Fat/Water Separation Using a Concentric Rings Trajectory

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Introduction: The concentric rings *k*-space trajectory enables flexible trade-offs between image contrast, signal-to-noise ratio (SNR), spatial resolution, and scan time [1–3]. By further taking advantage of its circularly-symmetric sampling nature, we present a time-efficient method to acquire image data and reconstruct separate fat/water images.

Concentric Rings Acquisition: A set of *N* uniformly-spaced concentric rings (Fig. 1 top left) is used to sample *k*-space [1–3]. Sinusoidal gradients are designed for the outermost ring (Fig. 1 top right), and then scaled down appropriately to acquire one ring per TR. This results in a sampling density that resembles 2D projection-reconstruction (2DPR). While keeping the readout window length fixed, we can be more efficient with gradient power by retracing the central *N/2* rings (dashed line, Fig. 1 top left) to acquire the same desired samples through two revolutions (Fig. 1 bottom) [2]. Similar to multi-echo acquisitions, Set_1 and Set_2 can be reconstructed individually to convey information regarding fat/water phase evolution differences at their respective time points. Furthermore, each retraced ring is sampled continuously in time and in a circularly-symmetric fashion in *k*-space. This allows us to obtain fat/water phase information at additional time points by reconstructing *intermediate sets* extracted from the retraced readout (Fig. 1 bottom).

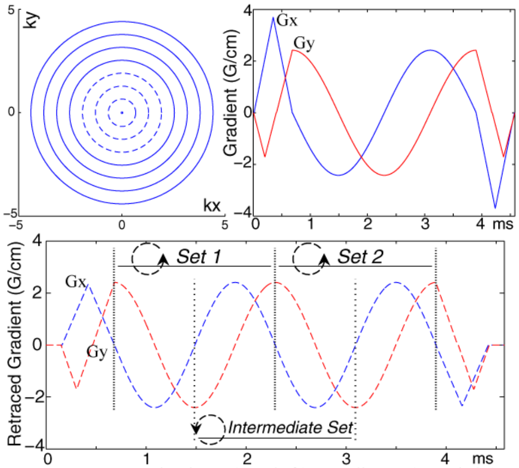

Fig. 1. Concentric rings (top left), gradients (top right), and retraced gradients (bottom) for the central rings. Readout window length is fixed.

Fat/Water Separation: Signal contributions from fat and water can be formulated as a matrix equation [4, 5], where *cf* is the specified demodulation frequency, $\Delta\omega$ is the fat/water frequency shift, and each $img_{x,cf}$ corresponds to a source image acquired at arbitrary time point t_x and reconstructed at *cf*:

$$\begin{bmatrix} img_{1,cf} \\ img_{2,cf} \\ img_{3,cf} \end{bmatrix} = \begin{bmatrix} e^{i\cdot(0-cf)\cdot t_1} & e^{i\cdot(\Delta\omega-cf)\cdot t_1} \\ e^{i\cdot(0-cf)\cdot t_2} & e^{i\cdot(\Delta\omega-cf)\cdot t_2} \\ e^{i\cdot(0-cf)\cdot t_3} & e^{i\cdot(\Delta\omega-cf)\cdot t_3} \end{bmatrix} \cdot \begin{bmatrix} W_{cf} \\ F_{cf} \end{bmatrix} = A_{cf} \cdot \begin{bmatrix} W_{cf} \\ F_{cf} \end{bmatrix}$$

Reconstructing Set_1 and Set_2 from the retraced central rings produce img_1 and img_2 respectively. To obtain img_3 at a third time point, we reconstruct data corresponding to an *intermediate set* taken from the same readout (Fig. 1 bottom). Higher-resolution outer rings are incorporated into the equation by demodulating at *cf* and adding its reconstruction to all $img_{x,cf}$ as common information. The water image $W_{cf=0}$ can be obtained by setting $cf = 0$ and then finding the pseudo-inverse of $A_{cf=0}$. Similarly, the fat image $F_{cf=\Delta\omega}$ can be calculated by first specifying $cf = \Delta\omega$ in the equation [5]. Field inhomogeneities are not included in the current formulation, but can be accounted for with further processing based on this linear equation [4, 5].

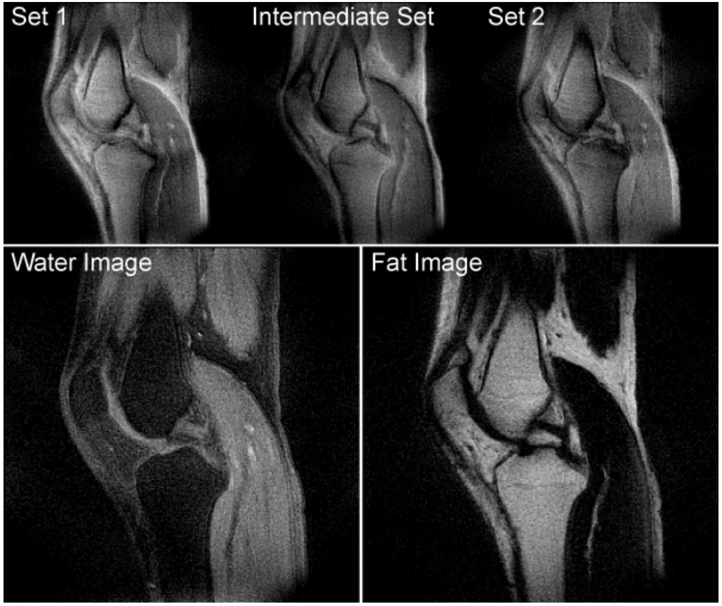

Fig. 2. Sagittal knee images. The three source images at water center frequency (top row) and reconstructed water/fat images (bottom row).

Results: Experiments were performed on a GE Signa 1.5 T Excite system. 128 rings with the central 64 retraced were acquired for a 20 cm FOV, achieving isotropic in-plane resolution of 0.78 mm. The readout window was 3.2 ms for all rings and readout bandwidth was +/-125 kHz. Each revolution of the central rings was thus sampled in a short time window of 1.6 ms and limited the effects of field inhomgeneities. To demonstrate the method, we used the rings in a spoiled gradient-echo sequence with TE/TR/θ = 3.4 ms/60 ms/40° to acquire a single 4 mm slice of the knee. Total scan time was 8 seconds. Set_1 and Set_2 were reconstructed to obtain the first two source images, while an *intermediate set* centered between Set_1 and Set_2 was used to produce the third (Fig. 2 top row). These three source images were used to calculate separate water and fat images of the same slice (Fig. 2 bottom row). Using a multi-slice acquisition in the future will enable greater coverage in the same amount of scan time.

Conclusion: Our presented method acquires registered image data at multiple time-points very efficiently. The concentric rings trajectory by itself already enables shorter scan times than Cartesian imaging or 2DPR for a prescribed FOV and spatial resolution [1–3]. Retracing the central rings to acquire data through two revolutions requires no extra scan time compared with a regular concentric rings acquisition, thereby preserving its scan time advantage. The time efficiency of the concentric rings is then enhanced by extracting a third intermediate time point from the same two-revolution readout, making this method even more efficient than conventional multi-echo approaches. Extracting additional intermediate time points makes it possible to improve the conditioning of the matrix problem, and potentially resolve more than two chemical-shift species with just two revolutions [4]. Further SNR analysis will help determine the optimal utilization of these intermediate sets. A simple least-squares approach was used here, but the source images can be used with more sophisticated multi-point fat/water separation algorithms for greater robustness. Potential off-resonance blurring can also be corrected by combining multi-frequency reconstruction with fat/water separation [5].

References: [1] Zhou X, et al., MRM 1998; 39(1): 23-27. [2] Wu HH, et al., *Proc. 14th ISMRM*, p. 341, 2006. [3] Wu HH, et al., *Proc. 15th ISMRM*, p. 414, 2007. [4] Reeder S, et al., MRM 2004; 51(1): 35-45. [5] Gurney PT, et al., *Proc. 15th ISMRM*, p. 1635, 2007.