MR Spectroscopic Imaging Using a Concentric Rings Trajectory

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Introduction: MR spectroscopic imaging (MRSI) provides invaluable information regarding *in vivo* metabolic processes to aid in clinical diagnosis. However, long scan times are required to resolve both the spatial and spectral dimensions. Fast imaging trajectories, such as EPI [1] and spiral [2], can encode multiple dimensions at once, providing a reduction in scan time compared to conventional MRSI. The disadvantage of these fast trajectories is their sensitivity to system imperfections, including eddy currents, timing errors, and gradient delays. These effects can degrade the reconstruction quality if not properly accounted for. In this work, we present the use of a concentric rings readout trajectory for MRSI. The concentric rings offer many advantages for MR imaging [3-6]. Furthermore, its unique circularly symmetric sampling nature enables a time-efficient retracing acquisition to simultaneously encode spatial and spectral information [6]. MRSI using concentric rings offers a scan time advantage over conventional MRSI, while also demonstrating robustness to eddy currents, timing errors, and gradient delays.

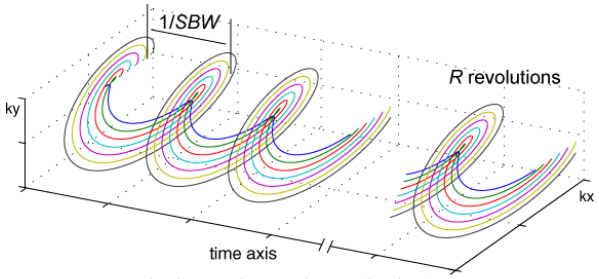

Fig. 1. Concentric rings trajectory in 3D (*kx, ky, t*)-space.

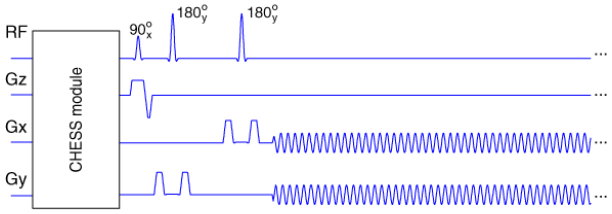

Fig. 2. PRESS sequence using concentric rings for readout.

Concentric Rings: A set of N uniformly spaced concentric rings are used to sample (k_x, k_y) [3-6]. Gradients are 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 more than once after signal excitation [5, 6], it is possible to sample the signal evolution along t and simultaneously encode (k_x, k_y, t) for MRSI (Fig. 1). The achieved spectral bandwidth (SBW) depends on the speed of retracing, which is constrained by the desired spatial coverage. The spectral resolution is determined by the total readout length, i.e., the total number of revolutions R in the retracing design. Spectral BW 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 $m = 0 \ldots M\text{-}1$.

Spectroscopic Imaging: The concentric rings are used as the readout trajectory in a PRESS-localized imaging sequence (Fig. 2). A CHESS module [7] consisting of 3 minimum-phase pulses (90^o-90^o-α) and gradient spoiling is applied prior to PRESS localization for water suppression. Shim parameters are obtained using a product prescan for the same imaging volume. Acquisition starts shortly after the last gradient crusher to collect one side of the spin echo. Data reconstruction consists of 3D gridding in (k_x, k_y, t)-space, 4 Hz exponential line broadening, 2-fold zero-padding in (k_x, k_y), 4-fold zero-padding in t, and finally a 3D Fourier transform along all three axes to produce a dataset in (x, y, f)-space.

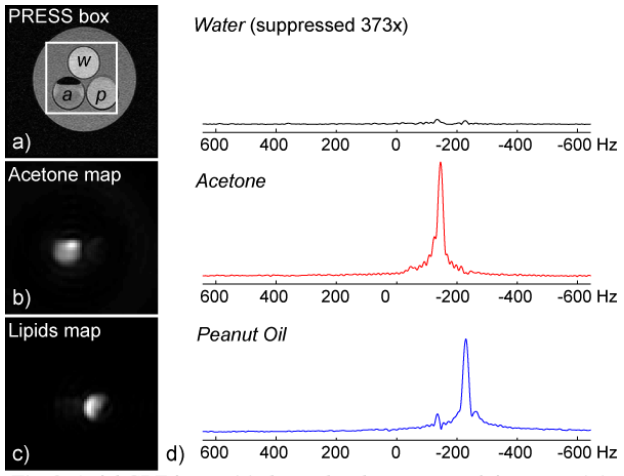

Fig. 3. Axial GRE image (**a**) shows the phantom containing water (*w*), acetone (*a*) and peanut oil (*p*). A PRESS box localized the center of the FOV (white square). The acetone map (**b**) and lipids map (**c**) are shown. Representative spectra from each of the three species are displayed in magnitude mode with the same scale (**d**).

Experiments: Setup: Experiments were performed on a GE Signa 1.5 T Excite system using a birdcage head coil. A 16 cm FOV was encoded using 16 rings (32x32 matrix), achieving isotropic in-plane resolution of 5 mm. Slice thickness was 5 mm. Each ring was acquired over R = 128 revolutions (0.77 ms per revolution) to achieve a nominal spectral BW of +/-644 Hz and a spectral resolution of 10 Hz. Sequence parameters were TE/TR = 50 ms/2 s. Total scan time for one acquisition was 36 s. Phantom Results: We imaged a phantom containing bottles of water, acetone, and peanut oil set in agar gel (Fig. 3a). A PRESS box of dimensions [x, y, z] = [60, 60, 5] mm was localized in the center of the FOV (white square). Maps of acetone (Fig. 3b) and peanut oil (Fig. 3c) were calculated by summing the spectra of each voxel over a range of +/-10 Hz about their respective resonant frequencies. Spectra from the center of each bottle are shown in magnitude mode (Fig. 3d), with dominant peaks at the expected -150 Hz for acetone and -220 Hz for lipids. The CHESS module achieved 373-fold suppression of water signal with α=130^o. Since the +/-644 Hz spectral BW achieved by a single scan (M=1) was sufficient to represent the chemical shift species of interest, we did not combine multiple scans for this particular experiment.

Discussion: We have implemented and demonstrated the feasibility of MRSI based on a concentric rings readout trajectory. The rings simultaneously encode (k_x, k_y, t), thus offering additional reduction in scan time when compared to EPI-based MRSI [1], which encodes (k_x, t) after each excitation. For the same FOV and spatial resolution, this translates into roughly a 50% reduction in the minimum scan time. The concentric rings retracing design maximizes the readout duty cycle by continuously retracing each ring with no sampling dead time. In contrast, unipolar fly-back EPI requires periodic blips and spiral-based readouts require frequent rewinding lobes. Bipolar EPI utilizes both polarities of the oscillating gradient, but needs to correct for phase discrepancies due to system imperfections to align the even/odd echoes. Since the rings are always retraced in the same rotational direction, such correction is not required. The rings can be extended to encode (k_x, k_y, k_z, t)-space by implementing slice encoding.

References: [1] Posse S et al., MRM 1995; 33: 34-40. [2] Adalsteinsson E et al., MRM 1998; 39: 889-898. [3] Matsui S et al., JMR 1986; 70: 157-162. [4] Zhou X et al., MRM 1998; 39: 23-27. [5] Wu HH et al., MRM 2008; 59: 102-112. [6] Wu HH et al., MRM 2008 (in press). [7] Webb PG et al., MRM 1994; 31: 365-373.