k-t-EPI: k-t-undersampled EPI acquisition and reconstruction in cerebral perfusion

Rebecca Ramb[1], Elias Kellner[1], Iulius Dragonu[1], Frederik Testud[1], Irina Mader[2], Jürgen Hennig[1], Maxim Zaitsev[1], and Bernd Jung[1]

[1]*Dept. of Radiology, Medical Physics, University Medical Center, Freiburg, Baden-Württemberg, Germany,* [2]*Dept. of Neuroradiology, University Medical Center, Freiburg Brain Imaging, Freiburg, Baden-Württemberg, Germany*

Purpose: Single-shot echo planar imaging (EPI)[1,2] is the most commonly used technique to achieve whole brain coverage at reasonable spatial and temporal resolution for applications like measurement of cerebral perfusion, diffusion or fMRI. However, EPI suffers from image blurring, susceptibility, chemical shift and eddy current artifacts due to long readout times with fast switching of high gradient amplitudes. The reduction of the echo train length and faster k-space traversal offered by parallel imaging techniques such as SENSE[3] and GRAPPA[4] can effectively reduce these artifacts, e.g.[5,6,7], yet, trading in artifact reduction for a loss in signal-to-noise ratio (SNR) mainly through the g-factor amplification. The SNR decrease limited previous applications to reduction factors of R=2 or R=3, where the SNR loss for R=3 often already exceeded the acceptable limit[6]. In order to overcome SNR limitations, we propose k-t-EPI: interleaved EPI acquisition following a k-t-undersampling pattern, together with k-t-GRAPPA[8] reconstruction exploiting dependencies within k-space and temporal neighbors. The method is applied for - but not limited to – dynamic susceptibility contrast (DSC) weighted imaging of cerebral perfusion.

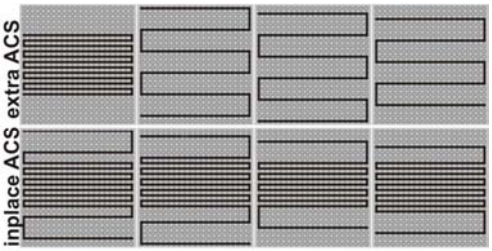


Figure 1: k-t-EPI k-Space acquisition pattern over several time frames for R=4.

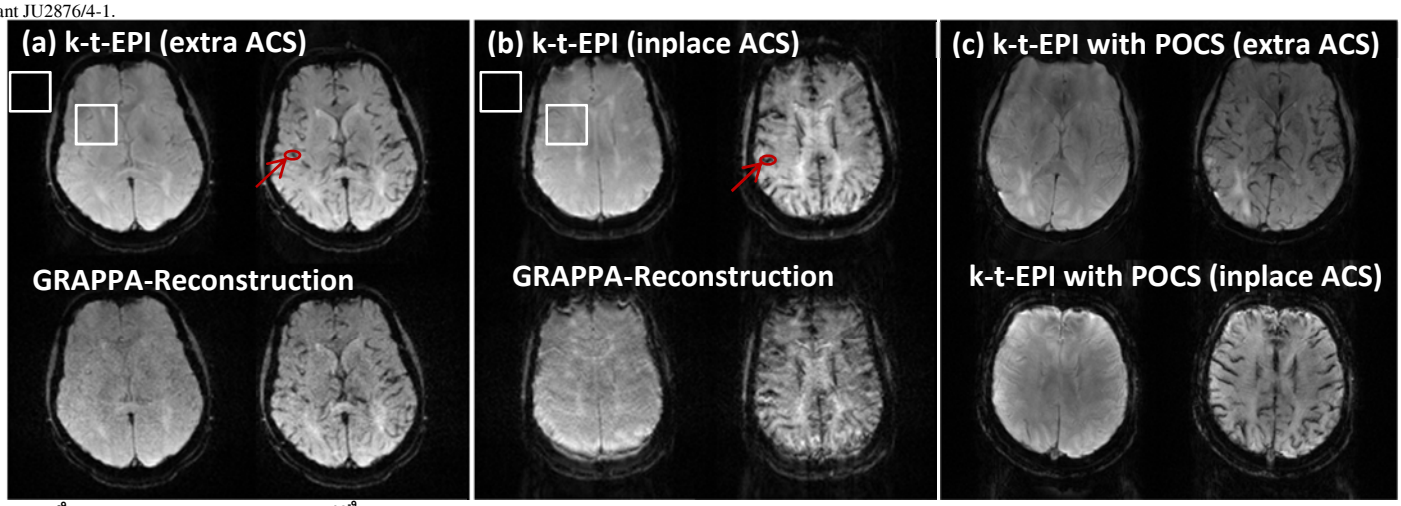
Methods: A single-shot EPI sequence was developed with interleaved readouts in accordance with the k-t-undersampling patterns shown in *Fig.1*. Autocalibration signal (ACS) were acquired either (a) extra, i.e. in separate readouts prior to the actual scan, or (b) inplace, i.e. incorporated in the actual scan (*Fig.1*). In order to compare the gain in SNR and the temporal fidelity, all acquired data sets were additionally reconstructed using standard GRAPPA for each time frame separately. First pass bolus perfusion acquisition - 15 slices, 40 time frames, 0.5 M Gadolinium Chelate (Multihance, Bracco Imaging, Italy), 0.1 mmol/kg body weight at rate of 3 ml/s - was performed in ten patients with different diagnostic background on a 3T clinical scanner (Tim TRIO, Siemens, Erlangen, Germany) with R = 4 and TR = 1.5 s. Further imaging parameters were: (1) 1.6×1.6×5.0 mm^3 resolution, (a) extra ACS (24 lines, 16 time frames), TE = 23.3 ms, matrix size 134×134 (3 patients) and (b) inplace ACS (20 lines), TE = 28.58 ms, matrix size 138×138 (3 patients), as well as with (2) 1,2×1,2×5,0 mm^3 resolution (matrix size 178×178), (a) extra ACS (24 lines, 16 time frames), TE = 23.3 ms (2 patients) and (b) inplace ACS (20 lines), TE = 30.1 ms (2 patients). For (2), 7/8-Partial Fourier was additionally applied and reconstructed using POCS[9]. Image reconstruction was performed offline in Matlab (The Mathworks, USA).

Results: *Fig.2* shows single time frames prior and during bolus arrival acquired with extra *(a)* or inplace *(b)* ACS strategy and additionally reconstructed using GRAPPA. Despite the high reduction factor, all k-t-EPI images provide sufficient SNR, while images using GRAPPA reconstruction exhibit much higher noise. The inplace acquired images exhibit more blurring artifacts during bolus passage compared to extra ACS acquisition, however with slightly better performance in unfolding the fold-over artifacts. For GRAPPA, inplace acquired images show a signal drop in the frontal part which is not visible in k-t-EPI. *Fig.2(c)* illustrates the accessibility of high spatial resolution (1.2×1.2×5.0 mm^3) with the proposed method and further reduction of the echo train length using 7/8-Partial Fourier encoding. *Fig.2* further depicts magnitude signal intensity versus time within a vessel ROI (red ellipse, *Fig.2(b,c)*) exhibiting the known signal drop due to contrast agent passage for extra *(d)* and inplace *(e)* ACS acquisition. For GRAPPA, the curves are affected by noise and SNR decrease. k-t-EPI seems to smooth out fast contrast changes in the case of extra ACS acquisition, but shows the same fast response as GRAPPA for inplace acquisition. The table in *Fig.2* displays SNR estimates derived from the indicated 17×17-sized signal and noise regions and averaged over all time frames.

Discussion and Conclusion: The proposed k-t-EPI approach allows for higher reduction factors while maintaining sufficient SNR, thereby preserving the benefits of single-shot EPI and the advantages of parallel imaging like reduction of echo train lengths and faster k-space traversal. Higher reduction factors facilitate higher spatial or temporal resolution, shorter TE or improved coverage through increased number and decreased thickness of slices within the time of repetition. Optimal trade-off between these aspects needs to be investigated in the context of particular applications. Higher spatial resolution with stable and fast temporal acquisition offered by k-t-EPI is especially suitable for application in first pass bolus passage experiments like DSC-MRI, and DCE-MRI, as well as for arterial spin labeling, but may also be useful for fMRI. Shorter TE could be further advantageous for perfusion MRI, whereas in fMRI the optimal TE is fixed and the goal would be shortening single volume acquisition times and thus shorter TR and/or increased spatial resolution or increased SNR at given TR. In clinical imaging of stroke, faster imaging could be beneficial for the estimation of cerebral blood flow. In tumor imaging, higher spatial resolution could diminish partial volume effects of veins in the estimation of cerebral blood volume. k-t Acceleration can induce temporal blurring, therefore, it is of great importance to further analyze the optimal choice of the involved parameters, i.e. acquisition strategy (extra or inplace), reduction factor, kernel geometries and number of ACS lines, with respect to temporal fidelity.

References: [1]Mansfield et al. J. Phys. 1977 [2]Ordidge et al. BJR 1981 [3]Pruessmann et al. MRM 1999 [4]Griswold et al. MRM 2002 [5]Griswold et al. MRM 1999 [6]Preibitsch et al. NI 2003 [7]Newbould et al. ISMRM 2006 [8]Huang et al. MRM 2005 [9]McGibney et al. MRM 1993

Acknowledgements: We thank Ralf Deichmann for sharing his FLASH-EPI sequence which served as a basis for the sequence development and the German Research Foundation (DFG), grant JU2876/4-1.



SNR	extra	GRAPPA
kt-EPI	39,89	20,55
inplace	46,05	15,70

Figure 2: (a,b) Reconstructed images of two patients prior and during bolus passage acquired with k-t-EPI, R=4, 1.6x1.6x5.0mm³ resolution and extra or inplace ACS data. (c) Reconstructed images of two patients - extra and inplace ACS - with k-t-EPI, R=4 and 7/8-Partial Fourier acquisition with 1.2x1.2x5.0mm³ resolution. (d,e) Average magnitude signal intensities versus time of the indicated area (red) for extra and inplace ACS acquisition. Table: Time averaged SNR estimations using the indicated signal and noise regions (white).