Radial Undersampling that is Variable in k_z

D. C. Peters[1], R. Nezafat[1], and W. J. Manning[1,2]

[1]Cardiology, Beth Israel Deaconess Medical Center, boston, MA, United States, [2]Radiology, Beth Israel Deaconess Medical Center

Introduction: 3D radial imaging, with projections in the x-y plane, and slice-encodings in z (i.e. "stack of stars"), can be accelerated with undersampling, with maintained spatial resolution and acceptable artifacts. To date, undersampling has been applied uniformly in kz (1-4) (Fig. 1B). This investigation compares a uniformly undersampled acquisition to a radial undersampling pattern which varies in kz-dimension , acquiring a greater number of projections for central kz-space (Fig. 1A).

Theory: For undersampled radial, only high spatial frequencies are undersampled. The critical k-space radius in the kx-ky plane at which undersampling starts (the Nyquist limit, here called Nyq(kr)) is given by Eq. 1 for a given FOV and number of projections (Np) (5). We sought to develop a trajectory for which this critical radius is at a constant distance from the k-space origin, in 3D (Eq. 2). This requires that Np vary with kz value, i.e. according to slice-encoding value (Fig. 1A). Figure 1 demonstrates that using a variable number of projections, Nyq_{kr} varies with kz, allowing smaller Nyq_{kr} for larger kz, as in Eq. 2, and shown as red contours in Fig. 1b. In Fig. 1b the kz value (green vertical arrow), and Nyq_{kr} (kz)(green horizontal arrow) determine the distance indicated by the blue arrows, indicating the absolute distance from the k-space origin at which undersampling begins for kz=0, and for non zero kz.

$$Nyq_{kr} = Np\frac{1}{\pi \cdot FOV} \qquad (1)$$

$$[Nyq_{kr}(kz)]^2 + [kz]^2 = [Nyq_{kr}(0)]^2 \qquad (2)$$

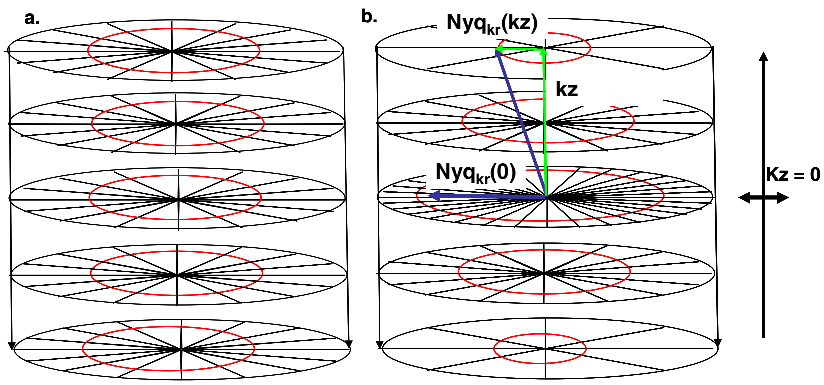

Figure 1: A) Uniform undersampling in kz. B) Variable undersampling in kz, by acquiring more projections for central kz-space, shown by the black sampling pattern. The red contours show the radius beyond which k-space is undersampled, Nyq_{kr}(kz), which is dependent on Np by Eq. 1. The blue arrows indicate the distance from the k-space origin to this critical radius, which depends on kz and Nyq_{kr}(kz), as stated in Eq. 2.

Methods: All imaging was performed on a 1.5 T Philips Intera Achieva. Phantom data was acquired on the scanner using uniform (Np=128) and variable undersampling (128, 64, 32 for central, middle and edge kz-space data) with scan parameters: 3D radial SSFP, 256 Nr x 60 Nz, 1.2 x 1.2 x 2 mm. In healthy subjects, a 3D radial SSFP acquisition covered the whole left ventricle in short-axis. Scan parameters were: 160 Nr, 320 cm FOV, 13 Nz 10 mm slices, TR/TE/θ= 3.1ms/1.5ms/40º, 10 views per heart-beat. Fully sampled images (Np=160), uniformly undersampled images (Np=38), and variably undersampled images were acquired. The variably undersample images were reconstructed offline and kz-space data was weighted according to the undersampling level. The simulations, performed in Matlab, used the fully sampled data set as input, and compared variable undersampling (Np varying from 20 to 48) to a uniform undersampling with idential number of total projections (Np=37).

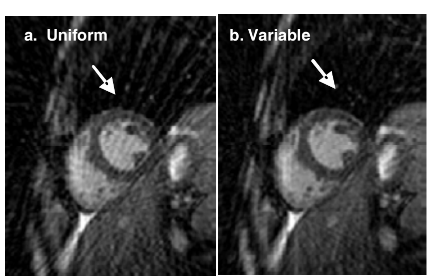

Figure 2: Simulation results for a) uniform (Np=37) and b) variable undersampling with equal total Np. Note the reduced artifacts in b (arrows).

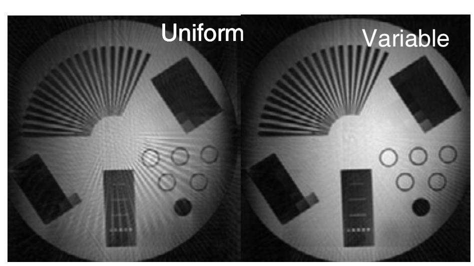

Figure 3: Phantom comparison of uniform and variable undersampling with equal scan time.

Results: Figure 2 shows the results of simulations for a 13 slice 3D cardiac function acquisition. The optimal sampling pattern varied sinusoidally from 20 to 48 to 20 Np dependent on kz value. Fig 2a and 2b compare uniform undersampling and variable undersampling using this pattern. Figure 3 compares images of the phantom acquired in equal scan time, using variable and uniform undersampling, showing reduced artifacts.

Conclusions: This variable undersampling provides reduced artifacts compared to uniform undersampling for some applications. In the future, its application to contrast enhanced MR angiography will be investigated.

References: 1)KK Vigen et al, MRM. 2000 Feb;43(2):170-6. 2) DC Peters et al, MRM. 2000 Jan;43(1):91-101. 3) AC Larson et al. MRM 2002 Oct;48(4):594-601. 4) E. Spuentrup, Radiology. 2004 May;231(2):581-6. 5) DC Peters et al. MRM. 2001 Apr;45(4):562-7.