Combination of Multiplexed EPI with EPIK (EPI with Keyhole) for Reduced Image Distortions at 3T

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Target Audience

This work demonstrates the implementation of an accelerated version of M-EPI at 3T and should be of significant interest to the fMRI community.

Purpose

The relatively high imaging speed of EPI has led to its widespread use in dynamic MRI studies such as functional MRI or diffusion weighted imaging. Since the advent of EPI, a number of approaches have been suggested to shorten acquisition time. Nearly all the successful efforts shorten the acquisition time by reducing the number of sampling points required to reconstruct a single-slice image, e.g., parallel imaging or sparse data sampling approaches [1]. Although those methods decrease scan time for spatial encoding, they do not significantly decrease the acquisition time for an entire volume imaging. An approach to achieve this purpose, M-EPI (Multiplexed EPI) method has been presented by Feinberg et al. [1]; it achieves simultaneous excitation of multiple slices per TR using a set of multi-band RF pulses. However, the fact is that use of a set of RF pulses causes an increase of readout duration for the sampling of multi-slice data, which in turn increases image distortions. To overcome this problem, in this work M-EPI was combined with EPIK [2], which has been proven to be effective in reducing the EPI image distortions generated from the relatively long readout. EPIK is ideally suited for this purpose since it avoids temporal correlations in the data through the use of a sliding window and continual updates of the high-frequency lines in k-space. Experiments were performed at 3T and the method was validated with phantom as well as human brain data.

Methods

The M-EPI sequence is essentially a combination of two techniques: TM (Temporal Multiplexing) and SM (Spatial Multiplexing). An illustration of the sequence diagram and its slice-excitation profiles is depicted in Fig. 1. As shown in Fig. 1, TM uses one more selective RF pulse (RF_2) in a TR loop to excite another adjacent slice simultaneously; two echoes from the two respective slices are obtained during each readout gradient and its matrix size should be doubled to cover the sampling for two echo lines. For separation of the signals, a dephasing gradient (G_{dep12}) is imposed between RF pulses. This gradient creates a different phase history in each respective slice, which in turn makes each respective echo refocus at different positions during readout [3]. The idea of SM is to apply sinusoidal modulation to a sinc RF pulse to produce multiple clones each of which has a symmetric frequency offset; in this illustration, the original one (at 0 frequency offset) is also included to achieve 3-slice excitation as shown in Fig. 1. Signal separation was performed based on the parallel imaging reconstruction method by means of the distinct sensitivity profiles at each different slice position [4]. With the combination of the TM and SM above (i.e. in the M-EPI example above), in total six slices can be simultaneously excited per TR. In this work, M-EPI is further combined with the EPIK acquisition scheme resulting in M-EPIK. Figure 1c shows the schematic representation of the k-space trajectory for a three-shot EPIK sequence. In this acquisition, each measurement scans the central k-space region (keyhole region: K_K) completely with $\Delta ky = 1/FOV$, whilst the peripheral k-space regions (sparse region: K_S) are sparsely sampled with $\Delta ky' = 3/FOV$ (SPARSE factor of 3) resembling a multi-shot EPI scheme. By sharing the sparse region data from three consecutive scans with the keyhole region updated for every measurement, one obtains an image per TR excluding 2 initial dummy runs. In a time-series of images, the forth acquisition replaces the data from the first in a sliding window fashion. Furthermore, this example features one-fourth of k-space as the keyhole region. Thus, the total number of phase encoding lines to be sampled reduces to 1/2 (i.e. 1/4 + (3/4)/3) of that for an M-EPI sequence. Especially at high field strengths, a reduced signal-loss and reduced image distortions stemming from susceptibility variations can be expected in the M-EPIK images compared to the M-EPI images. For this work, the same configuration described in the illustration was implemented on a Magnetom Tim Trio 3T MRI scanner (Siemens, Erlangen, Germany) with a 12-channel phased array coil from the manufacturer.

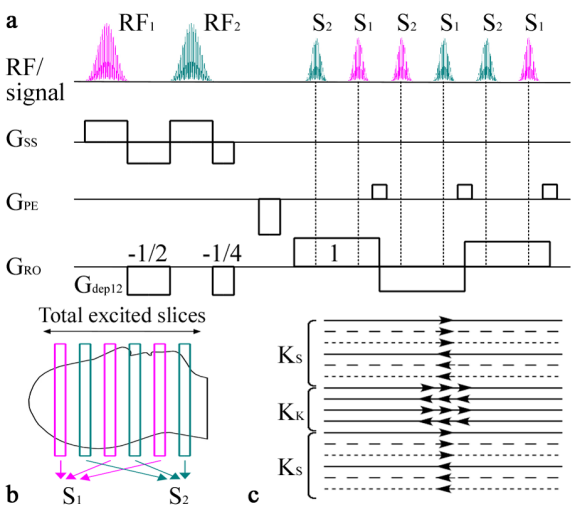

Figure 1 (a) An M-EPI sequence diagram and (b) its excitation profiles. The RF_1 and RF_2 pulses excite three slices simultaneously marked by S_1 and S_2, respectively. (c) Schematic representation of the k-space trajectory for a three-shot EPIK. The solid, dashed and fine-dashed lines in K_S regions indicate the sampling positions performed during three consecutive measurements, respectively.

Results

For comparison, both M-EPI and M-EPIK sequences were employed in the experiments. Phantom and human brain data were acquired with the following imaging parameters: FOV = 224 × 224 mm^2, matrix size = 64 × 64, slice thickness = 3.5 mm (3.5 × 3.5 × 3.5 mm^3 isotropic voxel), TR/TE = 3000/40 ms, 24 slices with a distance factor of 25 % and bandwidth = 1502 Hz/Px. Figure 2 shows the reconstructed phantom and human brain images for the very same slice position from the M-EPI and M-EPIK scans. Visual inspection of the phantom images suggests that there was no significant difference in terms of the spatial resolution between the two reconstructed images (Figs. 2a and b). Due to the relatively low bandwidth of EPI along the phase encoding direction, the human brain M-EPI image (Fig. 2c) displays severe geometric distortions, particularly around the frontal, temporal lobes and the fourth ventricle (marked by white arrows). Those distortions were significantly reduced in M-EPIK image (Fig. 2d); although the apparent signal dropout in the marked area appears to be smaller in Fig. 2c, this is actually a consequence of the regions being severely distorted.

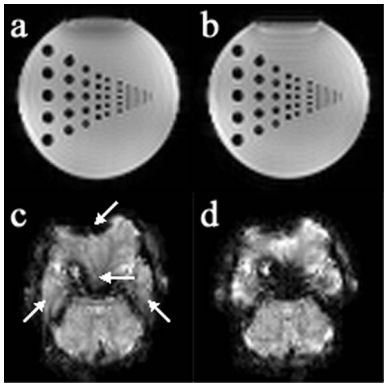

Figure 2 Reconstructed images of phantom (a, b) and human brain (c, d) data. Left and right column display the images obtained from M-EPI and M-EPIK, respectively.

Conclusion

M-EPIK was implemented and validated at 3T with phantom and human brain data. It was shown that the EPIK scheme was well combined with M-EPI sequence and M-EPIK outperforms M-EPI in terms of the robustness against the geometric distortions. For comparison, the same TR was used in both M-EPI and M-EPIK imaging, but each effective minimum TR was about 13.23 ms and 10.87 ms in M-EPI and M-EPK, respectively, which is approximately 5.3-fold and 6.4-fold faster when compared to 69.66 ms in a comparable single-shot EPI case.

References

1. Feinberg DA et al., PloS One 2010;5(12):1-11. 2. Zaitsev M et al., Magn Reson in Med 2001;45:109-117. 3. Feinberg DA et al., Magn Reson Med 2002;48(1):1-5. 4. Larkmann DJ et al., J Magn Reson Imaging 2001;13(2):313-317.