A Fast 3D Trajectory with Orthogonal Oversampling

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INTRODUCTION: This work presents a new set of rapid 3D center-out k-space sampling trajectories. Shapes called "hubs", composed of modified spiral trajectories, are combined to measure k-space in overlapping, orthogonal directions. The method is fast, very evenly weighted (increasing SNR), has the beneficial motion properties of spirals (as well as the blurring constraints), and produces very incoherent aliasing and motion artifact. Because k-space is sampled multiple times in orthogonal directions, undersampling (e.g. for parallel imaging or compressed sensing) results in fewer 'holes' that are less contiguous than for (e.g.) stack of spirals.

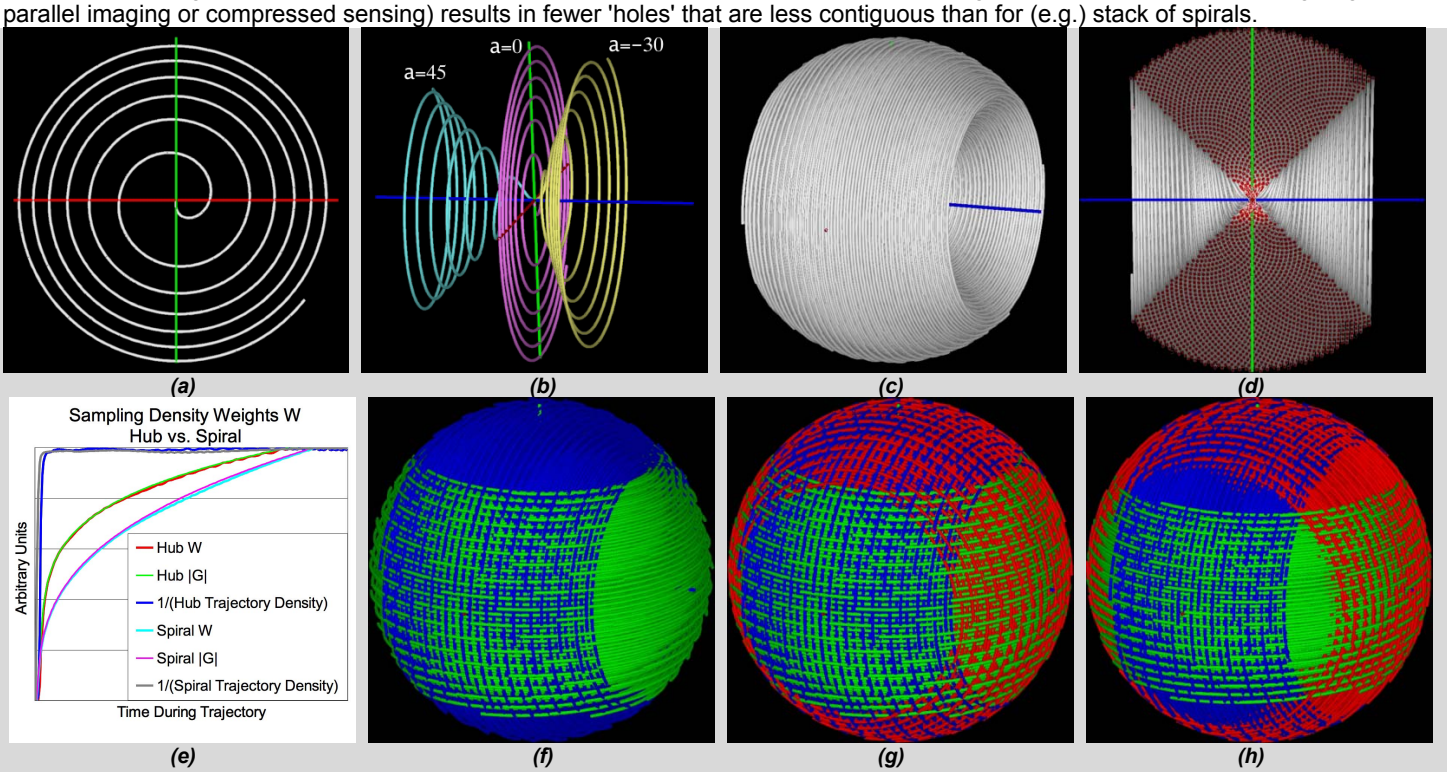

*Fig. 1. The z-axis hub is formed from **(a)** a base 2D {kx, ky} spiral waveform with variable radial density proportional to 1 / |kr|. The trajectory is shaped in 3D to **(b)** follow a 3D cone with angle α about the kz axis, with the base {kx, ky} trajectory scaled by cos(α), and k_z = tan(α) |{kx, ky}|. Multiple trajectories **(c)** are rotated by the golden angle [2] about kz as α varies from - α_0 to + α_0, to complete the z-axis hub. A cross-section **(d)** in the {ky, kz} plane illustrates a hub's uniform sampling pattern between trajectories for α_0=45˚. Sampling weights W, and inverse sampling densities along trajectories (|G|) and between trajectories (W/|G|) are shown **(e)** for 1 trajectory of a single hub and an Archimedean spiral. Full sampling can be achieved via **(f)** 2 orthogonal hubs, α_0 = 45˚, or 3 orthogonal hubs, with **(g)** α_0 = 45˚ or **(h)** α_0 = 36˚.*

METHOD: Figure 1 describes the trajectory. The stronger readout gradients (Fig. 1e) allow multi-hub MRI to equal the speed of a stack of Archimedean spirals, even with overlapping measurements (with the caveat that a sphere rather than a cylinder is sampled). Table 1 shows the required # TR's for complete sampling for 40/150 gradients, FOV/res = 240/1 mm, and ADC=14.2ms. Also shown are the relative SNR's from data weighting [1] and the numerically estimated k-space sampling efficiency for R=4 (used trajectories for FOV = 120mm (1/4 total arms) to grid sampling density weights [1] for FOV=240mm, then integrated over k-space (normalized by R=1 result)).

REFERENCES: [1] Johnson et. al., 2009, MRM 61(2):439-47. [2] Winkelmann et al, 2007, IEEE TMI, 26:68-76.

TABLE 1	Stack of Spirals	2 hub, α_0 = 45˚ (Fig. 1f)	3 hub, α_0 = 45˚ (Fig. 1g)	3 hub, α_0 = 36˚ (Fig. 1h)
# TR's (arms)	10*240 = 2400	2*1143 = 2286	3*1143 = 3429	3*914 = 2742
Relative SNR = sum(w)/[sqrt(N) rms(w)]	0.966	0.917	0.960	0.933
(R=4) / (R=1) sampled volume (estimate)	0.32	0.40	0.53	0.47

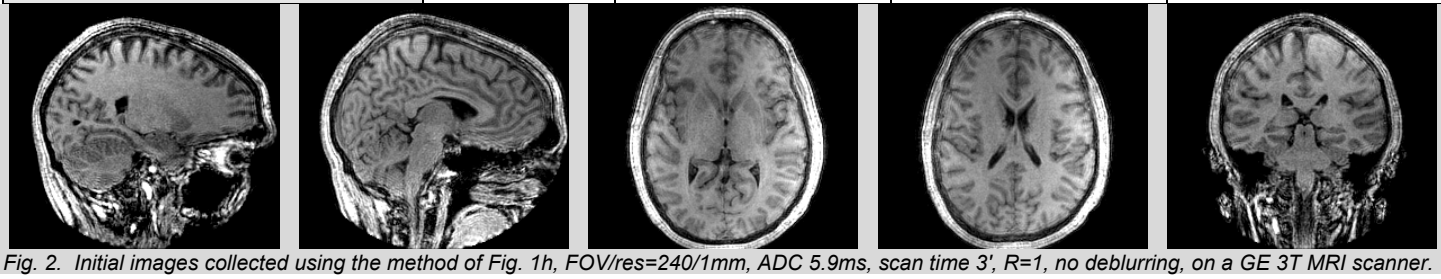

Fig. 2. Initial images collected using the method of Fig. 1h, FOV/res=240/1mm, ADC 5.9ms, scan time 3', R=1, no deblurring, on a GE 3T MRI scanner.