Free-breathing cardiac 3D cine MRI at 3T using golden-ratio Cartesian radial sampling and variable flip angle

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Target Audience: MR physicists and radiologists/cardiologists who are interested in advanced cardiac cine imaging.

Introduction: Conventional cardiac 2D cine MRI involves subject's multiple breath-holds to cover the entire left ventricle. However, this approach may yield slice misregistration due to inconsistent breath-hold positions and may cause discomfort in patients having difficulty in holding their breaths multiple times. To overcome this limitation, free-breathing cardiac 3D cine imaging has been investigated [1-3]. We propose a new 3D cine imaging technique that 1) provides a reduced specific absorption ratio (SAR) with a variable flip angle (VFA) scheduling and 2) allows for flexible retrospective selection of temporal window from raw data continuously acquired during free breathing.

Methods: Experiments were performed on a GE HDxt 3T scanner with an 8-ch cardiac receive coil. Two healthy adult volunteers and two obese adolescents with sleep-disordered breathing participated in the imaging study. A 3D balanced SSFP (bSSFP) sequence was used for cardiac cine. Imaging parameters: FOV = 30×25×12.5 cm^3, slab thickness = 8 cm, 2.5 mm isotropic resolution, acquisition matrix = 120×100×50, TR=4.0 ms, scan time = 2min 30sec. Data acquisition was continuous and based on a 3DFT golden-ratio Cartesian radial sampling (GR-CAPR) [4,5] as shown in Fig 1. Full-spoke GR-CAPR with even number of the (k_y,k_z) encodes along the spoke was adopted to avoid a significant change in the (G_y,G_z) gradients when traversing low frequency in k-space and thus mitigate eddy current effects in bSSFP [6]. VFA scheduling was employed in which flip angles were weighted based on the distance from the (k_y,k_z) origin (see Fig 2a) to reduce SAR [9]. Plethysmograph (PG) data was collected. R-wave location was estimated by subtracting 280 ms from each PG trigger [7]. Retrospective data binning to cardiac phases in an expiratory respiration phase was performed. L1-SPIRiT reconstruction [8] was used to obtain time-resolved 3D images with N=25 phases after a view sharing of GR-CAPR data. Images corresponding to an end-systole and an end-diastole were selected after a manual inspection.

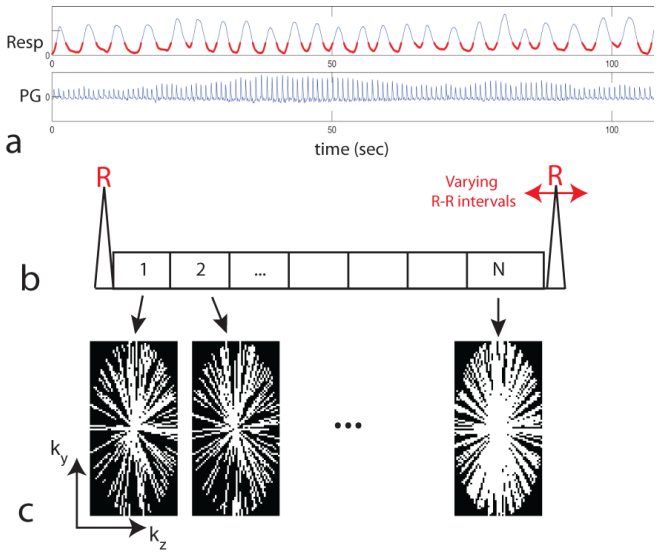

Fig 1. (a) An example of acquired respiration and PG signals. Samples corresponding to expiration are indicated by red. (b) Data binning within R-R with N cardiac phases. (c) Sampling pattern after a data binning. Note a denser sampling with longer temporal window available at the cardiac phase N, which corresponds to a stable diastolic phase.

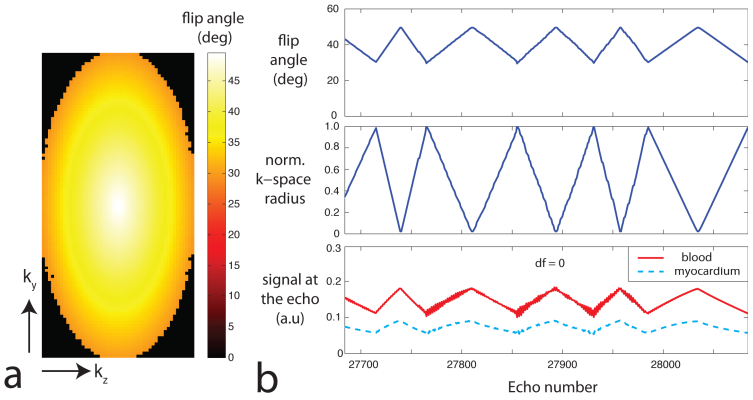

Fig 2. Proposed variable flip angle scheduling. (a) Variable flip angle distribution in the (k_y, k_z) domain. (b) Variations in (top) flip angle, (middle) k-space radius in the GR-CAPR, and (bottom) signal behavior at on-resonance.

Results and Discussion: Figure 1c shows an actual result on the sampling patterns at certain cardiac phases when retrospectively binning the data. This shows a relatively denser sampling near the k-space origin than the periphery for every cardiac phase. Figure 2 contains simulation results for the proposed VFA and shows that the signal behavior of the myocardium and blood is weighted on the (k_y, k_z) space linearly despite some signal oscillations (see the red plot in Fig 2b). The proposed VFA approach took advantage of the fact that most energy is concentrated in low spatial frequency and utilized relatively larger flip angle in low spatial frequency than in high spatial frequency. The SAR ratio between the constant and VFA schemes was calculated and the SAR was reduced by 47% for the VFA scheme. Image blurring due to the k-space weighting is expected, but has not been demonstrated in this study. The proposed GR-CAPR offered the benefit of uniformly spaced sampling azimuthally in the (k_y, k_z) space when retrospectively selecting cardiac phases. Future work will investigate 1) various VFA schemes for finding maximal blood-myocardium contrast, and 2) higher resolution imaging (~1 mm isotropic resolution) of the whole heart with a longer scan time (~4 min) and higher acceleration.

Conclusion: We have demonstrated the feasibility of a new 3D cardiac cine imaging during free breathing with a good depiction of the blood-myocardium contrast in systole and diastole.

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References: [1] M Henningsson et al., JMRI 2013:37;986-992. [2] Usman et al., ISMRM 2013, p609. [3] Seeger et al., Pediatr Radiol 2009:39;1333-1342. [4] YC Kim et al., MRM 2013 (Early View). [5] Haider et al., MRM 2008:60(3);749-760. [6] Bieri et al., MRM 2005:54;129-137. [7] Lanzer et al., Radiology 1984:150;121-127. [8] Murphy et al., IEEE TMI 2012:31;1250-1262. [9] Srinivasan and Ennis, MRM 2013 (Early View).

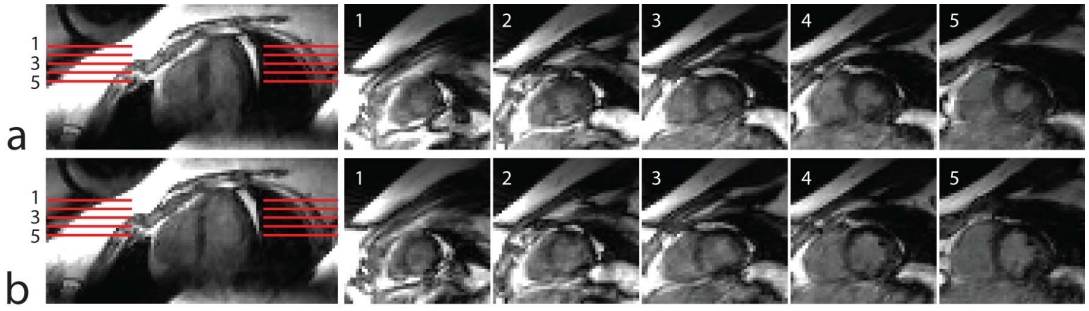

Fig 3. Free-breathing 3D cine in-vivo results. 4-chamber and short-axis view images (1 to 5: apex to mid) during (a) systole and (b) diastole in an expiratory phase from a 16 year old female obese patient. 3D bSSFP sequence with GR-CAPR and variable flip angle scheduling was used with a 2.5 mm isotropic resolution. Note a good depiction of the blood and myocardium borders in the 4-chamber and short-axis views.