Fast-Spin-Echo Imaging and Fat/Water Separation Using a Concentric Rings Trajectory

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Introduction: Fast spin-echo (FSE) sequences [1] are routinely used to produce T_2 and proton-density weighted images. By acquiring multiple refocused echoes each TR, FSE reduces the scan time significantly. Since acquisition occurs during T_2 decay, appropriate acquisition ordering is required to distribute the signal transition in *k*-space. In this work, we present an FSE sequence based on the concentric rings 2D trajectory that is capable of fat/water separation. The concentric rings [2, 3] are inherently centric-ordered, provide smooth weighting in *k*-space, and enable shorter scan times. These properties make it well suited as a readout trajectory for FSE imaging where T_2 decay modulates the acquired signal. Previous work has demonstrated that high resolution images can be obtained from the murine brain using an FSE sequence based on concentric rings [2]. A potential problem for the rings is off-resonance due to field inhomogeneity and chemical shift. Here, we take advantage of the unique circularly symmetric sampling nature of rings and implement a time-efficient retracing acquisition for fat/water separation [3, 4]. This allows the FSE sequence based on concentric rings to account for field inhomogeneity and resolve bright fat signal that arises from multiple refocusing pulses.

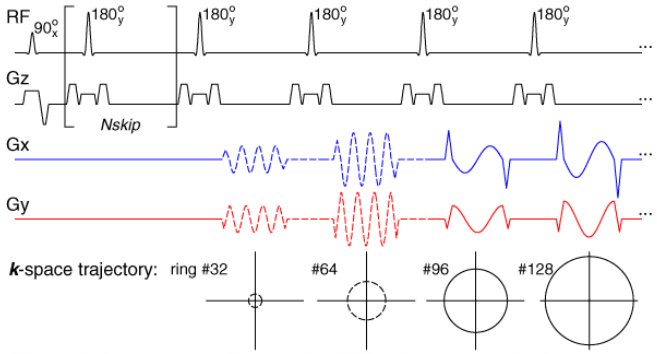

Fig. 1. Pulse sequence diagram for FSE using concentric rings. Skipping initial echoes controls T_2 contrast. Rings in the center of *k*-space (dashed line) are acquired through 3 revolutions to enable fat/water separation. This example has N=128 rings and ETL=4.

Sequence Design: Rings: 2D *k*-space is sampled using a set of N uniformly spaced concentric rings [2, 3]. Sinusoidal gradients are designed for the outermost ring, and then scaled down appropriately to acquire each ring (Fig. 1). The readout window length is held constant for all rings. With such a design, gradient delays and timing errors only manifest as a bulk rotation of the reconstruction. To enable fat/water separation, the central $N/2$ rings are sampled through multiple revolutions with a time-efficient retracing method (Fig. 1, dashed lines) [3]. Similar to multi-echo acquisitions, the data from each revolution can be reconstructed individually to characterize the fat/water phase evolution difference at their respective time points. An iterative multi-point Dixon algorithm is used to calculate separate fat and water images [4, 5]. It is also possible to perform a direct spectroscopic reconstruction of the retraced dataset for fat/water separation [4]. Fast Spin-Echo: The concentric rings are incorporated into an FSE sequence [1] by acquiring one ring per RF Hahn echo (Fig. 1) with the acquisition window centered about the echo. The full set of rings is interleaved across echo trains, such that N = ETL x NTR (ETL: echo train length, NTR: number of echo trains). Initial echoes can be skipped (N_{skip}) before the start of the acquisition to control the amount of T_2 contrast and maintain a smooth signal transition in *k*-space [6]. Since the rings are inherently centric-ordered in 2 dimensions, both center-out and center-in acquisition ordering schemes can capture the desired image contrast in a smooth and timely fashion.

Experiments: Setup: Experiments were performed on a GE Signa 1.5 T Excite system. Axial brain images were obtained using a quadrature head coil. Slice thickness was 5 mm. A 22 cm FOV was encoded using N = 128 rings (256x256 matrix), achieving isotropic in-plane resolution of 0.86 mm. The readout window was 4.8 ms for all rings and readout bandwidth was +/-125 kHz. The central 64 rings were acquired over 3 revolutions (1.6 ms per revolution) to enable SNR-efficient fat/water separation. Results: Fat and water images from the same slice are shown in Fig. 2 with proton-density (top) and T_2-weighted (bottom) contrast. Both scans were acquired with interleaved center-out ordering, ETL = 8, NTR = 16, echo separation = 12 ms, TR = 4 s, and total scan time = 1 min 08 s. The proton-density image had N_{skip} = 0 (effective TE = 12 ms) and the T_2-weighted image had N_{skip} = 10 (effective TE = 132 ms).

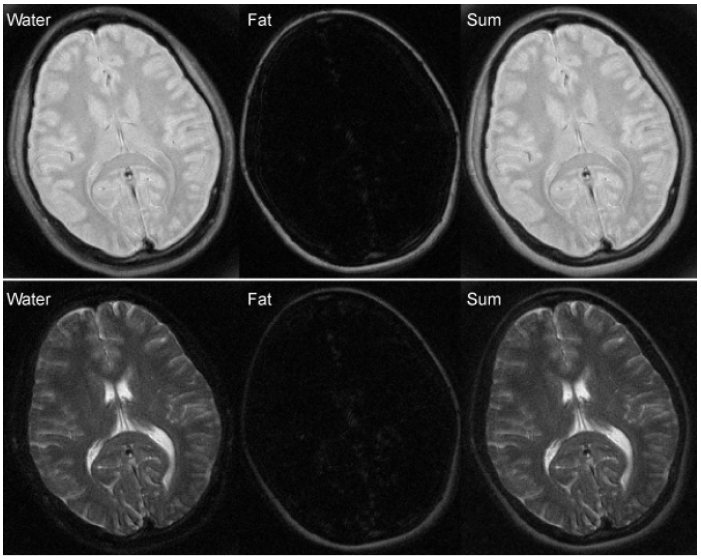

Fig. 2. Axial brain images: proton-density (top row) and T_2-weighted (bottom row). Water, fat, and combined images are shown.

Discussion: Although we acquired the proton-density and the T_2-weighted images as separate scans, they can be combined to utilize the initial N_{skip} echoes of the T_2-weighted scan, similar to conventional multi-echo spin echo imaging. Compared to 2DFT, concentric rings require half the number of excitations to cover a prescribed FOV and spatial resolution (128 rings for 256x256 matrix). For the same ETL and TR, this decreases NTR by 50% and translates into a 50% reduction in scan time. This reduction in scan time can be used to improve SNR or spatial resolution. Alternatively, the reduction in scan time can be traded off to decrease the ETL, resulting in less signal transition due to T_2 decay and less RF power deposited per TR. Volumetric spatial coverage can be achieved with 2D multi-slice imaging or by extending the 2D rings to a 3D stack-of-rings acquisition. It is also possible to employ a variable-angle refocusing train to prolong the ETL and shape a desirable signal transition profile [7].

Conclusion: We have demonstrated that images with the desired clinical contrast can be obtained using an FSE sequence based on the concentric rings trajectory. FSE based on rings offers a scan time advantage while also being robust to gradient delays and timing errors. In addition, the time-efficient retracing design allows the rings to be robust to off-resonance effects by accounting for field inhomogeneity and resolving bright fat signal.

References: [1] Hennig J et al., MRM 1986; 3: 823-833. [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., MRM 2008 (in press). [5] Reeder S et al., MRM 2004; 51: 35-45. [6] Block W et al., MRM 1997; 37: 582-590. [7] Busse RF et al., MRM 2008; 60: 640-649.