Exploring the Limits of Resolution in Contrast Enhanced MRA with Ultrashort Echo Time Imaging

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TARGET AUDIENCE: Scientists and clinicians interested in high resolution neuro-vascular imaging.

PURPOSE: Imaging at high spatial resolution is requisite for imaging the intracranial vasculature; however, achieving high spatial resolution is challenging due to competing factors including SNR, scan time, and artifacts. As the resolution increases the need for flow compensation increases[1] and in the case of contrast enhanced imaging, required scan times often lead to artifacts related to passage of contrast during the acquisition[2]. Unfortunately, the use of flow compensation with traditional Cartesian encoding lowers SNR and increases sensitivity to higher order motion effects and would ultimately lower the achievable spatial resolution of CE-MRA. In this work, we investigate high spatial resolution angiography utilizing accelerated ultra-short echo (UTE) imaging, which has the potential to dramatically increase acquisition efficiency while offering improved flow compensation and robustness to artifacts.

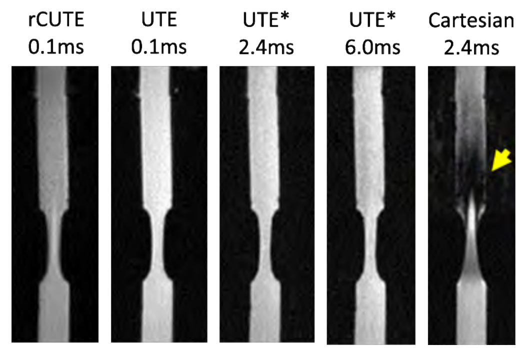

Figure 1. *Stenosis phantom images collected at a peak flow rate of 1 L/min. Arrow demark signal loss in Cartesian encoding to complex flow distal to the stenosis. Notably, this signal loss appears to arise due to gradients as the signal dropout is not seen in delayed echo UTE.*

METHODS: Data are collected with center out sampling utilizing either 3D center out radial or 3D radial-cones (rCUTE[2]) trajectories. Both these trajectories provide ultra-short echo times on the order of 80µs and near 100 duty cycle; however, radial-cones offers substantially higher k-space collection efficiency(~4x). Initial experiments were first performed in flow phantom models to investigate the effects of echo time, higher order motion, and trajectory. Utilizing a stenoses flow phantom (nominal inlet diameter 6.8mm, nominal 85% narrowing) connected to a computer controlled flow pump (Compuflow MR1000, Shelley Medical, London, ON, CA), pulsatile flow was simulated with peak flow rates of 0, 0.5, and 1 L/min. Under flowing conditions, images were collected with 3D UTE, 3D rCUTE, and Cartesian sampling with 75% fractional echo and flow compensation in the readout dimension. Furthermore, 3D UTE images were delayed to mimic Cartesian echo times (2.4ms) and a late echo time (6ms). For phantom scans, all data were collected with and identical scan time (3:24) with nominal spatial resolution of 0.57mm isotropic. Images were visually evaluated for signal loss and flow artifact, and percent stenosis was determined at the maximal narrowing. As part of an ongoing, HIPPA compliant IRB approved study, healthy human subjects were recruited to assess the feasibility of two contrast enhanced UTE protocols compared to 3D TOF. Subjects were scanned with 1) Fast CE-UTE(rCUTE sampling, flip=18°, ±125kHz,scan time=2:45, TE/TR=0.1/4.8ms, FOV=22x22x18cm^3, Voxel size=0.69mm isotropic=0.32mm^3) 2) High Res CE-UTE (3D radial sampling, flip=10°,±62.5kHz,scan time=2:45, TE/TR=0.1/4.1ms,FOV=22x22x18cm^3, Voxel size=0.57mm isotropic=0.19mm^3), 3) 3D TOF(flip=20°,±41.67kHz,2x ARC, 3-slab - FOV=22x18.7x9.5cm^3, TE/TR=2.5/25ms, Voxel size=0.4x0.7x1mm^3=0.28, scan time=7:47). During CE-UTE sampling, a single dose of Gadobenate Dimeglumine (0.1mm/kg, 500mM) was administered at an injection rate 0.5ml/s followed by at least 30ml saline flush. CE-UTE imaging began 30s after the start of the injection.

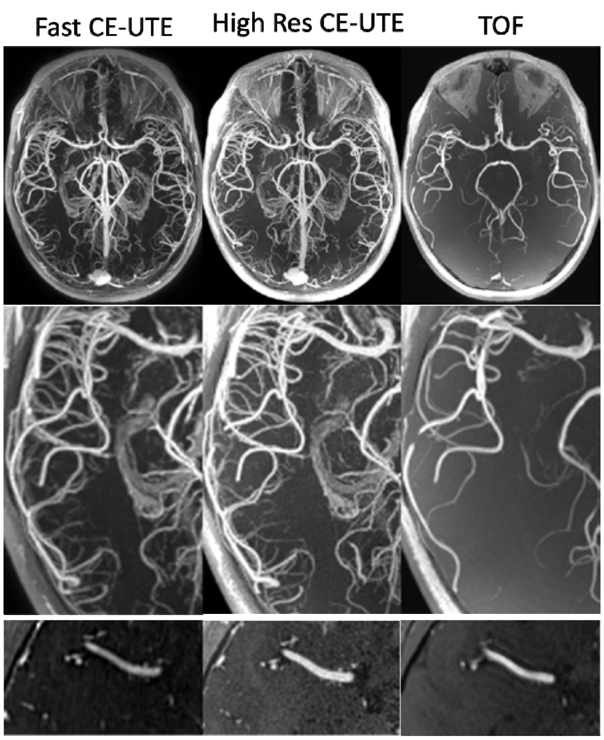

Figure 2. *Representative mip and source images collected with Fast CE-UTE, High CE-UTE, and 3D TOF. Despite the high resolution 3D TOF protocol, CE-UTE images are sharper and depict more small vessels at the cost of venous overlay.*

RESULTS: Fig 1 shows images from phantom studies collected at the highest flow rate investigated. rCUTE demonstrates modestly increased sensitivity to flow. Echo time had no substantial effect on flow sensitivity. Substantial and readily observable effects appeared to arise from Cartesian encoding suggesting higher order flow as the source of artifacts. Fig 2 shows representative comparison of Fast UTE, High Res UTE, and TOF images. CE-UTE images contain venous contamination; however, the high SNR and spatial resolution allows separation even in challenging areas such as the Carotid siphon. Fast UTE images show slightly higher contrast as the cost of lower spatial resolution. Artifacts and resolution loss were not observed in any of the UTE images, suggesting insensitivity to bolus arrival

DISCUSSION AND CONCLUSION: High resolution angiography with CE-UTE appears to a promising image scheme for high resolution angiography of the head. Single-pass CE-UTE is more similar to computed tomography angiography (CTA), which has seen widespread success in recent years. Both are highly robust to flow and artifacts but also have potential venous overlay. CE-UTE offers potential for higher spatial resolution and reduce contamination from calcified structures. A direct comparison is warranted. Importantly and similar to CTA, UTE MRA exams can be acquired in substantially less time than 3D TOF which substantially reduces sensitivity to motion a major confounding factor to high resolution.

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REFERENCES: **1.** Parker et al. 03' JMRI 18(1). **2.** Fain et al. 99' MRM 42:1106. **3.** Johnson ISMRM 12' #285