Accelerated QSM

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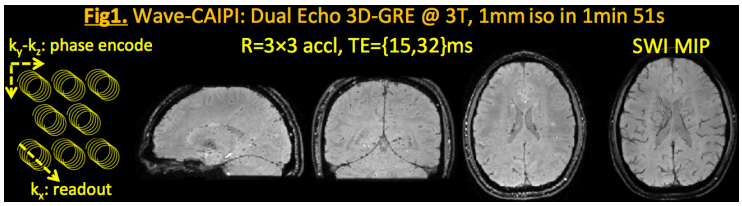
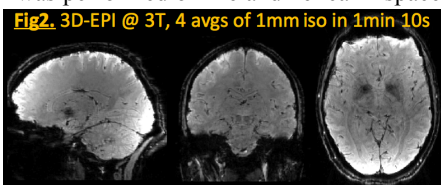
INTRODUCTION: SWI and QSM harness the tissue magnetic susceptibility as a contrast mechanism for detailed depiction of the vasculature, deep gray matter and the cortex. The tissue susceptibility is derived from the phase of the GRE signal, which attains maximum contrast-to-noise ratio when the TE is equal to the tissue T_2* relaxation time. Due to long TE and whole brain coverage requirements, SWI and QSM acquisition using conventional 3D-GRE is relatively slow. When coupled with multiple head orientation requirement of COSMOS [1] and STI [2], the scan time becomes prohibitively long. As the SNR benefit of ultra high field permits smaller voxel sizes, acquisition time remains relatively long despite the reduction in the optimal TE=T_2*. To reduce the scan time, it is possible to employ (a combination of) *i*) parallel imaging acceleration, *ii*) efficient k-space trajectory, and *iii*) echo-shift to exploit the unused sequence time due to long TE. In this abstract, we review and provide examples for each category.

METHODS&RESULTS: ***i*) Parallel imaging:** uses coil sensitivity encoding to reconstruct data from undersampled acquisitions. Since 3D-GRE entails phase encoding in both k_y and k_z axes, acceleration in two dimensions becomes feasible. This has been employed for R=2×2-fold speed-up using GRAPPA [3,4], and R=2.5×2-fold acceleration with SENSE [5,6]. Parallel imaging performance can be improved using 2D-CAIPI [7], which controls the voxel aliasing pattern by shifting the position of k-space samples. Aliasing can also be distributed along the fully-sampled k_x axis, which further improves parallel imaging and forms the basis of Wave-CAIPI [8]. As shown in ***FIG1***, this allows R=3×3-fold acceleration with high image quality, where two flow-compensated echos were sampled for improved SNR in 1min 51s. Image reconstruction was performed online and helical k-space trajectory was estimated automatically from the undersampled data [9].

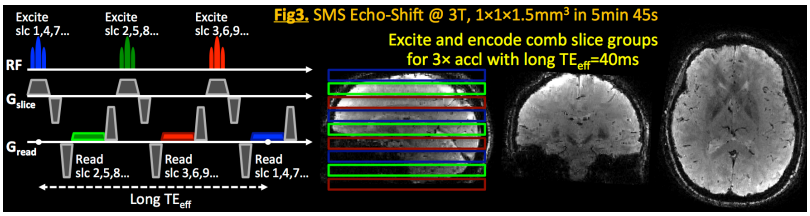




ii*) Efficient trajectories:** ***EPI covers a plane of k_x-k_y per excitation, making it an efficient tool for phase imaging. Single-shot 2D-EPI allows whole brain coverage at 2mm isotropic resolution in 7s [10], and can be further sped up using Simultaneous MultiSlice (SMS) [11]. 3D-EPI [12] follows an EPI trajectory for in-plane sampling, with phase encoding along the k_z axis. This results in an efficient encoding strategy with the SNR benefit of 3D signal averaging. ***FIG2*** demonstrates a whole brain 3D-EPI acquisition at 1mm isotropic resolution, which took 1min 10s for 4 averages. This acquisition used R=3-fold GRAPPA acceleration to reduce distortion. Segmented EPI is another strategy that mitigates distortion by covering the k_x-k_y plane in multiple excitations. Combined with the SNR efficiency of 3D encoding, this allows a 4min acquisition at 0.55mm isotropic resolution with low distortion [13]. 2D-CAIPI is also applicable to 3D-EPI, which permits high acceleration rates to interchangeably achieve faster acquisition or reduced distortion [14,15].

PROPELLER collects low-resolution data strips, aka *blades*, that are rotated about the k-space center, and allows motion detection/correction [16]. Each blade can be rapidly acquired using (3D-)EPI, yielding a fast, motion robust acquisition with low distortion [17]. ***SPIRAL*** trajectories are extremely efficient, and evenly distribute undersampling to k_x-k_y axes for improved parallel imaging. Stack-of-spirals use phase encoding along k_z axis and provide SNR boost through 3D encoding. This allowed a whole brain acquisition at 1mm isotropic resolution in just 2.5min, with comparable SNR to that of a 20min 3D-GRE [18].

iii*) Echo-shift:** exploits the unused time before the long TE to encode different subsets of the FOV. These subsets can be chosen as contiguous slabs [19] or as comb-shaped slices in ***FIG3 which eliminate slab boundary artifacts. This also facilitates parallel imaging since a comb slice group spans the entire FOV along z, improving the distance between aliasing voxels [20].



DISCUSSION: While EPI is very efficient, achieving high resolution is difficult due to T_2* blurring during the long echo train. Segmented EPI or 3D-GRE would be more suitable for such applications, while sacrificing some acquisition efficiency. EPI also suffers from B_0-related distortion, which can be mitigated by segmented acquisition, higher in-plane acceleration, or post-processing. Spiral trajectories are similarly efficient, but require more involved non-Cartesian reconstruction. B_0 artifacts in spiral acquisition manifest as blurring rather than distortion, and can be mitigated by incorporating the field map in the reconstruction [21], or by a segmented (multi-shot) approach. On the other hand, echo-shift is more suitable for GRE readout rather than EPI or spiral encoding since GRE acquisitions have more dead time. Echo-shift is especially useful for phase imaging since it minimizes unused time while achieving long TE, and can be combined with parallel imaging for >20× acceleration [22].

REFERENCES: 1] T Liu MRM09; 2] C Liu MRM10; 3] M Griswold MRM02; 4] D Khabipova NIMG15; 5] K Pruessmann MRM09; 6] X Li NIMG12; 7] F Breuer MRM06; 8] B Bilgic MRM15; 9] S Cauley ISMRM16; 10] H Sun MRM15; 11] K Setsompop MRM12; 12] C Langkammer NIMG15; 13] P Sati MSJ14; 14] B Poser ISMRM14; 15] M Narsude MRM15; 16] J Pipe MRM99; 17] S Holdsworth JMRI15; 18] B Wu NIMG12; 19] Y Ma MRM16; 20] H Ye ISMRM16; 21] B Sutton TMI03; 22] B Bilgic ISMRM16