REAL-TIME CARDIAC MRI USING A GOLDEN-RATIO-ORDERED SPIRAL TRAJECTORY AND SELF-CONSISTENT PARALLEL IMAGING

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Introduction: Real-time MRI has the potential to improve imaging of dynamic processes, accommodate free-breathing exams, and monitor interventional procedures, but faces challenging trade-offs between temporal resolution, spatial resolution, spatial field of view (FOV), and more. In this work, we present a real-time MRI technique that combines the speed and favorable motion/flow properties of spiral imaging with the flexibility of golden-ratio acquisition ordering[1,2] and acceleration from self-consistent non-Cartesian parallel imaging[3]. The scan acceleration offered by our technique is used to improve spatial resolution and increase the spatial FOV, while maintaining adequate temporal resolution.

Methods: Acquisition: An interleaved uniform-density spiral trajectory is first designed to encode the desired in-plane spatial resolution (*e.g.*, 1.6 mm) at a reduced FOV (*e.g.*, 20 cm). The number of interleaves is chosen to be a Fibonacci number (*e.g.*, 21). A single interleaf is then taken from the initial spiral design and continuously rotated by an angle increment based on the golden ratio ($d\theta = 360^o \cdot 2/(\sqrt{5} + 1) \approx 222.4969^o$) for data acquisition[1,2] (Fig. 1).

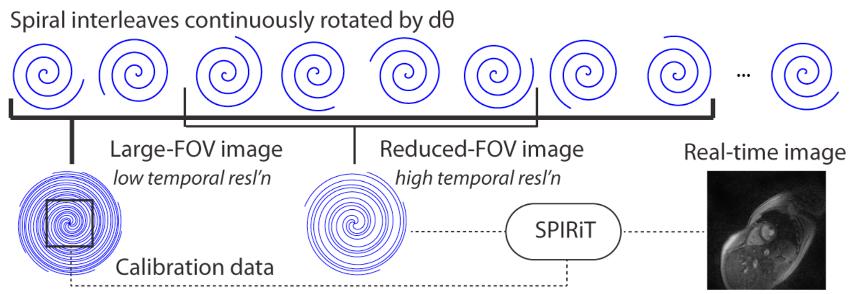

Fig. 1. Golden-ratio-ordered spiral MRI combined with SPIRiT.

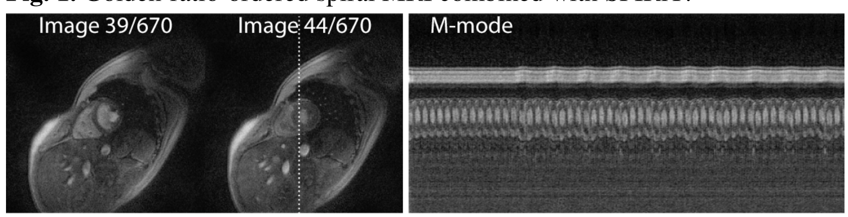

Fig. 2. Representative real-time cardiac MR images (**left**) and M-mode display for pixels along the dotted line (**right**). Note the visualization of cardiac and respiratory motion with good depiction of interfaces.

Reconstruction: The uniform distribution of golden-ratio-ordered spiral interleaves in both k-space and time enables the reconstruction of multiple image streams with varying temporal resolution and FOV from the same data acquisition (Fig. 1). In particular, two image streams can be reconstructed: (1) Images free of spatial aliasing over a large FOV (*e.g.*, 40 cm), albeit at a lower temporal resolution (e.g., from groups of 55 interleaves) and (2) Images with higher temporal resolution (*e.g.*, from groups of 21 interleaves), but with a reduced aliasing-free FOV. By extracting calibration data from the large-FOV images, self-consistent non-Cartesian parallel imaging reconstruction can be performed using SPIRiT[3] to remove aliasing from the reduced-FOV images and obtain high-temporal-resolution large-FOV real-time images. Sliding-window reconstruction is implemented to continuously update both image streams and increase the display frame rate.

Results: Healthy volunteers were imaged on a 1.5 T MRI system using an 8-channel cardiac array. Data were acquired using a spiral GRE sequence with 8-mm slice thickness, 1.6-mm in-plane resolution, 20-cm nominal FOV (21 interleaves), and TE/TR/FA = 1.6 ms / 8 ms / 20^o. Figure 2 shows representative images from a short-axis cardiac scan during 43 sec of free breathing. SPIRiT with R = 2 produced 40-cm FOV images every 21 interleaves (raw temporal resolution of 168 ms, raw frame rate of 6 fps). This represents roughly a ***12-fold reduction*** in the number of signal excitations with respect to fully-sampled 2DFT encoding for the same 250x250 matrix. The display frame rate was 16 fps (8-TR sliding window). There was 1.5 ms of dead time each TR to account for long-term gradient heating effects on our scanner. For short-term imaging, the dead time can be eliminated to improve temporal resolution by ~20%.

Discussion and Conclusion: For the images shown here, scan acceleration was used to achieve a relatively high in-plane resolution of 1.6 mm (vs. >2 mm for standard real-time MRI) and cover a relatively large 40-cm FOV. At the same time, the raw temporal resolution of 168 ms and display frame rate of 16 fps was capable of visualizing cardiac and respiratory motion (Fig. 2). Depending on the imaging scenario, it may be desirable to aim for higher temporal resolution while reducing the spatial resolution and FOV. Additional constraints can be incorporated into the SPIRiT framework to facilitate higher acceleration and/or improve image quality.

References: 1. Winkelmann S, *et al.*, IEEE TMI 2007; 26: 68-76. 2. Kim YC, *et al.*, MRM 2011; 65: 1365-1371. 3. Lustig M, *et al.*, MRM 2010; 64: 457-471.