac cycle, with three slices being excited per cycle. To evaluate the performance of EPIK, further data were acquired using a single-shot doubly-refocused EPI sequence [5]. A half K-space acquisition was performed with a matrix size of 62×96, which was then interpolated to 128×128. The true resolution was therefore 2.5×2.5mm^2 in-plane. Four datasets were acquired with the bandwidth set to 125 kHz. All other parameters were the same as used for the EPIK sequence. To test the use of the EPIK dataset for connectivity studies, the EPI images were registered to the non-DW EPIK image. A voxel located in the mediodorsal nucleus of the thalamus was then seeded using the probabilistic approach developed by Behrens [8].

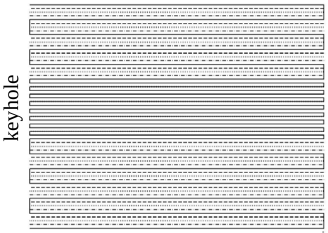

Figure 1: K-space trajectory for an EPIK sequence with 4 segments.

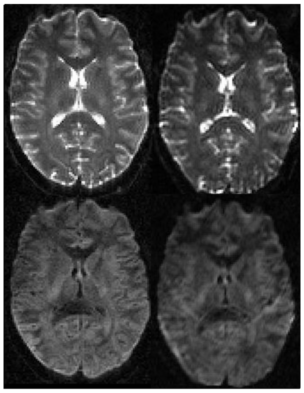

Figure 2: Non-DW (top) and DWI (bottom row) - relative intensities changed to facilitate its visualisation. Images acquired with EPIK (left) and single-shot EPI (right) sequences.

Results and Discussion:

Fig. 2 shows a slice imaged with the EPIK and the single-shot EPI sequences. The images on the top row have no-diffusion-weighting, versus those on the bottom row that do. Note that the relative intensities between these two sets were changed for easier visualisation. By looking at the images obtained with the two different sequences it is possible to verify that the effective image resolution was increased with the EPIK technique. From this figure it can also be noted that image distortion is reduced for the EPIK image, although different acquisition bandwidths impair a more direct comparison.

Probabilistic tractography produced connectivity distributions that tended to divide more in the EPIK data. As an example, the distributions obtained for a voxel located in the mediodorsal nucleus are shown in Fig. 3, overlaying the non-DW EPIK image. While the distribution obtained with EPI (in red) projects to a single cortical gyrus, the distribution obtained with EPIK (in blue) also identified branching towards a second gyrus. This result shows that the higher image resolution and the reduced image distortions offered by EPIK provide it with an increased sensitivity when performing fibre-tracking.

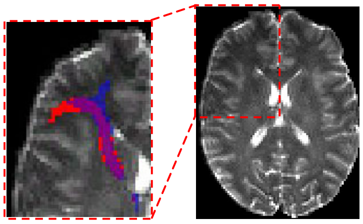

Figure 3: Connectivity distributions seeded from a voxel located in the mediodorsal nucleus of the thalamus, EPIK (in blue) and EPI (red), overlaying the non-DW EPIK image. In purple are the voxels shared by both distributions.

Conclusion:

We propose an alternative scheme for covering K-space for DWI that allows a more efficient use of the navigator data, as it also contributes to an increase in the SNR of the final images. An advantage of this method, compared to other self-navigated methods, is that it is easier to implement since it inherently uses the Cartesian grid. When compared to the standard DW-IEPI followed by the acquisition of the 2D navigator, the EPIK sequence provides the advantage of always guaranteeing that the navigator suffers from exactly the same phase shifts as the original data. It also ensures that the Nyquist criteria will always be satisfied in the central navigator region even if some of the interleaves are rejected, which is not necessarily the case with DW-IEPI [9].

In comparison to single-shot techniques, the EPIK sequence does have the disadvantage of considerably lengthening the acquisition time. However, this enables an increase in the resolution of the DWI which, as shown above, may have a significant impact when performing fibre-tracking. The use of a multi-shot technique results, in addition, in reduced image distortions due to a reduced echo train length. The EPIK sequence does offer the potential to increase the resolution of DWI even further. This can be achieved by covering K-space over a larger number of shots, provided that sufficient repetitions are acquired so as to maintain the required level of SNR.

References:

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