DIR Black-Blood Imaging Using Concentric Rings with Fat/Water Separation

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Introduction: Suppression of signal from blood, *i.e.* black-blood (BB) imaging, is crucial for visualizing the myocardium and studying the progression of atherosclerosis in the vessel wall. Popular black-blood techniques include spatial saturation, double inversion-recovery (DIR) [1, 2], and motion-sensitive dephasing [3], with DIR being the most widely utilized. In this work, we present a new DIR black-blood MRI method (DIR-Rings) based on a non-Cartesian 2D concentric rings trajectory [4, 5], which requires *half* the number of readouts compared to 2D Cartesian encoding and supports *2D center-out ordering* to maximize the effectiveness of the DIR preparation. In addition, the concentric rings are acquired with a time-efficient multi-revolution design to enable fat/water separation for enhanced image contrast [5].

Methods: Sequence Design: As shown in Fig. 1a, a DIR module is played out right after the cardiac trigger, using adiabatic pulses for the non-selective (solid rectangle) and slice-selective (hollow rectangle) inversions. The full set of concentric rings is divided into interleaved segments and acquired with 2D center-out ordering over multiple heartbeats with 2 R-R ECG triggering. Each ring is acquired through R revolutions using a gradient-echo (GRE) sequence (Fig. 1b) to reconstruct R source images with uniform echo separation dTE for fat/water separation [5, 6].

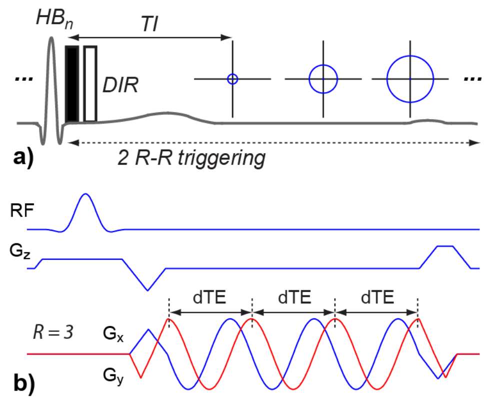

Fig. 1. (**a**) DIR-Rings imaging using segmented 2D center-out sampling. Heartbeat (HB) n is shown. (**b**) Each concentric ring is acquired over R revolutions in a GRE sequence for fat/water separation.

Cardiac Imaging: 2D axial slices were acquired on a GE Signa 1.5 T Excite system using an 8-channel array. A set of 120 rings (*2-fold* reduction vs. 2D Cartesian) was used to encode an FOV of 30x30 cm^2 and resolution of 1.25x1.25 mm^2. All rings were acquired with R = 3 (dTE = 1.63 ms) using a GRE sequence with TE/TR/FA = 1.6 ms/8.8 ms/20^o. Slice thickness was 8 mm. Inversion time (TI) for DIR was 600 ms (heart rate ~70 bpm). With 10 rings/segment and 12 segments, 24 heartbeats were required for this single-breath-hold scan.

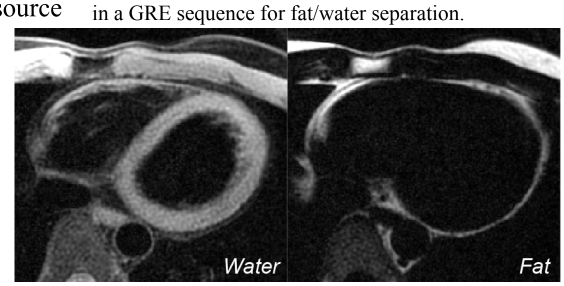

Fig. 2. DIR-Rings cardiac images with fat/water separation.

Carotid Imaging: 2D axial slices were imaged on the same scanner using a custom 3-channel array [7]. A set of 120 rings (*2-fold* reduction vs. 2D Cartesian) encoded an FOV of 17x17 cm^2 and resolution of 0.7x0.7 mm^2. An RF-spoiled GRE sequence with TE/TR/FA = 1.6 ms/8.5 ms/20^o was used and the central 54 rings were acquired with R = 3 (dTE = 1.5 ms) [5]. Slice thickness was 8 mm. TI was 500 ms (heart rate ~80 bpm). With 20 rings/segment and 6 segments, 12 heartbeats were required for this free-breathing scan.

Results: Fig. 2 displays representative DIR-Rings cardiac images from a healthy volunteer. With blood suppressed throughout the FOV, the myocardium and aortic wall become clearly depicted. Fat/water separation isolates epicardial fat and further improves visualization of the myocardium. Representative DIR-Rings carotid images from a healthy volunteer are shown in Fig. 3, with zoomed-in views of the right and left common carotid arteries (CC) and jugular veins (JV). Fat/water separation again improves visualization of the outer vessel wall.

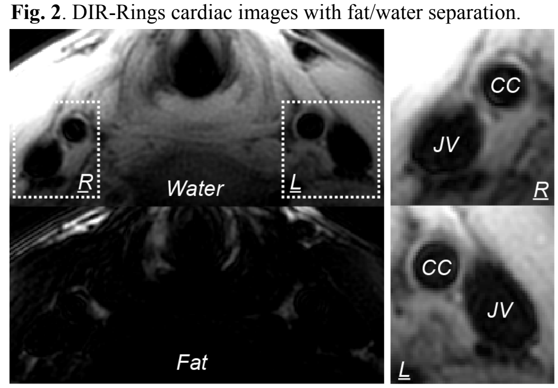

Fig. 3. DIR-Rings carotid images with fat/water separation. Enlarged views of the right (R) and left (L) common carotid arteries (CC) and jugular veins (JV) are also shown.

Discussion and Conclusions: The 2D concentric rings require fewer readouts than 2D Cartesian encoding and can be acquired with 2D center-out ordering to maximize the effectiveness of DIR black-blood preparation while simultaneously reducing scan time. The time-efficient multi-revolution acquisition resolves off-resonance effects [4] that can degrade non-Cartesian image quality and enables fat/water separation [5] to improve visualization of the myocardium and vessel wall. A lower segmentation factor was used for cardiac imaging (10/seg) than carotid imaging (20/seg) to minimize cardiac motion during the scan, and this segmentation factor can be used to trade-off improvements in capturing prepared contrast to further reduce scan time. In addition to the GRE implementation shown here, the concentric rings can be acquired using fast spin-echo [8] to achieve multiple contrast weightings. Furthermore, the concentric rings can be extended to a 3D stack-of-rings trajectory [9] that supports 3D center-out ordering for even higher efficiency in capturing black-blood preparation. The concentric rings fat/water imaging technique can also be used to enhance motion-sensitive dephasing [3] and other black-blood preparation approaches.

References: [1] Edelman RR, *et al.*, Radiology 1991; 181: 655-660. [2] Simonetti OP, *et al.*, Radiology 1996; 199: 49-57. [3] Nguyen TD, *et al.*, JMRI 2008; 28: 1092-1100. [4] Wu HH, *et al.*, MRM 2008; 59: 102-112. [5] Wu HH, *et al.*, MRM 2009; 61: 639-649. [6] Reeder SB, *et al.*, MRM 2004; 51: 35-45. [7] Barral JK, *et al.*, *Proc. 17th ISMRM*, p. 1318, 2009. [8] Wu HH, *et al.*, *Proc. 17th ISMRM*, p. 2645, 2009. [9] Wu HH, *et al.*, MRM 2010; 63: 1210-1218.