First-pass Coronary MR Angiography Using a Spiral-Ring Trajectory

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Purpose: 2D multislice interleaved spiral imaging [1] for coronary magnetic resonance angiography (MRA) has been shown to be capable of imaging multiple slices with sub-mm in-plane resolution and high temporal resolution within a breath-hold. However, an important issue with this sequence is blood-lesion contrast. In this work, we developed a spiral-ring [2] version of the sequence, which is aimed for first-pass contrast-enhanced coronary MRA for potentially better blood-muscle and blood-lesion contrast.

Methods: Spiral-Ring: The spiral-ring trajectory [2] is generated by segmenting a relatively long 2D interleaved spiral trajectory. By dividing each of N_{intlv} interleaves into N_{seg} segments (Fig. 1), a total of $N_{rdout} = N_{intlv} \times N_{seg}$ readouts with $1/N_{seg}$ of the original readout duration are made to have the same k-space coverage as the original spiral trajectory. Considering that each set of segments (e.g., a set of N_{intlv} 1st segments) collects full-FOV information for a specific spatial frequency band, the spiral-ring trajectory better captures the transient contrast generated by magnetization preparation and a contrast agent compared to a conventional 2D spiral sequence. Due to the phase discontinuities at the boundaries of segments, the trajectory requires slice-by-slice shimming and multifrequency reconstruction [3] to reduce off-resonance effects.

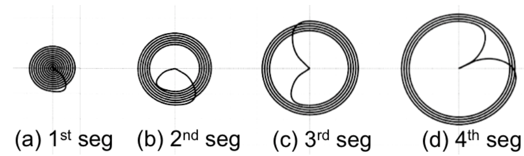

Fig. 1. A spiral-ring trajectory formed from a 2D interleaved (N_{intlv} = 4) spiral trajectory. Each interleaf is divided into N_{seg} = 4 segments (only one interleaf shown).

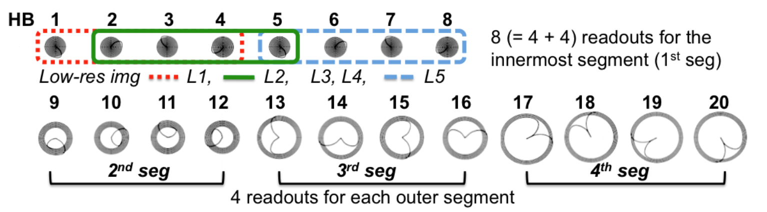

Fig. 2. Acquisition scheme for a first-pass 20-heartbeat (HB) breath-hold scan. Among N_{seg} = 4 segments, the innermost segment is acquired redundantly (8 vs. N_{intlv}=4) to generate five low resolution images (L1~L5), then combined with the same sets of outer segments to provide five view-shared time-resolved datasets.

Pulse Sequence: During each heartbeat of a breath-hold, one of N_{rdout} readouts for all the slices is acquired sequentially [1]. A saturation pulse is applied right before the acquisition of each slice to selectively saturate a slice that is N_{shift} acquisitions after. This saturation scheme allows enough recovery of contrast-enhanced blood for blood-muscle and blood-lesion contrast, without introducing an explicit delay time between the preparation and the acquisition [4]. A total of N_{rdout} heartbeats is needed to collect all the k-space data, but the first set of segments that collects the innermost k-space data is acquired redundantly. In Fig. 2., e.g., each set of segments needs to collect N_{intlv} = 4 interleaves for the full-FOV coverage, but the set of innermost (1st) segments is acquired more times (8 vs. 4) and combined with the same sets of outer segments to provide five view-shared time-resolved datasets [5].

Imaging Parameters: Phantom and in vivo studies were performed on a GE Excite 1.5 T scanner with an 8-channel cardiac coil. The RTHawk real-time system (HeartVista, Inc) [6] was used for fluoroscopic triggering for bolus detection [5] as well as for the prospective shim correction, pulse generation, and multifrequency reconstruction. Informed written consent approved by our IRB was obtained prior to scanning. The spiral-ring was formed from a variable-density spiral [7] (28/22 cm FOV at k-space origin/edge, respectively) with N_{intlv}/N_{seg} = 4/4 and acquired with an SPGR sequence to provide in-plane resolution = 1 mm, slice thickness = 5 mm, readout duration = 8 ms, TR (temporal resolution for each slice) = 26 ms, and flip angle = 60°. The total scan time was 20 heartbeats as illustrated in Fig. 2. A total of 20 slices were acquired with N_{shift} = 2, which provides a 2·TR = 52 ms effective delay time for each saturation pulse.

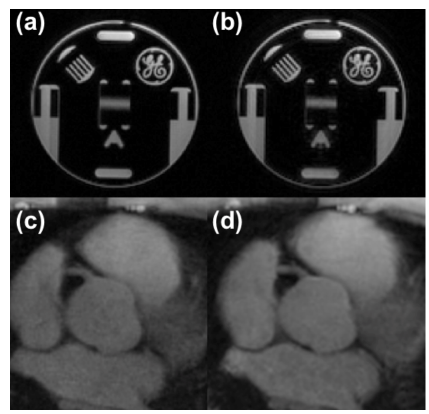

Fig. 3. Axial slices of phantom (top) and in vivo (bottom) datasets. **(a,c)** spiral **(b,d)** spiral-ring (without contrast)

Results: Figure 3 shows axial slices from phantom (top) and in vivo (bottom, without contrast) datasets, which demonstrates that the spiral-ring trajectory has a capability of providing comparable image quality to the regular spiral trajectory when prospective shim correction and multifrequency reconstruction were performed. The preliminary in vivo datasets in Fig. 4 shows that the transient contrast generated by the saturation pulse and contrast agent (MultiHance) can be effectively captured by the spiral-ring trajectory, which yields improved blood-muscle contrast compared to the regular spiral trajectory (not shown). The right coronary artery is well-depicted as indicated by dashed area.

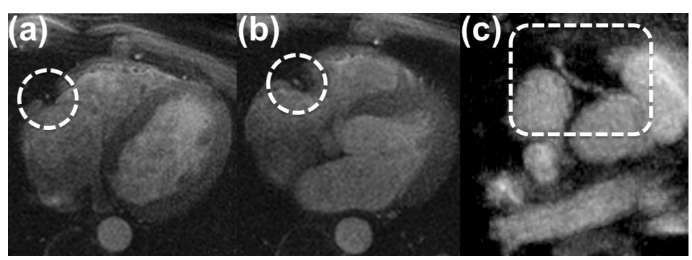

Fig. 4. (a,b) Representative axial slices, and **(c)** a maximum-intensity-projection image from two different in vivo datasets with spiral-ring (with contrast). Dashed areas indicate the right coronary arteries.

Discussion and Conclusion: We demonstrated the feasibility of the spiral-ring trajectory for first-pass coronary MRA. The time-resolved datasets may provide an extra degree of flexiblility that captures different coronary arteries with different timings of contrast filling.

References: [1] Yang et al., JACC 2003;41:1134. [2] Kerr et al., MRM 1997;38:355. [3] Noll et al., IEEE TMI, 1991;10:629 [4] Slavin et al., Radiology 2001;219:258. [5] Riederer et al., MRM 1988;8:1. [6] Santos et al., 26th IEEE EMBS, p.1048, 2004. [7] Tsai et al., MRM, 2000;43:452.