Robust ACS acquisition for 3D echo planar imaging

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Introduction: 3D echo planar imaging (3D EPI) has become a popular fast imaging sequence for BOLD fMRI [1-3] and more recently for structural imaging [4] or quantitative susceptibility mapping (QSM) [5]. The benefits of 3D EPI are greatest in high-resolution imaging which is beneficial at ultra-high field. This requires use of a large imaging matrix, which is only feasible in combination with parallel undersampling along the in-plane phase encoding direction to achieve the desired echo time for BOLD contrast and/or to control signal dephasing, as well as to avoid T_2* blurring caused by excessively long EPI readout trains. The quality of the subsequent parallel imaging reconstruction stands and falls with the quality of the calibration data (ACS), and depends strongly on the line-ordering scheme used for the ACS acquisition. In typical EPI, ACS are acquired using the same EPI readout train as is used for the undersampled imaging scans: covering a fully sampled ACS k-space therefore requires a number of segments equal to the in-plane undersampling factor. In 2D EPI, the time between the acquisitions of the ACS segments in steady-state is given by the volume TR, i.e. up to a few seconds. In the presence of physiological fluctuations caused by subject motion and frequency changes due to breathing, such segmentation results in periodic inconsistencies in the ACS k-space, which will compromise the image reconstruction. Choice of an adequate acquisition scheme is therefore important in order to minimize artefact levels in the final image. How segmentation affects GRAPPA reconstructions for 2D EPI has been investigated in detail previously in the context of the FLEET technique [6]. **We investigate different ACS acquisition schemes for 3D EPI GRAPPA reconstructions and propose a robust segmentation scheme that considerably reduces residual aliasing and provides high temporal stability.**

Methods: GRAPPA reference acquisition for 3D EPI involves a 3D ACS k-space consisting of lines (ky) and partitions (kz). Common sequence implementations first acquire one segment for all partitions before proceeding to the next segment (PAR-LIN order). With segments therefore being acquired seconds apart, 3D EPI is prone to the same segmentation errors as described for 2D EPI [6]. An in-house implementation of 3D EPI [1] was therefore modified to allow for comparison four different ACS acquisitions schemes: (a) PAR-LIN order, (b) LIN-PAR order (in-plane segments of a given partition acquired in immediate succession), (c) single-shot (a non-segmented readout that acquires as many ACS lines per partition as allowed by the readout), (d) FLASH reference scan. In vivo scans were performed on two subjects at 7T with the following parameters: sagittal matrix 192x192x176, 1mm isotropic voxels, TE=19ms, 6/8 PF, TR=50ms, in-plane GRAPPA 3, ACS reference k-space with 63 lines / 24 partitions. Image quality for each scheme was assessed by inspection of the artefact levels and computing temporal SNR over 50 repetitions within a brain mask. All experiments were performed on a 7T whole body MRI scanner (Siemens) equipped with 70mT/m gradients and a 32-channel head coil.

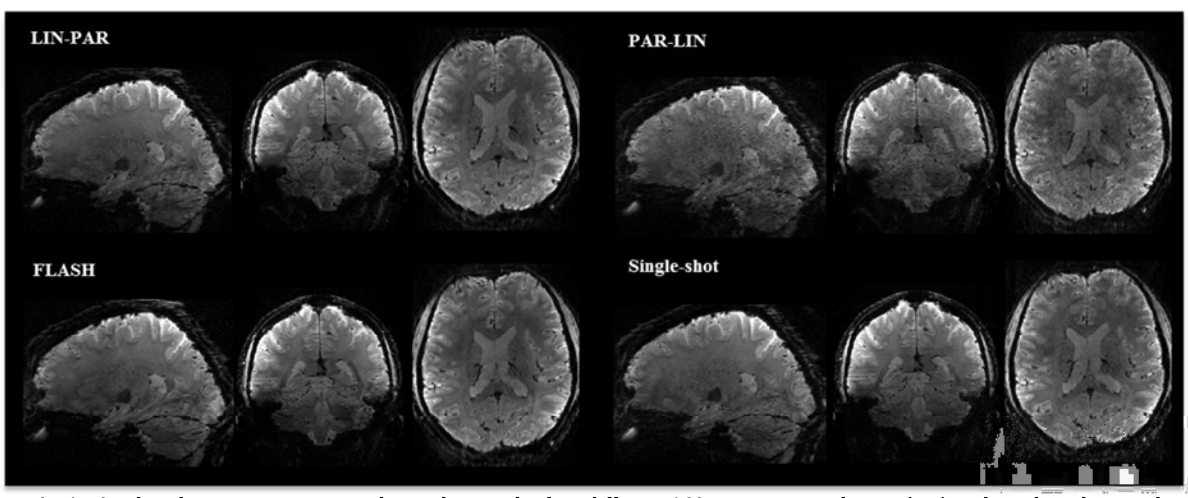

Fig 1: *Single volume 3D EPI images obtained using the four different ACS acquisitions schemes (top) and windowed sagittal views to depict the artefact levels (right).*

Results: Lowest image quality and tSNR (32.75 ± 0.04) was observed with the most commonly used 'PAR-LIN' scheme, which results in noise enhancement throughout the image and background. The proposed LIN-PAR scheme yielded the least residual aliasing and higher tSNR (33.91 ± 0.04). Highest tSNR was found with the FLASH reference scan (35.14 ± 0.05), albeit with a higher level of residual 'static' aliasing. The single-shot reference scan resulted in inferior image quality compared to both FLASH and LIN-PAR, but better than PAR-LIN.

Discussion: The superior performance of LIN-PAR is not surprising, as it can be viewed as the FLEET analogue in 3D. In contrast to 2D EPI, no dummy scans are necessary in 3D EPI since each RF pulse excites the whole volume, meaning that the steady-state is maintained irrespective of acquisition order. It should be noted that the data presented here were obtained on experienced subjects. More drastic artefacts are frequently observed with the PAR-LIN scheme in 'typical' subjects. In conclusion, these results exemplify the importance of the ACS acquisition schemes for optimal 3D EPI image quality irrespective of the application.

References: [1] Poser et al. NIMG 2010; [2] Van der Zwaag et al. MRM. 2012; [3] Lutti et al. MRM. 2013; [4] Zwannenburg et al. NIMG 2011; [5] Langkammer et al. ISMRM 2014; [6] Polimeni et al. ISMRM 2013.