Comparison of three radial trajectories for highly time-resolved, short TE imaging.

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Introduction: To reduce the effects of short T2 and off-resonance, short TE imaging with radial trajectory and ramp sampling of the FID is most often used (Fig 1a). However, for dynamic imaging, where good time resolution is also required, FID radial sampling may be slower than other trajectories, because the gradient projection angle θ ranges over $0 \le \theta \le 2\pi$. Alternatively, partial k-space asymmetric echo radial sampling can reduce imaging time because θ needs to cover a smaller angular range of $0 \le \theta \le \pi$ only (Fig 1b). The new partial Fourier Quark (Quadrant Radial K-space) trajectory [1] acquires a quadrant k-space [2,3] using radial trajectories over the smaller range $0 \le \theta \le \pi/2$. For the same angular resolution, this trajectory requires a factor of $0.5+0.41/\sqrt{2}$ fewer projections e.g. 101 versus 128 in an asymmetric echo radial 180° coverage. To increase oversampling towards the k-space origin, the starting coordinates of the k-space lines along a diagonal can be brought towards the origin as a function of θ. For example, Fig 1c shows the trajectory where the function determining the offset from k-space origin is proportional to θ^2. This work seeks to answer two questions using simulations: (1) under conditions of short T2 and off-resonance, which trajectory recovers most signal in the least time? (2) if angular undersampling is used for increased time resolution, which trajectory gives fewest artifacts?

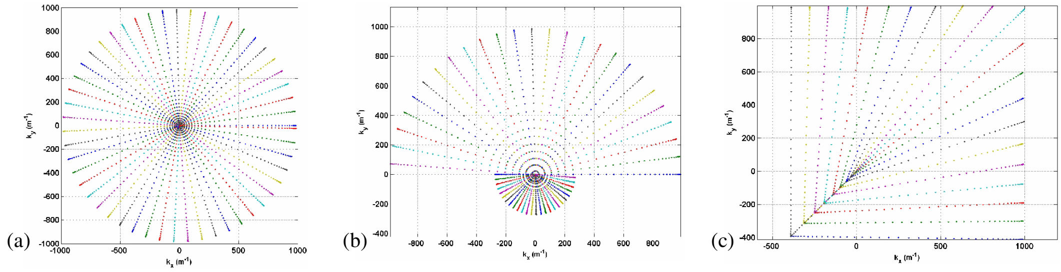

Figure 1. Trajectories for comparison (a) 2π radial (b) asymmetric echo radial, degree of asymmetry = 0.55 (c) Quark, with offset $\propto \theta^2$. Note that the sample points have been decimated for clarity, and are not regularly spaced because only gradient ramps are used.

Method

Signal recovery under short T2 and off-resonance: Data were simulated from a phantom of 3 equally sized disks of radius 1 cm. Disk 1 had T2 = ∞ and off-resonance df = 0, to assess k-space signal coverage in the absence of other effects. Disk 2 had T2 = 1ms, df = 0 to assess signal recovery for short T2. Disk 3 had T2 = ∞ and df = 200Hz to assess off-resonance effects only. For minimum acquisition time, gradients comprised only ramps and were set at a maximum slew rate of 62 T/m/s, with duration adjusted to give kmax = 1 per mm. Data were regridded, and density compensation calculated with the Voronoi method. Partial k-space data were reconstructed after zero filling. Magnetization was assumed to be constant i.e. steady-state or T1 = 0. Number of angular steps were 256 for 2π radial trajectory, 128 for π asymmetric radial (asymmetry factor 0.55), and 101 for Quark.

Angular undersampling artifacts: Data were simulated from a 256×256 phantom (see Fig 2). It had a central uniform disk, with 128 radial spokes extending to the edge to assess angular resolution in all directions. The simulation used 152 angular steps, spread over 2π for radial, π for asymmetric radial, π/2 for Quark. As above, gradients comprised only ramps, to simulate minimum acquisition time.

Results

Signal recovery under short T2 and off-resonance: The integrated signals over the disks are shown in the Table, normalized to that of 2π radial sampled Disk 1. Total sampling times have been normalized to the 2π radial sampling time. As expected the 2π radial trajectory recovers most signal in all cases. However, the Quark trajectory shows better recovery of signal and robustness to off-resonance than asymmetric radial and also has shortest sampling times of all 3 trajectories.

	Disk 1 T2=∞,df=0 normalized integrated signal	Disk 2 T2=1ms,df=0 normalized integrated signal	Disk 3 T2=∞,df=200Hz normalized integrated signal	Total sampling time, normalized to 2π radial sampling time
2π radial	1.00	0.83	0.99	1.00
Asym. radial	0.93	0.50	0.79	0.83
π/2 Quark	0.95	0.55	0.91	0.59

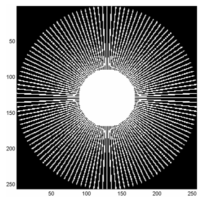

Figure 2: Phantom to evaluate angular undersampling

Angular undersampling artifacts: Fig 3a shows the PSF of the 2π radial trajectory. The radius of the flat region is small because (i) ramp sampling leads to local radial undersampling, and (ii) the spreading out of angular steps over the full 2π results leads to severe angular undersampling. Therefore, streak and folding artifacts appear which obscure the spokes of the phantom, thus reducing angular resolution (Fig 3b). The PSF of the asymmetric radial trajectory, Fig 3c, shows a wider FOV, because of the highly dense radial sampling of negative k-space points and because the angular steps are spread over π. In this case, because the phantom extends beyond the FOV, artifacts broaden the radial spokes and are present in the central uniform disk (Fig 3d). The Quark PSF, Fig 3e, shows a flat region smaller in size to that for asymmetric radial. However, the resulting artifacts appear more diffuse, and consequently, the reconstructed image (Fig 3f) shows a more uniform central region, and the spokes can be more easily resolved than with the other trajectories. Note, however, the uneven signal distribution in the upper right and lower left spatial quadrants due to the π/2 fanbeam k-space sampling.

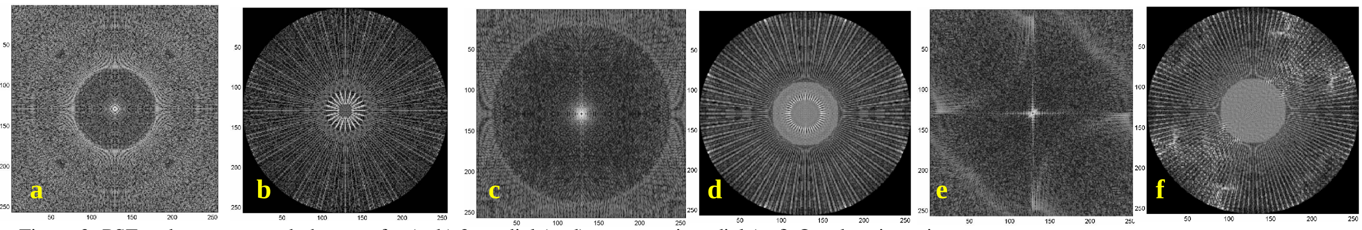

Figure 3: PSF and reconstructed phantom for (a, b) 2π radial (c, d) asymmetric radial (e, f) Quark trajectories.

Discussion: Our results show that 2π radial FID sampling gives the shortest possible TE and recovers signal best in the presence of short T2 and off-resonance. However, time resolution was poorest, and if ramp sampled and angularly undersampled, the FOV was also smallest. Asymmetric radial gives the largest FOV, because of the highly dense sampling of the negative k-space points. However, the time taken to ramp gradients up and down in this part slows down the method, making it time inefficient, less sensitive to short T2 components, and prone to off-resonance signal loss. Quark recovered more signal in less time than asymmetric radial, and although Quark has a slightly smaller FOV than asymmetric radial, the resulting artifacts appear diffuse. We conclude that Quark represents a good compromise for highly time resolved imaging in conditions of moderately short T2 and moderate off-resonance, e.g. Hyperpolarized 3He lung imaging. The fewer angular steps needed for Quark is also advantageous in Hyperpolarized 3He imaging, where fewer RF encoding steps may be required for SNR purposes.

References: [1] Lee KJ and Wild JM. Proc ISMRM #1666 (2007) [2] Xu Y and Haacke EM. JMRI (2001) 14:628. [3] Singh RK et al. JMRI (2004) 19:645