Radial-Cones: A New Sampling Scheme for Compressed Sensing Accelerated 3D Ultrashort Echo Time Imaging

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INTRODUCTION: 3D Ultra Short Echo Time (UTE) imaging holds the potential both to visualize rapidly decaying species that would not otherwise be visible[1] and to dramatically improve sampling efficiency. Unfortunately achieving both in a single scan is quite challenging. Short T2 imaging is generally performed with 3D radial sampling schemes due to robustness to signal decay. While partially compensated by compatiblity with compressed sensing (CS), they are 4 times less efficient than Cartesian acquisitions. As corollary, 3D UTE with twisting trajectories, such as Cones[2] and FLORET[3], are highly efficient with long readouts but suffer from structured artifacts in the presence of off-resonance, data inconsistencies, or undersampling. In this work, we embrace compressed sensing sampling theory to develop a hybrid 3D UTE trajectory, Radial Cones that combines the efficiency of 3D cones with the robustness of 3D radial sampling.

SAMPLING: Radial cones is graphically described in Figure 1. First a cone-like trajectory is designed to maximize k-space coverage of k-space per shot. The design of the cone starts with an SNR optimized radial gradient. Designed with an arc length based optimization[4], this gradient samples the oversampled center of k-space faster to counteract solid angle effects. Tangential gradients are subsequently designed to utilize excess slew and gradient. To maintain radial-like properties the cone radius is restricted to a fraction of the k-max (i.e. 1/8 k_{max}). Each shot samples one cone, and only differs by the cone axis (*r*) and angle about that axis (θ). Cone axes are distributed isotropically similar to 3D radials. Cone angles (θ) are set first by a random rotation about the cone axis and are then refined by iterative minimization of the potential energy between the individual shots to minimize large gaps. The end result is a trajectory which progresses from radial at the center of k-space to pseudo-random sampling at the edge of k-space.

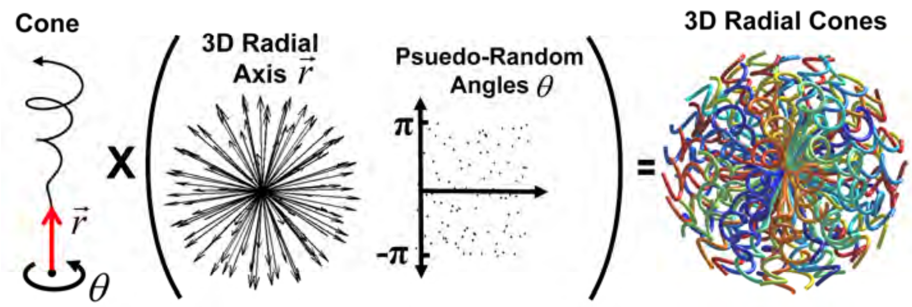

Figure 1. *Graphical description of radial cones. A cone gradient is oriented isotropically with psuedo-random cone angles for each shot. This results in nearly isotropic set of cones with a highly diffuse undersampling pattern.*

METHODS: All experiments utilized or assumed the performance of a 3T clinical scanner (MR750, GE Healthcare, Waukesha, WI). Highly undersampled 3D UTE radial and radial cones trajectories were designed utilizing 2,500 shots with a short 1.2ms readout, TE=80μs, and 1.0mm isotropic resolution. For cranial imaging, this corresponds to a ~60x acceleration for radial sampling. For each trajectory, we performed (1) point spread function (PSF) analysis, (2) realistic simulations with data from the BrainWeb database, (3) single-channel in-vivo imaging of a QA phantom, and (4) initial in-vivo cranial imaging with a 32-channel head coil. Reconstruction errors and overall image quality was asses for images reconstructed with gridding and CS-SENSE utilizing an L1 total variation penalty.

RESULTS: Simulated, phantom, and in-vivo data are shown in Figure 2. The peak (14.3% vs. 4.5%) and average (4.3% vs. 2.3%) aliasing intensity are substantially reduced with radial cones sampling. In phantoms and in-vivo images, radial cones demonstrate lower intensity and reduced structure to artifacts. When reconstructed with compressed sensing (CS) both trajectories show improved image quality; however, radial images are of low resolution due to irrecoverable large gaps at the edge of k-space. Reconstruction accuracy in digital phantoms was substantial higher in radial cones, RMSE = 1.3% versus 3.2%.

DISCUSSION AND CONCLUSION: The proposed radial cones sequence allows the acquisition of short readout 3D UTE images with high data collection efficiency and improved performance with CS. Initial comparisons to 3D radial sampling show improved performance. As the radial cones uses a single trajectory, it is both easily to implemented and characterize on standard systems.

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REFERENCES: [1] Bergin *et al.* Radiology,179:777 [2] Irarrazabal *et al.* MRM 33:656 [3] Pipe *et al.* MRM 66:5 [4] Lustig *et al.* IEEE TMI 27:866

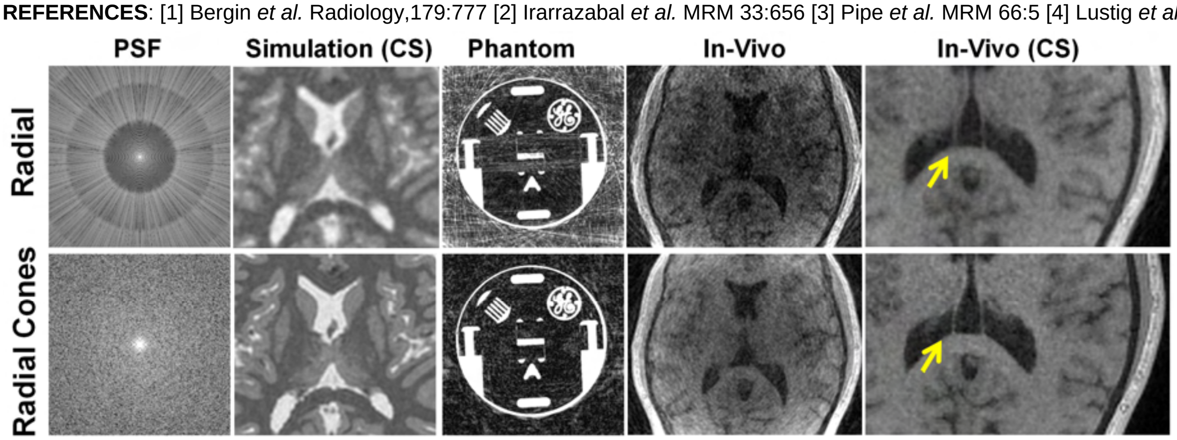

Figure 2. *Images comparing 60x accelerated UTE Radial sequences to UTE Radial Cones. Point spread functions and phantom images show less coherent artifacts for radial cones. Initial in-vivo brain images show less artifact with a standard reconstruction and higher resolution with a compressed sensing (CS).*