3D SAP-EPI motion-corrected fast susceptibility weighted imaging

S. J. Holdsworth1, S. Skare1, K. Marty1, M. Straka2, and R. Banmer1
1Lucas MRS/I Center, Stanford University, Stanford, CA, United States

Introduction: Susceptibility-weighted imaging (SWI) has been utilized as a useful contrast mechanism in MRI that accentuates the paramagnetic properties of venous blood products (1,2). With the use of both magnitude and phase images, SWI can provide improved conspicuity of venous blood vessels and other sources of susceptibility effects (2). Typically, the SWI acquisition uses a high-resolution, three-dimensional gradient echo (GRE) sequence. However, the GRE acquisition used for SWI suffers from a long scan time (~5 mins at 3T), which decreases patient throughput and increases the chances of motion artifacts. A 3D GRE-EPI trajectory has been proposed as a faster alternative. However, unless the data are acquired with several interleaves, the images may suffer from considerable blurring and geometric distortion artifacts. The problem with using multiple interleaves is that, like standard GRE, it makes 3D GRE-EPI vulnerable to motion. Here, a 3D short-axis readout propeller (SAP)-EPI trajectory (3) is suggested as an alternative approach to 3D GRE and 3D GRE-EPI. SAP-EPI can achieve higher resolution than EPI with significantly reduced distortions (4). As a result, fewer interleaves can be used (GRAPPA-acceleration factor $R \leq 4$), making the use of parallel imaging (PI) applicable. With PI, each interleave can be acquired in a single breath (5). However, PI-enhanced EPI still suffers from distortion artifacts. On the other hand, multi-shot EPI used to gridding (in $k$-space) renders thicker and more prominent larger vessels – even small patient motion could result in an unusable image. Fig. 3

Methods: The 3D SAP-EPI $k$-space trajectory is shown in Fig. 1. Experiments were conducted on a healthy volunteer using a 3T whole-body GE Excite system and an eight-channel head coil. The following scan parameters were used for the SAP-EPI and interleaved EPI sequence: matrix size = 256 x 256, TR/TE/FA = 55ms/20ms/20º, FOV = 24 x 24 x 12.8cm$^3$, 64 $z$-partitions, $	ext{slthk} = 2$ mm. The SAP-EPI sequence used 8 blades of width $64 \times \text{NEX} = 4$, a brick frame rate of 3.5 s, and a scan time of 1:48 min. The EPI sequence used 32 interleaves for an equivalent scan time. Two 3D SAP-EPI datasets were acquired, the second with a through-plane rotation of –10º. Blade data were mixed, such that every second blade was chosen from the rotated dataset. The $R$ bricks per brick angle originating were 3D motion corrected (in the image domain). All bricks together were then motion corrected prior to gridding (in $k$-space). A high resolution flow-compensated GRE sequence was acquired for comparison (matrix size = 512 x 256, rectangular FOV = 0.75, TR/TE/FA = 37ms/20ms/20º, $z$-partitions = 32, slthk = 2mm, scan time = 5mins). All data were processed by generating a phase mask using a 2D Hanning window. The mask was multiplied by the magnitude image 5 times to produce the final SWI image.

Results: A comparison between the original magnitude images acquired with 3D GRE, interleaved EPI, and SAP-EPI is shown in Fig. 2. Although the resolution and SNR is highest for the GRE scans, both the interleaved EPI and SAP-EPI scans demonstrate darker vessels in a number of regions. In addition, interleaved EPI and SAP-EPI have a considerably reduced scan time and a better extent of brain coverage (64 partitions in 1:52mins for interleaved EPI and SAP-EPI, versus 32 partitions in 5mins for GRE). Although the scan time of the interleaved EPI scan is equivalent to the SAP-EPI and the vessels are slightly more conspicuous, it has reduced;

Discussion: Perhaps one of the greatest hindrances to the adoption of SWI in the clinics is the long scan time associated with standard GRE. However, with parallel imaging, the scan time of GRE can be reduced by up to a factor of 4 (8-channel head coil) – although this can result in a significant SNR penalty. EPI can be used to significantly speed up the acquisition, but with an SNR which makes it more compatible with PI. However, PI-enhanced EPI still suffers from distortion artifacts. On the other hand, multi-shot EPI used to gridding (in $k$-space) renders thicker and more prominent larger vessels – even small patient motion could result in an unusable image. Fig. 3