3D Cardiac Cine Imaging Using a 3D Cones Trajectory

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Introduction: Cine imaging is a widely accepted clinical tool for assessing cardiac wall motion and performing volume measurements. Conventional cine sequences acquire multiple cardiac phases of a single 2D slice during a breath-held scan, with multiple slices collected over multiple breath-holds. While respiratory artifacts are minimized and the temporal resolution is high for each slice, it can be time consuming to collect the full set of slices and there may be misregistration among the slices. In this work, we present a novel 3D cardiac cine sequence based on the 3D cones non-Cartesian trajectory [1, 2] which can capture the temporal events of a 3D volume within a single breath-held scan. The 3D cones trajectory is a fast sampling method that enables a high degree of scan time reduction. Furthermore, its robust motion and flow properties are beneficial for cardiac imaging [2]. We demonstrate the 3D cones cine sequence using a cardiac-triggered segmented acquisition strategy [3].

Methods: The 3D cones trajectory samples *k*-space data on a series of conical surfaces with apices coinciding at the *k*-space origin (Fig. 1) [1, 2]. Each conical surface is covered using a set of spiraling readouts. The 3D cone readouts are incorporated into an SSFP cine sequence (Fig. 1a) and the full set of readouts for all cone surfaces are organized into interleaved segments that are acquired over multiple heart beats (HBs) [3]. A sample acquisition segment consisting of 4 cone readouts (i.e., 4 TRs) is shown in Fig. 1b. Adjacent readouts are paired to mitigate SSFP artifacts caused by abrupt transitions in *k*-space [4]. After each cardiac trigger, catalyzation cycles (*CC*) are first played out to establish SSFP steady state. Multiple segments are then acquired to characterize multiple cardiac phases (Fig. 2). When a sufficient number of HBs have been acquired, the full set of segments (thus the full set of cone readouts) is available to reconstruct a cine time frame for each resolved cardiac phase. To further disrupt motion artifacts, the readout segments are bit-reversed permuted across HBs. This ordering scheme has the additional feature of allowing the reconstruction of time frames with coarser temporal resolution when only a fraction of the desired HBs are acquired (dotted red lines in Fig. 2).

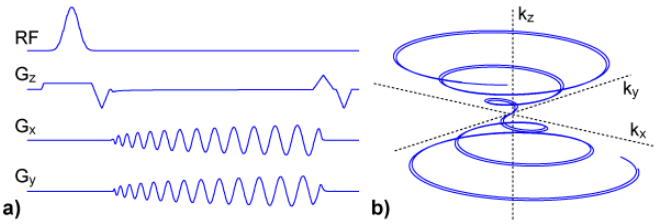

Fig. 1. (a) SSFP sequence using the 3D cones for readout. **(b)** Sample acquisition segment consisting of 4 cones. Note the pairing to reduce SSFP artifacts.

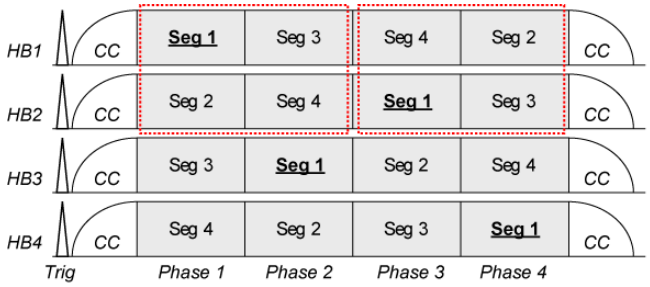

Fig. 2. The full dataset is acquired using a triggered, segmented approach. Catalyzation cycles (*CC*) establish and exit the SSFP steady state for each HB. Segments are bit-reversed permuted over HBs to allow reconstruction of coarser time frames covering more than one phase (dotted red lines) when only a fraction of the HBs are acquired. This example has 4 segments and resolves 4 phases.

Experiments: Setup: Cardiac scans were performed on a GE Signa 1.5 T Excite system. An axial slab of the heart was imaged using an 8-channel cardiac coil. Trigger signals were obtained from a finger plethysmograph. An SSFP sequence with TE/TR/θ = 0.68 ms/4.98 ms/50° was used and the readout bandwidth was +/-125 kHz. 6 TRs with cosine-ramp-weighted flip angles were used for catalyzation (30 ms) [2]. We designed a 3D cones trajectory to support a FOV of 24x24x8 cm^3 and resolution of 2x2x8 mm^3 (120x120x10 matrix) using a total of 330 cone readouts, which was divided into 33 interleaved segments of 10 readouts each (i.e., 50 ms / frame). 12 cardiac phases were resolved (600-ms window) and a total of 33 HBs were acquired. The 10 slices were scanned within a single breath-hold of ~30 sec. Images were reconstructed using 3D gridding and a sum-of-squares coil combination. The image matrix was interpolated to 240x240x20. Results: The 50-ms cine time frames (corresponding to 12 cardiac phases) reconstructed using all acquired HBs are shown in Fig. 3 for the central axial slice. Systole is captured in the first few frames and the pulsing of the descending aorta is observed in the cine loop. Right system blood is brighter as it comes from outside the excited slab [2].

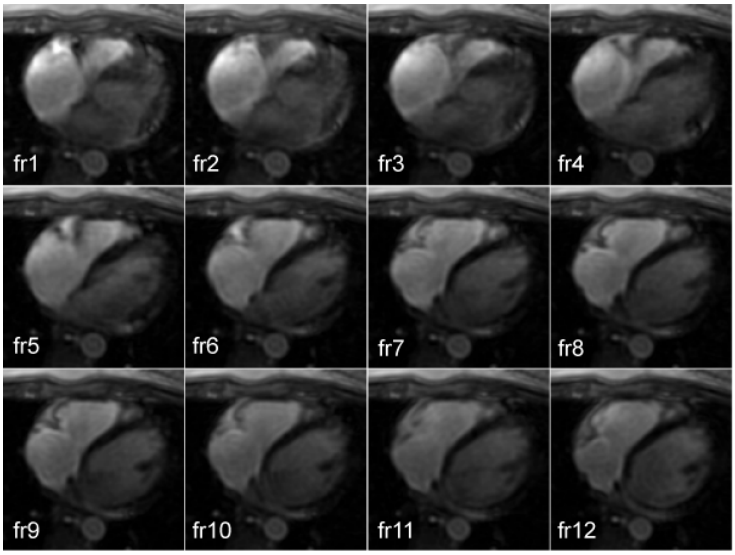

Fig. 3. The 12 cine time frames (fr_x) from the central axial slice of the 3D volume. The in-plane FOV has been cropped to a 12x12 cm^2 square region encompassing the heart. Systole is captured in the first few frames.

Discussion: Resolved cardiac phases of multiple contiguous slices can be acquired within a single breath-held scan using the proposed 3D cones cine sequence. Currently, the prospective triggering approach requires a shorter acquisition window to accommodate HB variations and also catalyzation cycles to manage the SSFP steady-state transition between triggers. The current sequence can be extended to provide complete coverage of the cardiac cycle by scanning continuously and performing retrospective cardiac gating. Also of great interest is the possibility of performing self navigation using the interleaved acquisition segments [5] and to track inter-HB variations with the reconstruction of coarser time frames permitted by the bit-reversed permutation scheme (Fig. 2). Fat suppression is possible by methods such as alternating-TR SSFP [6]. Further acceleration using parallel imaging and/or variable-density sampling can extend the 3D coverage and enhance the spatial resolution for the 3D cones cine sequence.

References: [1] Gurney PT, et al., MRM 2006; 55: 575-582. [2] Gurney PT, PhD Thesis, Stanford University, 2007. [3] Atkinson DJ, et al., Radiology 1991; 178: 357-360. [4] Bieri O, et al., MRM 2005; 54: 129-137. [5] Larson AC, et al., MRM 2004; 51: 93-102. [6] Leupold J, et al., MRM 2006; 55: 557-565.