Stack-of-Spirals CAIPIRINHA Trajectory for Rapid Volumetric Imaging

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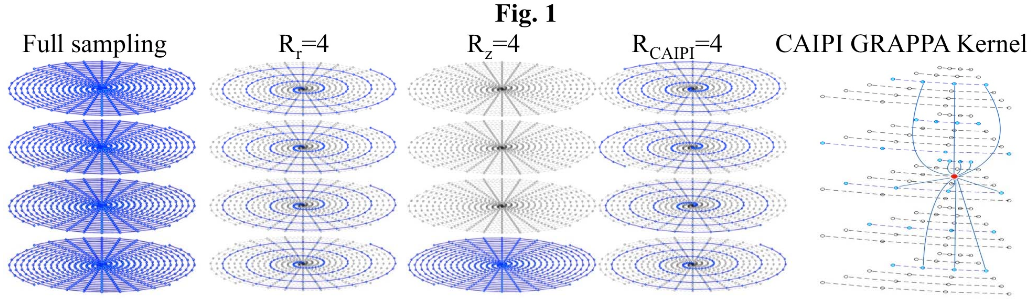
Target Audience: MRI physicists and engineers.

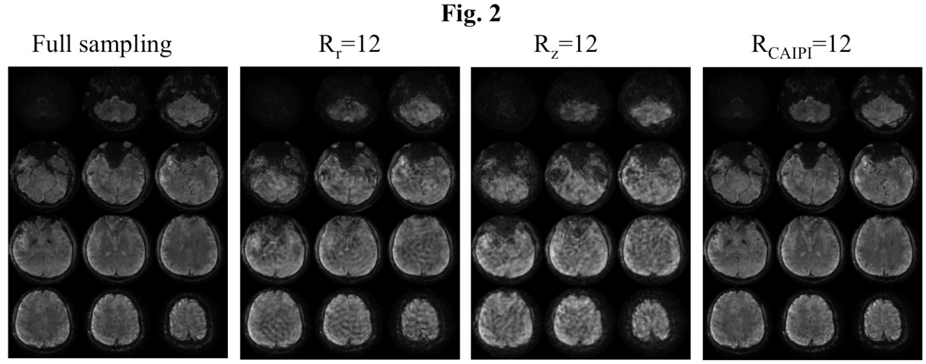
Purpose: The stack-of-spirals trajectory has been shown to be a very time efficient method to traverse a volumetric k-space for high-resolution imaging (1). Rapid volumetric imaging is useful for high-resolution fMRI at high magnetic fields (2). The long scan times needed for high resolutions however can compromise the temporal resolution of the BOLD signal. Recent advances using controlled aliasing in volumetric parallel imaging (2D CAIPIRINHA) have been shown to produce high accelerations with improved g-factors (3). This abstract presents an undersampled stack-of-spirals trajectory with rotated gradients to produce a 2D CAIPIRINHA like spiral sampling for rapid high-resolution volume imaging for fMRI and other applications. A 3D GRAPPA (4) method to reconstruct the undersampled stack-of-spirals data is also presented for fast reconstruction. We found that .75x.75x2mm^3 resolution whole brain volumes could be acquired in 2 seconds with a 30ms TE with a reconstruction time of approximately two minutes.

Fig. 1



Methods: Figure 1 shows four stack-of-spirals sampling strategies for four interleaves and four phase encoding steps. Normally acceleration can be obtained be skipping interleaves or phase encoding steps. For example the second and third diagrams in Fig. 1 show trajectories with an in-plane reduction factor of four (R_r=4) and a through-plane reduction factor of four (R_z=4). By rotating the spiral gradients 90° for the R_r=4 trajectory a CAIPIRINHA like sampling can be created as shown by the trajectory R_{CAIPI}=4. This sampling scheme takes better advantage of modern 3D volumetric receiver arrays allowing for higher accelerations. These three stack-of-spirals undersampling methods with factor-12 acceleration were compared using *in vivo* brain scans on a Siemens 3T Tim Trio MRI scanner using a 32-channel head coil. The imaging sequence was a gradient echo stack-of-spirals sequence (TE/TR=30/31.2ms, FOV=192mm, 64 slices with 2mm thickness). Twelve spiral-in interleaves were used to achieve a 0.75×0.75mm^2 in-plane resolution. The images were reconstructed using a 3D GRAPPA method for a stack-of-spirals. Starting with a previously proposed approach (4), the spiral data were first interpolated onto a projection grid. The estimation of the GRAPPA coefficients and the missing data were carried out on this projection grid. Figure 1 (right) shows a segment of the entire projection grid. The red dot is a missing data point, which is estimated using six points in the same spiral plane and six points with the same spiral radius along the through-plane direction. The projection grid was separated into 64 segments for the GRAPPA operations. The final *in vivo* images were reconstructed from the estimated full data using gridding. The reconstruction code was written in MATLAB and run on a 2.66 GHz Apple iMac.

Fig. 2



Results: Figure 2 (left) shows brain images reconstructed from the fully sampled stack-of-spirals trajectory using a gridding reconstruction. The second and third figures show images reconstructed from the data undersampled by a factor R_r=12 and R_z=12, respectively. Aliasing artifact is very noticeable in these images. The fourth figure shows the images reconstructed from the data acquired using the CAIPIRIHNA stack-of-spirals (R_{CAIPI}=12). Visual inspection shows that these images have comparable quality to the fully sampled images. The estimation of the GRAPPA coefficients and reconstruction of undersampled data took about 35 and 2 minutes, respectively.

Discussion & Conclusion: The use of 2D CAIPIRINHA like sampling for stack-of-spirals volumetric imaging shows significantly improved image quality compared to conventional undersampling methods. Incrementally rotating the spiral trajectory leads to rotated aliasing between spirals, and the in-plane receiver sensitivities can be used to increase the encoding power along the through-plane direction. Even with a reduction factor of 12, the images reconstructed from the undersampled data are almost alias free. We also show that the undersampled stack-of-spirals data can be reconstructed using a 3D GRAPPA approach. The reconstruction times using other iterative methods for non-Cartesian images acquired at sub-millimeter resolution can be prohibitively long, especially for fMRI experiments. Although the estimation of the kernel coefficients took about 35 minutes, the reconstruction for each volume only took approximately two minutes. In addition, the performance of the MATLAB reconstruction can be further optimized or even replaced with a more efficient C program using parallel programming.

References: (1) Breuer et al., MRM 2006, 55:549. (2) Hu et al, MRM 2007. 58:947. (3) Griswold, MRM 2002, 47:1202. (4) Heidemann et al, MRM 2006, 56:317.

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