Rapid Fat-Water-Separated Cardiac Cine Imaging Using Concentric Rings and k-t BLAST

H. H. Wu[1,2], T. Shin[2], D. G. Nishimura[2], and M. V. McConnell[1,2]
[1]Cardiovascular Medicine, Stanford University, Stanford, CA, United States, [2]Electrical Engineering, Stanford University, Stanford, CA, United States

Introduction: Cine imaging is an established clinical technique for assessing cardiac function. In many situations, it is also desirable to have complementary information identifying fat signal in the heart to characterize masses, detect fatty infiltration and ARVD (arrhythmogenic right ventricular dysplasia), and better visualize pericardial disease [1]. In this work we present an integrated technique that produces co-registered cines of both water and fat signal from a short single-breath-hold scan. The concentric rings readout trajectory [2-4] is used to efficiently encode chemical shift information for fat/water separation and to provide two-fold scan-time reduction compared to 2D Cartesian encoding. Additional acceleration from *k-t* BLAST [5, 6] further reduces the scan time and helps balance spatial and temporal sampling requirements.

Methods: Acquisition: Each ring is acquired through *R* revolutions every TR (Fig. 1a) to reconstruct *R* source images at different effective echo times (echo separation dTE) for fat/water separation [2-4]. In addition to reducing the scan time, the concentric rings have favorable motion/flow properties [2] and are robust to gradient imperfections [4]. To support *k-t* BLAST acceleration [5, 6], a central region in *k*-space (N_{cal} rings) is always acquired for each cine frame to serve as training data, while the outer region is undersampled in a time-interleaved fashion (Fig. 1b). The set of rings required for each undersampled cine frame is divided into interleaved segments and acquired over multiple heartbeats in a breath-held cardiac-triggered sequence (Fig. 1c) [7].

Reconstruction: Segments from multiple heartbeats are first collected into the undersampled cine frames. Since *R* revolutions are acquired for each ring, there are *R* source images for each cine frame and thus *R* "source cines". Each of the *R* source cines is reconstructed from the undersampled data using non-Cartesian *k-t* BLAST reconstruction [6]. An iterative least-squares algorithm [3, 4, 8] then reconstructs water and fat images for each cine frame based on the *R* source images, thus producing co-registered water and fat cines from a single acquisition. Data from multiple coils are combined using a sum of squares.

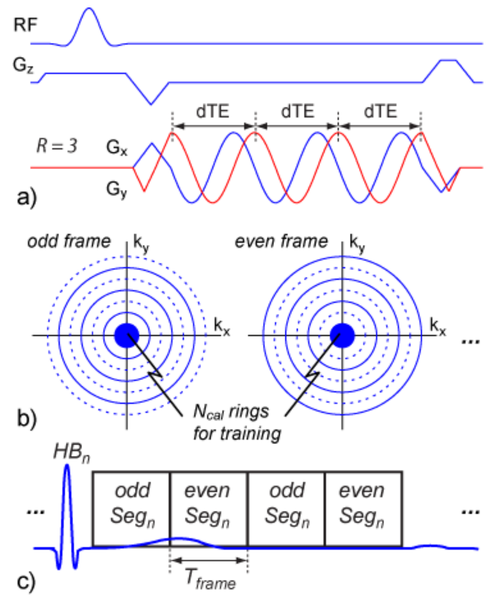

Fig. 1. (**a**) Concentric rings are acquired over multiple revolutions (*R* = 3 here) for fat/water separation. (**b**) Example showing 2-fold undersampling in *k-t* space where a central region of N_{cal} rings is always acquired and the outer region is undersampled in a time-interleaved fashion. (**c**) The rings required for each cine frame are divided into interleaved segments and acquired over multiple heartbeats.

Experiments: Setup: 2D axial cardiac cine scans were performed on a GE Signa 1.5 T Excite system using an 8-channel cardiac array. A fully sampled set of N = 90 rings was designed to encode an in-plane FOV of 32x32 cm^2 and resolution of 1.78x1.78 mm^2. All rings were acquired over R = 3 revolutions (dTE = 1.34 ms) using a gradient-echo sequence with TE/TR/FA = 1.6 ms/8.2 ms/15°. Slice thickness was 8 mm. N_{cal} = 10 rings in the center of *k*-space were acquired and the outer region was undersampled by a factor of 2. With 5 rings in each segment (T_{frame} = 41 ms/frame), 10 heartbeats were required for the single-breath-hold scan.

Results: Fig. 2 displays 3 cine frames from the co-registered water and fat cines obtained from a normal volunteer. Epicardial fat is successfully isolated in the fat images and the right coronary artery becomes visible in the water images (arrow).

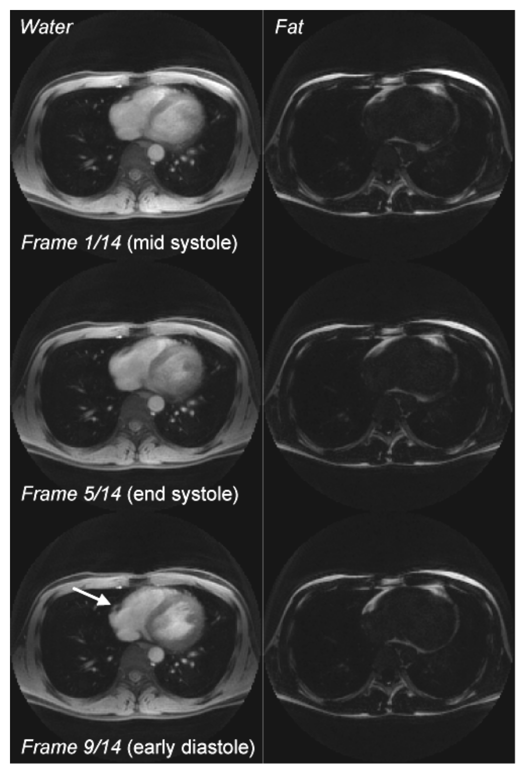

Fig. 2. Cine frames from water (left) and fat (right) cines reconstructed from a single 10-heartbeat scan.

Discussion: We have presented a rapid imaging technique that can produce fat and water cines of clinically relevant spatial and temporal resolution within a 10-heartbeat single-breath-hold scan. Since multiple revolutions are acquired within each TR to produce the source images (similar to a multi-echo sequence), the water and fat images are inherently co-registered. Higher *k-t* undersampling factors can be used to achieve higher spatial and/or temporal resolution. Additional applications of this technique include contrast-enhanced cardiac imaging [9] and quantification of cardiac lipid content for studying insulin resistance [10].

References: [1] Reeder SB, et al., JMRI 2005; 22: 44-52. [2] Wu HH, et al., MRM 2008; 59: 102-112. [3] Wu HH, et al., MRM 2009; 61: 639-649. [4] Wu HH, et al., MRM 2010; 63: 1210-1218. [5] Tsao J, et al., MRM 2003; 50: 1031-1042. [6] Hansen MS, et al., MRM 2006; 55: 85-91. [7] Atkinson DJ, et al., Radiology 1991; 178: 357-360. [8] Reeder SB, et al., MRM 2004; 51: 35-45. [9] Goldfarb JW, MRM 2008; 60: 503-509. [10] Szczepaniak LS, et al., Circ Res 2007; 101: 759-767.