Single-shot 3D GRASE with Cylindrical k-space using Circular and Fly-back k-space trajectories

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Objective:
Single-shot 3D GRASE has reached the point of producing sub-second whole brain coverage after continuous optimization of its spatial resolution and minimization of artifacts. The spatial encoding needs to be optimized within the time constraint of the RF pulse spacing of a CPMG sequence. Circular k-space trajectories have an advantage of isotropic resolution by excluding the corners of k-space and, in theory, require 21% less time for signal sampling [1]. The image resolution is determined by the radial distance from the k-space center as in spiral trajectories. Circular EPI for cardiac imaging [2] has been demonstrated as has the "fly-back" EPI k-space trajectory [3] which obviates echo time reversals in k-space to completely eliminate Nyquist ghosts. In the present work, cylindrical 3D k-space imaging is investigated by incorporating and combining the "fly-back" and circular 2D trajectories into single-shot 3D GRASE.

Materials and Methods:
Experiments were performed on 1.5T (Siemens, Sonata), 40mT/m maximum gradients. The imaging parameters were 63x64x24 data matrix, centric ordering, partial-Fourier 5/8ths on partition-axis, 15 RF refocusings, 24 images/3D volume, $TE_{effective}$: [circular./39.4ms, circular fly-back/63.1ms].
To minimize echo spacing, the "fly-back" (fb) refocusing gradient pulse utilized maximum gradient amplitudes: fb waveform area (Gmax x Tfb) = area of the (Gr x Tr) where Gr and Tr are readout gradient amplitude and duration and the time of fb refocusing Tfb = Tr x (Gr/Gmax) without accounting for slew rate variation.

Fig. 1 shows the 3D GRASE pulse sequence and circular trajectory in the first RF interval (left) and circular fly-back read gradients in the second RF interval (right). Comparison was made to conventional rectilinear EPI trajectory. To further investigate non-linear off-resonance phase errors in the circular trajectory, a comparison of the 2D PSF in fly-back square and fly-back circular k-space trajectories, we evaluated using .1 radian phase error across kp axis, Fig 2.

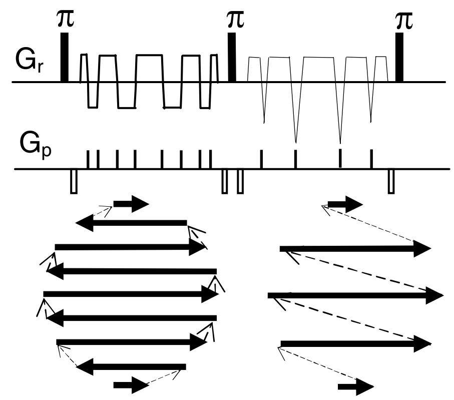

Fig. 1 (left) circular, (right) circular fly-back.

Results
Comparisons were made between circular k-space trajectories and conventional rectilinear EPI. The three different sequence trajectories had the following different RF 180°-180° spacing in the CPMG sequence as dictated by the different EPI trajectories all using identical 2005 hz/pixel bandwidth and 63 echoes between consecutive RF pulses: rectilinear/ 48.7 ms, circular/ 39.4 ms, circular fly-back/ 63.1 ms. The resulting differences in susceptibility signal loss between the circular and circular fly-back trajectories can be seen in the temporal lobes of the brain, Fig. 3. There is considerably greater ghost in the circular trajectory (mean/SD = 30.7/23.6) compared to fly-back circular (m/SD = 6.0/5.7) which is due to the absence of phase corrections. There were no ghosts present in the PSF, only a small asymmetry in the primary side-lobe of the PSF which was below observable levels in images. The fly-back circular image has complete absence of ghost except for a chemical shift artifact due to incomplete fat suppression and much fat at skull base. Fig 4 shows representative circular fly-back single-shot 3D images of the brain which had uniformly high image quality with no observable ghost artifacts.

Fig. 2 PSF of (right) rectangular, (left) circular k-space 3D GRASE

Discussions and Conclusion: Compared to conventional rectilinear EPI trajectory, the circular trajectory reduced the echo train length and RF pulse spacing by 19% for reduce susceptibility artifact. The "fly-back" circular trajectory increased these times by 29% while eliminating ghost artifacts. Phase correction in the circular trajectory will markedly reduce ghost intensity but its implementation is complicated by the variable readout times such that two signals of opposite Gr polarity cannot be used. Phase correction is currently being developed. In conclusion, the combined circular and fly-back trajectories produce high quality 3D GRASE images however the circular trajectory alone should be more optimal once phase corrections are used.

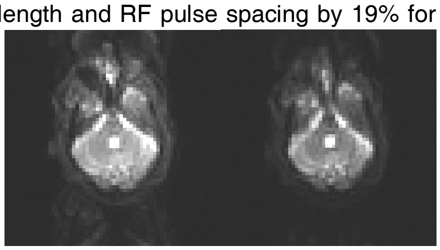

Fig. 3 (L) circular (R) circular fly-back.

References [1]. Bernstein MA, et al., *J.M.R.I*, **14**, 270-280, 2001
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[3]. Feinberg DA, *Mag.Res.Med*. **13**:162-169, 1990

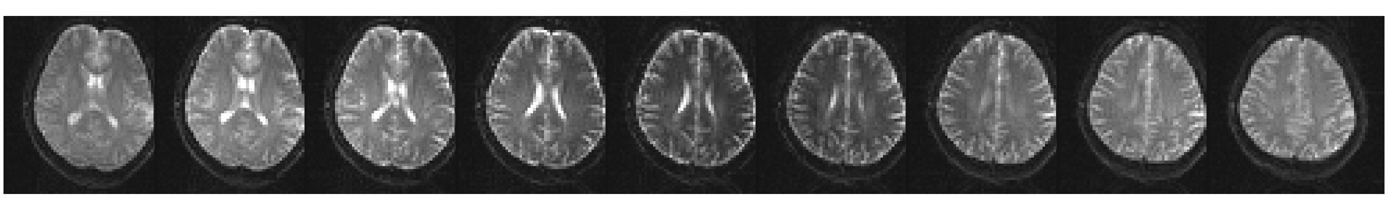

Fig. 4 Cylindrical 3D GRASE with circular fly-back trajectory.