MRI Using a Concentric Rings Trajectory with Built-in Off-resonance Correction

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Introduction: In this work, we design a sequence that collects k-space data with a set of uniformly spaced concentric rings [1]. This readout trajectory offers flexible trade-off between image resolution and scan time, being well suited for dynamic MRI. Also, since we acquire rings on a polar grid, this sequence offers a flexible design framework for variable density k-space coverage. As with non-Cartesian trajectories, off-resonance effects often manifest as blurring in the reconstructed image. To deal with this issue, we use a retracing method when acquiring rings near the center of k-space to obtain a field map with no extra scan time. This field map can be used in multi-frequency reconstruction to correct for the blur.

Trajectory and Gradient Design: A set of N uniformly spaced concentric rings is used to cover k-space (Fig.1a). Ring n has radius $n \cdot k_{r,Max}/(N-1)$, where $n=0\sim N-1$. A time-optimal gradient [2] is designed for the outermost ring which has radius $k_{r,Max}=(N-1)/FOV$. As in Fig.1b, an initial dephaser lobe is first used to reach the desired radial extent in k-space. Sinusoidal gradients are then played out to traverse the readout ring. This outermost readout ring is sampled to satisfy the Nyquist criterion, with sample spacing of $1/FOV$. We scale down this set of gradients by a factor of $n/(N-1)$ for $n=0\sim N-1$ to acquire all rings, one ring per TR. TR is fixed for the full pulse sequence, and thus we have the same readout window for each ring. To be SNR efficient, we sample each ring for the entire readout window, which produces sampling density similar to projection reconstruction. A modification to this design can be very useful for off-resonance correction. For the inner rings, $n=0\sim(N/2)-1$ (Fig.1c), we acquire a full set of samples by tracing the rings twice during the readout window to acquire Set_1 and Set_2, respectively (Fig.1d). Together, Set_1 and Set_2 form the full set of samples for each inner ring. Since the inner rings are oversampled, each set can be used by itself to reconstruct a low-resolution full-FOV image, with a time difference of ΔTE between them (Fig.1d). Consequently, a field map can be calculated from these two images and used for off-resonance correction. After correcting for off-resonance, magnitude images reconstructed from both Set_1 and Set_2 are averaged to obtain a final image.

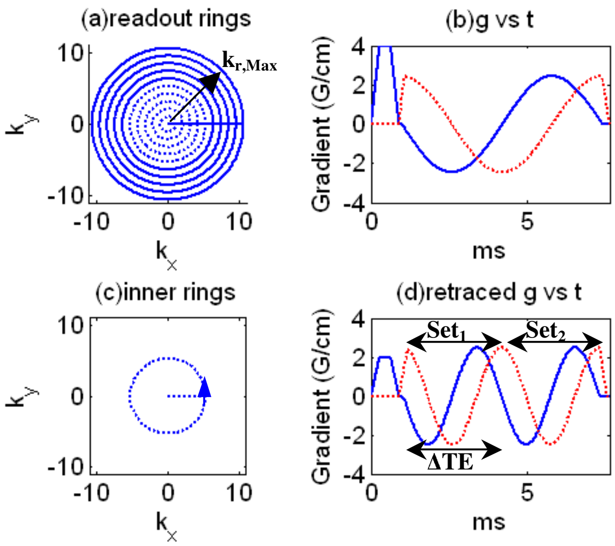

Fig.1 Gradient design: (a) set of readout rings, dotted lines are the inner rings (b) gradient design for outermost ring, solid blue line is G_x, dotted red line is G_y (c) inner rings traced twice (d) gradient design for inner rings, solid blue line is G_x, dotted red line is G_y

Image Reconstruction: Generally, gridding reconstruction can reconstruct data from non-Cartesian k-space trajectories. In this case, since the sampling pattern is essentially a polar grid, we can also format the data appropriately and employ filtered-back projection. Off-resonance blurring can be corrected by first computing a field map from the retraced inner rings, and then employing multi-frequency reconstruction [3].

Experimental Results: Experiments were conducted on a GE Signa 1.5T system, with G_{max} of 40 mT/m and $Slew_{max}$ of 150 mT/m/ms. The readout filter bandwidth was +/-125kHz and readout time was 6.4 ms for all rings. Full images were reconstructed with gridding.

(a) **(b)** **(c)**

Fig.2 (a) Phantom before off-resonance correction (b) Phantom field map (c) Phantom after off-resonance correction

<u>*Phantom*</u> 256 readout rings were acquired over a 24 cm FOV, yielding an isotropic in-plane resolution of 0.47 mm. In the uncorrected image (Fig.2a), blurring is evident at the water/air boundary (white arrow). After correcting for off-resonance, the blur is greatly refocused (Fig.2c).

<u>*In Vivo*</u> We acquired an axial brain image of a normal volunteer (Fig.3). 128 readout rings were acquired over a 24 cm FOV, yielding an isotropic in-plane resolution of 0.93 mm. Imaging parameters were: 5 mm slice, 4.8 ms TE, 30 ms TR, and 30º flip angle. TE is defined as the time between RF excitation and the first readout sample.

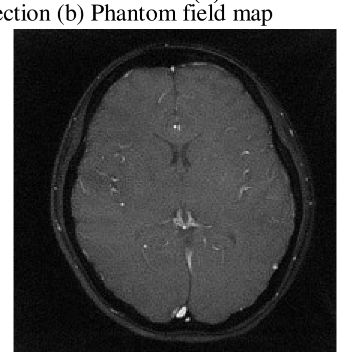

Fig.3 Axial brain image

Conclusion: We designed and implemented a concentric rings pulse sequence which has the built-in ability to correct for off-resonance effects. Experimental results show that high quality images are obtainable. The circular geometry of the concentric rings matches well with the energy distribution in k-space. Since the low-frequencies contain more energy, we acquire signal energy rapidly by starting from the center of k-space and expanding outward. This sequence also offers flexible trade-off between image resolution and scan time. As we acquire rings *0* to *N-1*, in-plane image resolution increases in an isotopic fashion with scan time. These properties are well suited for dynamic MRI, where we would update the low-frequency rings constantly and the high-frequency rings less often. This trajectory is also well suited for contrast preparation methods, and can be used in multi-spin-echo sequences. A set of uniformly spaced rings is considered in this work, but we can readily design variable-density k-space coverage by varying the radii of the rings. Variable-density sampling allows us more possibilities in striking a balance between SNR, image resolution, and scan time [4].

References:
1. X. Zhou, et al., MRM 39(1): 23-27, 1998
2. G.H. Glover, MRM 42(2): 412-415, 1999
3. K.S. Nayak and D.G. Nishimura, MRM 43(1): 151-154, 2000
4. CM Tsai and D.G. Nishimura, MRM 43(3): 452-458, 2000