Spatial and Spectral Encoding Using the Concentric Rings Trajectory

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Introduction: The concentric rings *k*-space trajectory can be used in spin-echo, fast spin-echo, gradient-echo (GRE), or SSFP sequences along with magnetization-preparation modules for a wide variety of imaging applications [1-5]. This non-Cartesian trajectory provides a scan time advantage over conventional rectilinear encoding methods while retaining a high degree of robustness to system imperfections such as timing errors and gradient delays. Furthermore, its unique circularly symmetric sampling nature [1-3] enables a time-efficient retracing acquisition [3-5] to simultaneously encode spatial and spectral information for MR spectroscopic imaging (MRSI). Direct spectroscopic reconstruction based on the retracing design allows the rings to resolve off-resonance effects and avoid potential blurring [5]. In this work, we investigate the trade-offs between spatial and spectral encoding for the concentric rings and present experimental results for fat/water imaging and general MRSI.

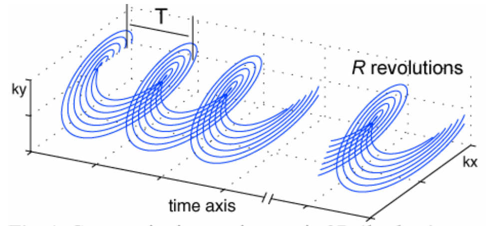

Fig. 1. Concentric rings trajectory in 3D (*kx, ky, t*)-space.

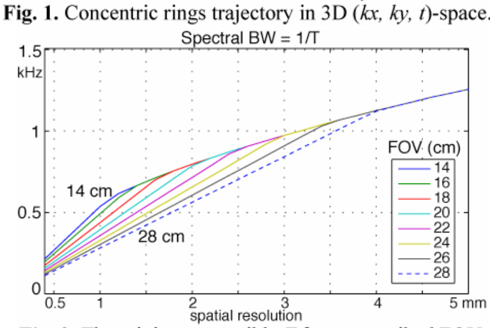

Fig. 2. The minimum possible T for a prescribed FOV and spatial resolution determines the max spectral BW.

Methods: *Rings:* N uniformly spaced concentric rings are used to sample (k_x, k_y) [1-3]. One set of gradients is designed for the outermost ring and then scaled down to acquire each ring. This design ensures that timing errors and gradient delays manifest only as a bulk rotation of the image in (x, y). By retracing each ring through R revolutions after signal excitation [3], it is possible to sample the signal evolution along t and simultaneously encode spatial and spectral information (Fig. 1). Spectral resolution is determined by R and the rings can be extended to encode (k_x, k_y, k_z, t)-space by implementing slice encoding. *Trade-offs:* For a given FOV and spatial resolution, the gradient and slew rate limits on the scanner constrain the minimum retracing period T (Fig. 1), which determines the spectral bandwidth $SBW = 1/T$ (Fig. 2). SBW can be increased M times by combining M scans where the starting angle of the rings in (k_x, k_y) are rotated by $2\pi m/M$ for $m = 0 \ldots M-1$. *Multiple Bands:* We can use different gradient designs for different "bands" in *k*-space to take advantage of the gradient power and minimize T (maximize SBW) for each band. Fig. 3 shows a 2-band design where the outer $N/2$ rings are sampled over $R = 1$ while the central $N/2$ rings are sampled over $R = 3$. Readout duration can be kept constant across all bands by stretching the gradients that are of shorter duration. *Reconstruction:* When slice encoding is implemented, an initial Fourier transform is performed along k_z to obtain a dataset in (k_x, k_y, z, t)-space. The retraced dataset for each z-slice is gridded in 3D (k_x, k_y, t)-space and then Fourier-transformed along all three dimensions to obtain a dataset in (x, y, f).

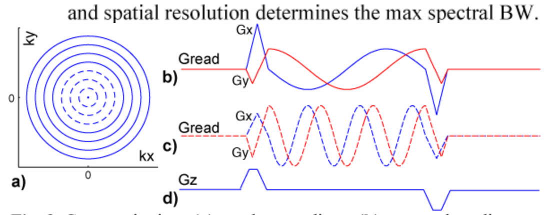

Fig. 3. Concentric rings (**a**), readout gradients (**b**), retraced gradients for the central rings (**c**), and the slice encoding waveforms (**d**).

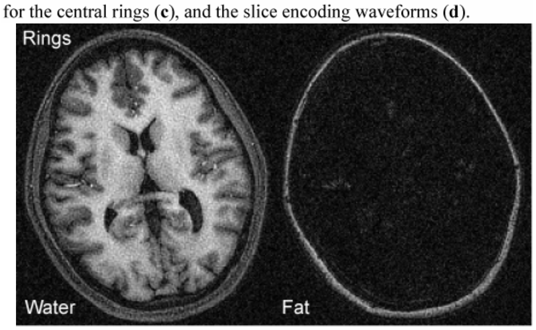

Fig. 4. Water/Fat images of the same axial brain slice obtained by 3D stack-of-rings with a direct spectroscopic reconstruction.

Experiments: All experiments were performed on a GE Signa 1.5 T Excite system with readout bandwidth of +/-125 kHz. *Fat/Water Imaging:* In-plane encoding was performed using 128 rings for a 24 cm FOV, achieving isotropic in-plane resolution of 0.94 mm. The rings were divided into 2 bands: the outer 64 rings were acquired with [R = 1, T = 4.8 ms] while the central 64 rings were acquired with [R = 3, T = 1.6 ms, SBW = 625 Hz] to enable fat/water imaging. This design maximizes the spectral bandwidth and resolution while balancing the extent of the central retraced band. Slice encoding was implemented to acquire 100 1-mm axial slices (Fig. 3d) and the rings were incorporated into a segmented IR-prepared spoiled-GRE sequence with total scan time of 4 min 33 s. Fat and water images from the same axial brain slice are shown in Fig. 4. *MRSI:* A single 2D axial slice was encoded using one 16-ring band with [R = 128, T = 0.77 ms, SBW = 1.2 kHz] for a 16 cm FOV and 5 mm in-plane resolution. Slice thickness was also 5 mm. The rings were incorporated into a water-suppressed PRESS-localized MRSI sequence with total acquisition time of 36 s. Results from an imaging phantom containing water/fat/acetone are shown in Fig. 5.

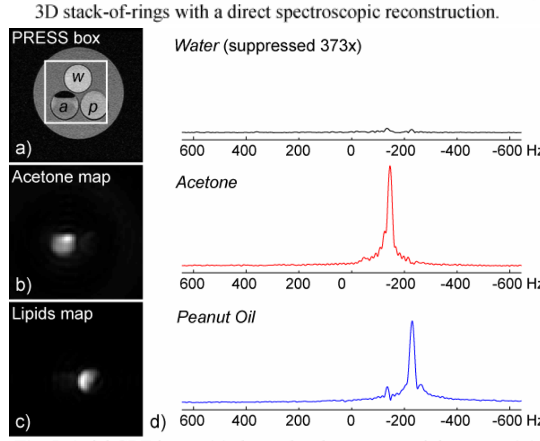

Fig. 5. Axial GRE image (**a**) shows the phantom containing water (*w*), acetone (*a*) and peanut oil (*p*). A PRESS box localized the center of the FOV (white square). The acetone map (**b**) and lipids map (**c**) are shown. Representative spectra from each of the three species are displayed in magnitude mode with the same scale (**d**).

Conclusion: For fat/water imaging, we find that retracing the central half (2 bands) encodes sufficient spectral information while preserving the robustness of the single-band design. A single band is sufficient for most MRSI applications, since the low spatial resolution allows for SBW > 1 kHz to cover a wide range of metabolites. In addition to the experimental results presented here, the trade-off analysis can guide the design of the concentric rings for many other MRSI applications. The same retraced acquisition can also be analyzed in the perspective of multi-point Dixon reconstructions [4, 5].

References: **[1]** Matsui S et al., JMR 1986;70:157-162. **[2]** Zhou X et al., MRM 1998;39:23-27. **[3]** Wu HH et al., MRM 2008;59:102-112. **[4]** Wu HH et al., *Proc. 16th ISMRM*, p.649, 2008. **[5]** Wu HH et al., MRM (in press).