## Single Phase 3D contrast-enhanced Intracranial Magnetic Resonance Angiography With Undersampled SWIRLS Trajectory at 3T

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### Introduction

The 3D non-Cartesian centrically ordered spherical shells trajectory [1, 2] has been demonstrated to be a well-suited acquisition technique for time-constrained applications such as the single phase contrast-enhanced magnetic resonance angiography (CE-MRA). It can cover the center of k-space with maximal efficiency and is robust to undersampling artifacts. The traditional shells trajectory is composed of concentric spherical shells covered by interleaved helical spirals and additional helical spirals to cover the “polar icecaps”. The polar icecap sampling can be inefficient and can cause phase discontinuities among interleaves. An improved version of shells, the SWIRLS trajectory [3] covers shells from pole-to-pole with a single continuous shot combining radial lines and helical spirals. It provides higher acquisition efficiency and more flexibility for variable sampling density design. This work explores the feasibility of applying the SWIRLS trajectory to CE-MRA at 3T. Off-resonance correction and non-uniform fast Fourier Transform (NUFFT) [4] reconstruction were also used to improve vessel signal and reduce image blurring.

### Method

The SWIRLS trajectory described in [3] was re-designed for a 3T scanner (GE, DVMR 20.1IB, Milwaukee, WI), which is capable of 50 mT/m gradient magnitude and 200 T/m/s slew rate. The nominal FOV was chosen to be 24 $cm^3$ and the isotropic spatial resolution was 0.94 mm. The TR was 7.4 ms, the flip angle was 35°, and the readout length was 4 ms for 512 samples, resulting in a ±62.5 kHz sampling bandwidth. A total of 128 shells were acquired. An 8-channel receive-only head coil was used. The acquisition time was approximately 1 minute. The same undersampling scheme used in [2] was applied.

Under an IRB-approved protocol, written consent was obtained prior to the study. A 2 mL test bolus was used in a timing fluoroscopy to determine the contrast arrival time. A 12 mL bolus of gadobenate dimeglumine contrast agent (Multihance, Bracco Diagnostics, Princeton, NJ) was injected into the right antecubital vein at a rate of 3 mL/s, followed by 25 mL of saline flush using a power injector.

Following the angiogram, a 3D B0 field map was acquired for off-resonance correction (ORC). A 3D GRE pulse sequence acquires two single-echo image sets. The FOV was 24 $cm^3$ and the imaging matrix was 256×128×120. The TR was 7.2 ms, the TE was 2.7 ms and the flip angle was 20°. The sampling bandwidth was ±62.5 kHz and the total acquisition time was 3 minutes and 27 seconds. The difference in TE between the two image sets was 1 ms.

Multichannel field-corrected image reconstruction was performed on a coil-by-coil basis using a NUFFT based gridding procedure (2X oversampled), with density compensation functions formed using a non-negativity constrained least squares estimation strategy similar that described in [5]. ORC was performed using standard time-segmentation [6], a cosine apodization window and L=8 time segments. On a dual six-core 2.66 GHz machine with 24 GB memory, a parallelized (OpenMP) C++ implementation of the reconstruction was able to process an 8-channel 256x256x256 volume in about 4 minutes.

Fig. 1

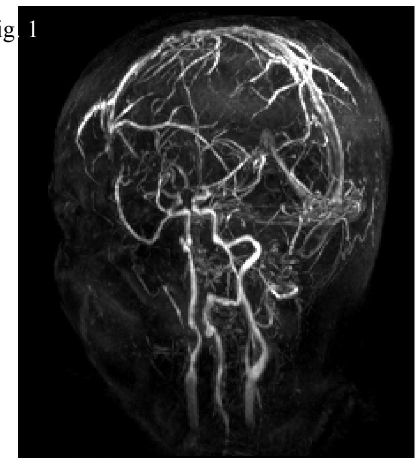
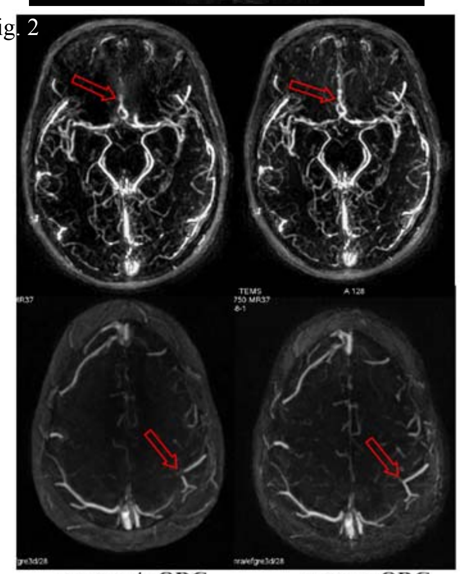


Fig. 2



recon w/o ORC recon w ORC

### Results

Figure 1 shows a rotated MIP reconstructed from the 3D CE-MRA study acquired on a patient covering the head and neck region. Good venous suppression and high spatial resolution can be observed. Figure 2 shows MIPs of the reformatted axial images. The first row shows 20 mm thick axial MIPs including the middle cerebral artery region. The off-resonance correction method was especially beneficial to the vessels in the sinus region. The lower 10 mm thick axial MIPs show some vessels close to the top of the brain, where the vessel signals were more severely impacted by inhomogeneity effects. The ORC shown in Fig 2 does not yet account for the off-resonant frequency of fat, so the correction degrades the image quality in the scalp.

### Discussion and conclusion

A spherical SWIRLS trajectory was successfully applied to 3T CE-MRA applications. NUFFT reconstruction can greatly boost the reconstruction efficiency and yield better image quality due to improved density compensation. Off-resonance correction can improve the appearance of the vessels and strengthen the lumen signal. The present work establishes the feasibility of applying the undersampled SWIRLS trajectory to image the coverage of the arteries in the entire head and upper neck with CE-MRA. Future work will include employment of regularized field map estimation strategies [7] for improved reconstruction performance (e.g., stabilized field correction in regions containing fat signal), and faster B0 mapping using multiple echoes and (or) parallel imaging techniques.

### References

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