3D SAP-EPI for Self-Navigated T1w Spoiled Gradient Echo Imaging

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Introduction: 3D T1-w Spoiled Gradient Echo (SPGR) imaging is commonly used in the clinical care as well as for research due to its high gray-white matter contrast and isotropic resolution. While the short TR makes the total scan time reasonable (~3-10 mins), certain patients have difficulties in remaining still during the scan, which leads to image ghosting and the need for reacquiring the data. Recently, an IR-prepared 2D PROPELLER T1-w sequence has been proposed (1), which is able to correct for in-plane motion. However in 3D, this poses difficulties because of the limited T1 relaxation time following the IR-prepared pulse. It would therefore be of great advantage to acquire *k*-space in an efficient fashion, using a sampling scheme that can detect and correct for the full 3D rigid body motion of the patient semi-continuously during the scan. As motion induced ghosting for 2D/3D Cartesian imaging occurs due to phase inconsistencies and shifts between *adjacent* lines in *k*-space, a design criterion to avoid this is to acquire *k*-space such that an image volume with full image FOV can be formed in a very short time frame during which the risk of motion is negligible.

Short-axis readout propeller EPI (SAP-EPI) (2) has been suggested as an alternative approach to EPI to achieve higher resolution without the penalty of increasing distortions. In the SAP-EPI scheme individual EPI 'blades' are rotated through a central strip in *k*-space, which similar to PROPELLER allows for 2D motion correction between the blades. To achieve the above goal for 3D imaging, a 3D GRE version of the SAP-EPI sequence is implemented here, by acquiring 3D 'bricks'. We will show that the acquisition of one brick can be performed with full brain coverage in a couple of seconds, making the risk of intra-brick motion (ghosting) small and leaving only the inter-brick 3D motion to be corrected. We demonstrate motion and distortion-corrected phantom data from controlled motion experiments. Initial human images are presented with good T1-w gray/white matter contrast, acquired with three averages in a sub-minute scan time.

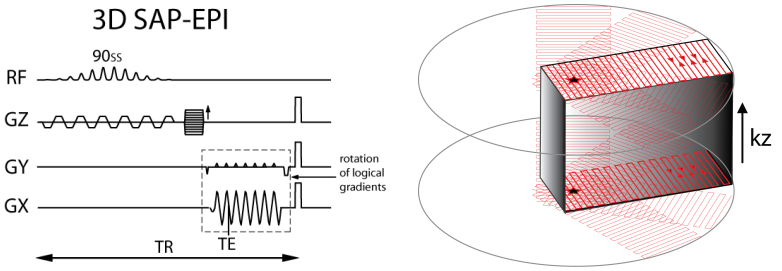

Figure 1. 3D SAP-EPI pulse sequence timing diagram and corresponding traversal of *k*-space.

Materials & Methods: The 3D SAP-EPI pulse sequence diagram and resulting *k*-space trajectory is shown in Fig. 1. A 90º spectral-spatial pulse was used for water-only excitation, followed by partition-encoding in the *z*-direction, a 3-shot SAP-EPI partial Fourier readout in *ky*, and finally crushers applied in all directions. For the following excitations, the shot index and brick angle in the *xy*-plane was altered. After a 1D FFT along k_z, referenceless Nyquist-ghost correction (3) was applied to each brick independently. For each brick, GRAPPA weights (4,5) were estimated on all interleaves and applied to each shot (6) to recover the brick sampling speed and allow for image based 3D motion correction between the shots. The data are then reconstructed with POCS (7,8) in the k_y-direction to fill in the remaining required extent of *k*-space. At this stage in the reconstruction, the data is FFT'd to the image domain for realignment and motion correction. First, the *R* bricks per brick angle originating from each shot are 3D motion corrected and averaged. Second, all bricks together are simultaneously motion and distortion corrected using a new technique based on ideas by Andersson et al. (9,10). This algorithm uses the combination of all blades for estimating the ΔB_0 field, correcting for motion and distortion on all blades without the acquisition of any extra data. Following this correction, image data is 2D-FFT'd back to k-space for gridding (11).

Experiments were conducted on a 1.5T whole-body MRI unit (GE Excite, G = 50mT/m, SLR = 150 mT/m/s) and an eight-channel head coil. The following scan parameters were used on a cylindrical phantom: a target resolution of 192x192, seven partial Fourier-encoded blades of width 48, overscans = 24, a GRAPPA-acceleration factor *R* = NEX=3, TR/TE = 43 ms/9 ms, FOV = 25.6 x 25.6 x 25.6 cm, and 64 *z*-partitions resulting in a slice thickness of 4 mm, a brick frame rate of 2.7 s, and a scan time of 57 s. Two phantom 3D SAP-EPI datasets were acquired, the second with an in-plane rotation of ~10º. Blade data were mixed such that every second blade was chosen from the rotated dataset. For human studies, the same scan parameters were used as in the phantom study.

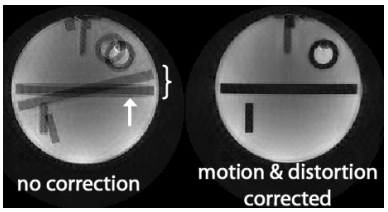

Figure 2. (left) Phantom image using mixed blade data from two 3D SAP-EPI acquisitions, one with the phantom rotated by ~10º. Every second blade (out of a total of seven blades) is chosen from the rotated dataset. (right) Same dataset after motion and distortion correction.

Results: A phantom image obtained from a mixed blade dataset is shown in Fig. 2. Without correction, distortions and motion (depicted by the white arrow and curly braces, respectively) are evident in the uncorrected image. These artifacts are largely corrected for with the application of the motion and distortion correction technique discussed above. Fig. 3 shows preliminary human data, depicting a subset of 64 partitions (4 mm thick) acquired in a scan time of 19 s per NEX.

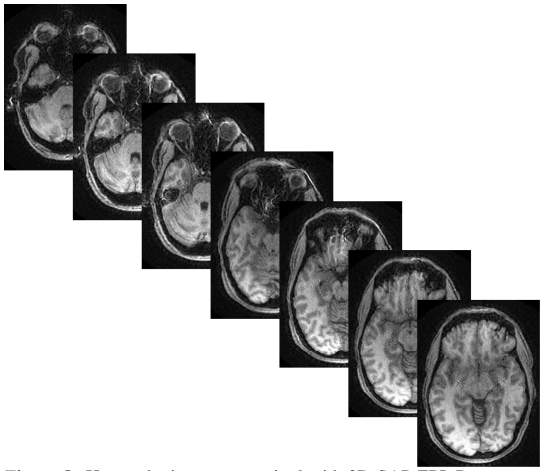

Figure 3: Human brain scans acquired with 3D SAP-EPI. Parameters were: a target resolution of 192 x 192, blade width of 48, 7 blades, *R* = NEX = 3, TR/TE = 43 ms/9ms, a FOV = 25.6 x 25.6 x 25.6 cm, and 64 partitions resulting in a voxel size of 4 mm.

Discussion & Conclusion: Here we have presented an efficient propeller-based readout method that does not require the acquisition of FSE readouts, and enables the fast acquisition of T1w-SPGR images. Its inherent ability to allow motion- and geometric- distortion correction (Fig. 2) without the acquisition of any extra data makes 3D SAP-EPI a promising alternative sampling strategy to standard 3D T1w SPGR – a technique that often suffers from ghosting artifacts due to motion. In the event that the brick frame rate (of 2.7 s in this case) results in motion between shots, this brick could be re-acquired. Initial experiments on a human volunteer (Fig. 3) yielded images with high grey/white matter contrast. For this work we plan to acquire and correct for controlled/step wise and continuous motion on volunteers and compare with conventional 3D T1w SPGR. In the case of under-sampled blades, we will estimate the GRAPPA weights using a continuous GRAPPA-kernel without the need for external calibration data (12,13). Using the scan parameters above, this would result in a total scan time of ~19 s (64 partitions, 7 blades, TR = 43 ms, brick frame rate = 2.7 s). For future work, we aim to perform fMRI with the acquisition of full TE blades. With the short scan time, immunity to ghosting and inherent ability to correct for motion and geometric distortions made possible through the use of 3D SAP-EPI, this sequence may be a useful alternative sampling strategy for high resolution 3D SPGR imaging.

References: 1) Takei N et al. ISMRM 2007:1728. 2) Skare S. et al. MRM 2006;55:1298-1307. 3) Nordell A et al. ISMRM 2007:1833. 4) Griswold MA. et al. MRM 2002;47:1202-1210. 5) Qu P. et al. JMR 2005;174(1):60-67. 6) Skare S. MRM 2007;57:881–890. 7) Haacke EM et al. JMR 1991;92:126-145. 8) Liang ZP et al. Rev MRM 1992;4:67-185. 9) Andersson JL. Neuroimage 2003;20(2):870-888. 10) Skare S. MRM 2005;54(1):169-181. 11) Jackson JI. IEEE Trans Med Imag 1991;10:473-478. 12) Skare S. et al ISMRM 2006;1734. 13) Skare S. et al. ISMRM 2006; 1743. **Acknowledgements:** This work was supported in part by the NIH (2R01EB002711, 1R21EB006860), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, Oak Foundation, and the Swedish Research Council (K2007-53P-20322-01-4).