Ultra High Resolution 3D Gradient Recalled Echo With Reduced FOV Spiral Selective Excitation.

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Introduction: Achieving higher spatio-temporal resolution imaging by restricting the acquisition to the volume of interest remains one the major challenging sequence design for MRI physicists. Radiologists would benefit for cardiac, brain and abdominal applications (anatomy, vascular, function...). For spin-echo based sequence designing excitation and refocusing pulses in two perpendicular axis respond to this need [1]. An alternative for gradient-recalled echo is to use 2DRF excitation [2]. Whether it is a spectral-selective, *sinc* shape RF [3] or spiral-selective excitation 2DRF was only applied for 2D acquisition such DTI [4], fat-water separation [5] and cardiac black-blood MRI [6]. The purpose of this study was to extend the use of 2DRF to true 3D volume imaging acquisition with fast gradient recalled echo to achieve ultra-high spatial resolution images, reducing the acquisition time and maintain high signal intensity.

Material and Method: A conventional 3D gradient recalled echo based sequence (Fast GRE) and fast spoiler gradient recalled acquisition (FSPGR) was modified by incorporating a cylindrical 2D spiral RF. pulse (width = 6 ms, nominal flip angle = 42.77°). We designed spatial cylindrical excitation with inward spiral trajectories using 2 oscillation gradients (Y and Z) with constant slew-rate to cover the 2D RF k-space and ending at its center. The diameter of the excited cylindrical volume (i.e. thickness of the 2D profile) is given by

$$D = \frac{T.\Delta f}{2.K_r}$$

T.Δf = time bandwidth product and K_r = Maximal k-space radius.

The Nyquist theorem applied in radial direction $\Delta k_r = 1/D$ (D is the diameter of the cylindrical FOV) and Δk_r is the distance between 2 k-space points in the radial direction (Figure 1), thus aliasing occurs when the spatial radius of the cylinder $r > 1/\Delta k_r$. The calculated peak B_1 = 0.003238 G, the maximum integral B_1^2 = 0.0002926 G^2 and the energy deposited = 0.007955 J at 12° flip angle.

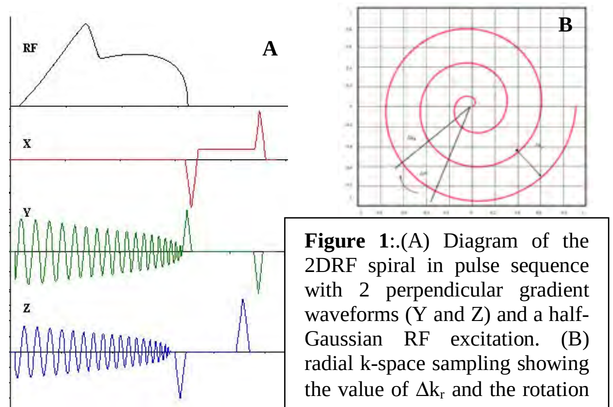


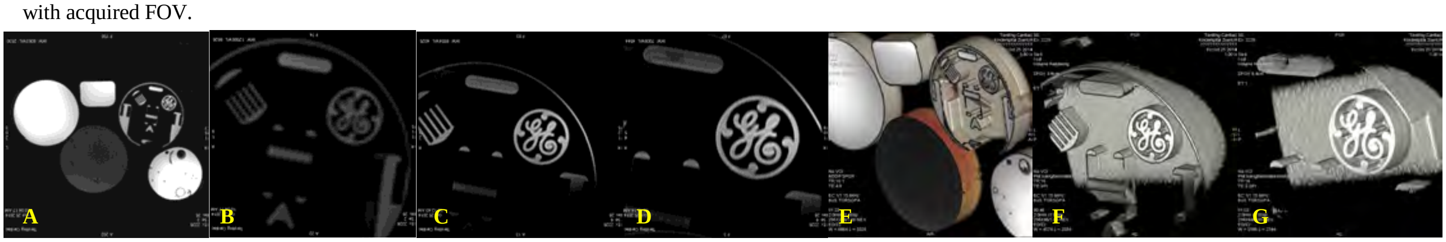
Figure 1:.(A) Diagram of the 2DRF spiral in pulse sequence with 2 perpendicular gradient waveforms (Y and Z) and a half-Gaussian RF excitation. (B) radial k-space sampling showing the value of Δk_r and the rotation angular variable θ.

Results: The sequence was implemented on GE scanners (1.5T and 3T) with maximum gradient amplitude of 40 mT/m per axis and a slew rate of 200 mT/m/ms. We tested the sequence on 8 channel torso-array coil and 8 channel head coils using the following imaging parameters: flip angle = 12°, BW=15.6 kHz, minimum TR and minimum TE, Xres = 256. For conventional sequence Yres = 256 and FOV = 256 x 256 mm^2 (64 slices acquired in 3'00") whilst the reduced FOV FGRE (or FSPGR) was performed with either FOV=96 x 96 mm^2 and Yres=96 (64 slices acquired in 1'36") and FOV=64x64, Yres=64 (64 slices acquired in 1'06"). The SNR was comparable to that of conventional RF excitation (Table 1) The slice thickness was set for 2 mm and zipped by 2 to achieve a 1 mm reconstructed thick slice.

Water Phantom	FSPGR	FGRE	Reduced FOV FSPGR	Reduced FOV FGRE
SNR	848	737	866	695

Table 1: SNR of images acquired with 8 channel head coil on 3T scanner with the following parameters: 64 slices, 2mm slice thickness, zipped x2, 1 Nex, FOV=360mmx360mm, matrix=256x256, flip angle = 12°, BW=15.6 kHz.

Figure 2: An example of images acquired in a 3T scanner with 8 channel Torso coil. (A) FSPGR 3D with FOV=360x360 mm and matrix 256x256 showing different phantoms and different shapes (2mm slice thickness zipped by 2, minTE, minTR, BW=15.6 kHz, 12° flip angle). On (B) the result of a zooming-in to display (A) in a 96 mm FOV. (C) represents a typical image of a slab acquired with our modified sequence with reduced FOV using same imaging parameters except FOV=96mm and Yres = 96. Reduced FOV sequence was also tested with 64 mm, Yres=64 and 2 Nex and displayed with acquired FOV (D). (E) is the result of volume rendering of (A) displayed at acquired FOV. (F and G) are respectively the resulting volume rendering of respectively (C) and (D) displayed with acquired FOV.



Conclusion: Reduced FOV acquisitions with 2DRF spiral excitation incorporated to 3D fast gradient echo sequence provides ultra high spatial resolution images with high signal, shorter minimum TE and TR and immune to flow artifact and no blurring. It performs also with inversion-recovery preparation pulse, multiple Nex, partial phases FOV, spatial-saturation bands and cardiac triggering. Potential clinical applications of these advantages include imaging of the vascular system (cardiac, neuro and cerebral) and the anatomy (heart, brain and extremities) where 3D volume rendering and reformat are routinely used. Future development involves modification of the sequence to incorporate time-of-flight and steady-state free precession technique.

References: [1] Feinberg et al., *Radiology* (1985); [2] Pauly et al., *JMR* (1987); [3] Alley et al. *MRM* (1997); [4] Finterbusch, *ISMRM 17*, 165; [5] Yuan et al., *ISMRM 17*, 2776; [6] Abd-Elmoniem et al., *MRM* (2012).