Accelerated multiplexed-EPI with PSF-based distortion correction at 9.4T

Seong Dae Yun[1] and N. Jon Shah[1,2]

[1]*INM - 4, Research Centre Jülich GmbH, Jülich, Germany,* [2]*Department of Neurology, RWTH Aachen University, Aachen, Germany*

Target Audience: This work demonstrates the implementation of accelerated M-EPI with PSF-based correction at 9.4T and should be of significant interest to the high-field fMRI community.

Purpose: The relatively high imaging speed of EPI has led to its widespread use in dynamic MRI studies. Since its first use, a number of attempts have been made to improve the performance of the EPI for higher resolution. One such approach is to combine the EPI with in-plane acceleration techniques such as multi-shot, parallel MRI and EPI with Keyhole (EPIK) [1,2]. As another approach for acceleration across the multiple planes (slices), multiplexed-EPI (M-EPI) has also been presented (Feinberg et al. [3]). This study i) verifies the use of the in-plane acceleration techniques on the M-EPI at 9.4T and ii) investigates the performance of each imaging method using quantitative assessment indices. As it has already been shown that EPIK outperforms EPI in terms of imaging speed and robustness against geometric distortions [1,2], we were motivated to employ the EPIK as one of the in-plane acceleration techniques. Furthermore, for the robust removal of the geometric distortions arising from the field inhomogeneities at 9.4T, the point spread function (PSF)-based correction method was also applied to each reconstructed image.

Methods: Essentially, the M-EPI has two technical backgrounds: SIR (Simultaneous Image Refocusing) and SMS (Simultaneous Multi-Slice). This work employed an acceleration factor of two for each technical principle, which lead to a total of four-slice simultaneous excitation per TR. A schematic sequence diagram for this configuration is depicted in Fig. 1a. To avoid high g-factor penalties in the SMS, the Blipped-Controlled Aliasing in Parallel Imaging (Blippd-CAIPI) approach [4] was integrated in the sequence; for simplicity, the details are not described in the figure. The M-EPI sequence was further combined with three in-plane acceleration techniques individually (two-shot, two-fold parallel MRI and EPIK) resulting in three different imaging sequences: two-shot M-EPI, two-fold M-EPI and M-EPIK. The EPIK acquisition was performed as described in Fig. 1c. 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 fourth 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 a comparable EPI sequence. For this work, the above configuration described in the illustration was implemented on a Siemens (Erlangen, Germany) 9.4T whole-body MRI scanner with a home-built 8-channel phased array coil.

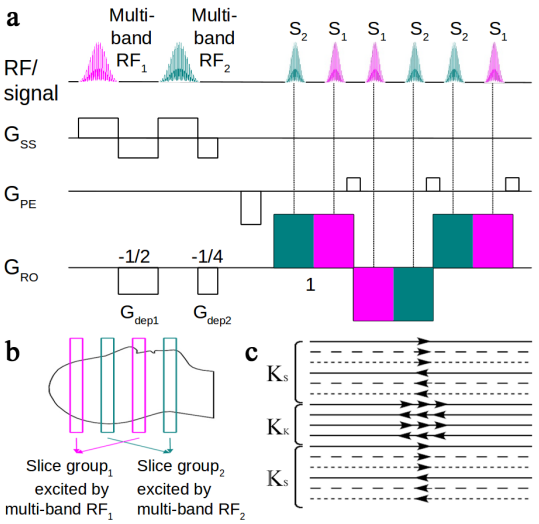
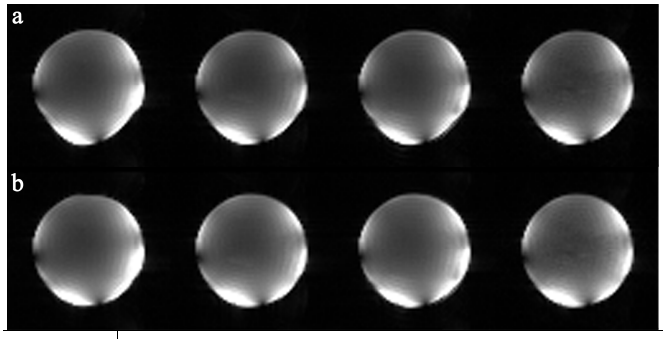


Figure 1 (a) An M-EPI sequence diagram and (b) its slice excitation profiles. (c) Schematic representation of the k-space trajectory for a three-shot EPIK. The solid, dashed and fine-dashed lines in KS regions indicate the sampling positions performed during three consecutive scans, respectively.

Results: M-EPI, two-shot M-EPI, two-fold M-EPI and M-EPIK data were acquired from an oil phantom with the following parameters: FOV = 240 × 240 mm^2, matrix size = 64 × 64, TR/TE = 3000/45 ms, receiver bandwidth = 1302 Hz/Px, slice thickness = 3 mm with a distance factor of 25% and 24 slices. Figure 2a shows reconstructed phantom slices for the very same slice position acquired with the four different sequences. Visual inspection of the phantom images suggests that all the images were reconstructed without any significant loss of signals or any severe degradation of image qualities. The two-fold M-EPI image was observed to have the most ghost artefacts around the centre of the image, which was mostly due to the SNR reduction induced by the pMRI acceleration. The M-EPI image exhibits the most geometric distortions (deformation of the shape from a true circle) and other images show reduced geometric distortions due to the use of a shorter readout. For more robust elimination of the geometric distortions, the PSF-based correction was applied to each reconstructed image and its distortion-corrected image was yielded as shown in Fig. 2b where all the images have a more circular shape than the non-corrected ones. To investigate the acceleration potential of each imaging method, the minimum TE and TR for 16 slices were computed in Table 1. As can be seen here, the minimum TE is greatly reduced by the in-plane acceleration techniques. And when considering that the minimum TR achievable from a comparable EPI sequence is 1268.32 ms, a large temporal reduction was achieved in all M-EPI based scans. To assess the effect of each imaging method on the temporal stability, temporal signal-to-noise ratio (tSNR), defined as the ratio of the signal average to the signal standard deviation across time-series, was calculated on the 50 volume time-series images (see Table 1). The tSNR of two-shot M-EPI and M-EPIK were comparable to that of M-EPI, which reveals that there was no significant temporal instability from shot to shot in those imaging methods. The substantial decrease of tSNR in the two-fold EPI is mostly due to the SNR reduction by the parallel MRI acceleration factor and its corresponding g-factor.



	M-EPI	2-shot M-EPI	2-fold M-EPI	M-EPIK
Min. TE/TR	44.73/364.64	26.01/292.08	26.01/289.76	26.79/292.88
tSNR	101.86	100.19	53.70	93.86

Figure 2 (a) Reconstructed images obtained with M-EPI, 2-shot M-EPI, 2-fold M-EPI and M-EPIK and (b) their corresponding PSF-based corrected versions; Table 1. Minimum TE/TR and tSNR for the above four sequences, cf. Min. TE/TR of a comparable EPI: 37.63/1268.32 ms.

Discussions and Conclusion: The present study verifies the use of various in-plane acceleration techniques compatible with M-EPI at 9.4T. The image qualities and temporal stability of each imaging method were also investigated. It was shown that the severe geometric distortions arising in the M-EPI based scans at 9.4T were effectively removed by the PSF-based correction method. The use of accelerated M-EPI methods is of great interest in dynamic MR studies as the method provides high volumetric throughput and the shortest possible TE suitable for low T_2^* regimes, particularly to ultra high field fMRI.

References: 1. Zaitsev M, Zilles K, Shah NJ. Magn Reson Med 2001;45(1):109-117. 2. Yun S, Reske M, Vahedipour K, et al. Neuroimage 2013;73;135-143. 3. Feinberg DA, Moeller S, Smith SM, et al. PloS One 2011;5(12):e15710. 4. Setsompop K, Gagoski BA, Polimeni JR, et al. Magn Reson Med 2012;67:1210-1224.