Fast Imaging Sequence For Free-Breathing Planning in Cardiac Imaging

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Introduction: Magnetic resonance imaging is the gold standard for assessing global and regional function of the heart; such as the analysis of ejection fraction, ventricular volumes, and quantification of myocardial wall-motion [1]. However, the initial planning step required to localize the heart principal axes is time consuming and requires at three or four breath-holds in order to get to the first targeted slices. In this work, we propose a fast black-blood pulse sequence which requires a scan duration of one heartbeat.

Methods: Pulse Sequence: Based on the modified STEAM sequence proposed in [2], Fig. 1 shows a diagram for the proposed sequence. First, modulation pulses are applied upon the detection of the QRS complex of the electrocardiogram (ECG). Then images are acquired at a demodulation frequency equal to the original one. This results in obtaining signal only from the tissues that maintained the original modulation and nulling the blood signal because of its flow. A reduced field of view (FOV) is achieved by localizing the modulation pulses such that only the region around the heart is modulated. Images are then obtained using multi-shot spiral acquisition. The combination of reduced FOV and spiral acquisition allow for acquisition of a complete set of images in just one cardiac cycle.

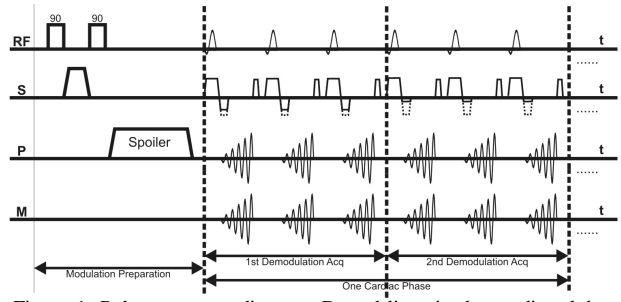

Figure 1: Pulse sequence diagram. Dotted lines in the gradient lobes represent the original gradient values without the demodulation.

***In Vivo* Experiments:** During regular cardiac imaging exams on a 3T MRI scanner (Philips Medical Systems, Best, the Netherlands), the proposed sequence was used for free-breathing image planning on twenty healthy volunteers. All subjects were imaged in the supine position. Following standard survey images using a scout sequence, two series of planning acquisitions are acquired using regular breath-hold cine and the proposed free-breathing technique. Each planning series starts with pseudo 2-chamber then pseudo 4-chamber and ends with the true short-axis plan. A true four-chamber plan was acquired depending on the need of this plan for the running exam.

Numerical Analysis: For each two corresponding results (using regular cine and the proposed technique), two values were calculated: the angle between the planes of the two slices and a distance between them. The distance was calculated as the average between the shortest distances between each slice center and the other slice.

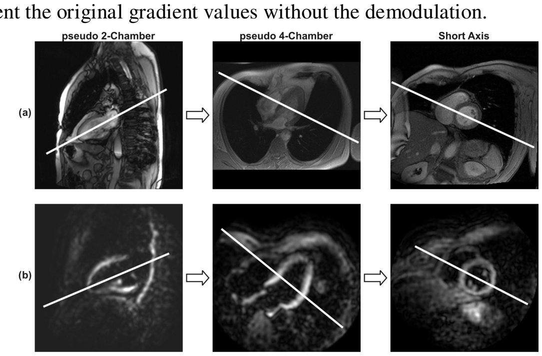

Figure 2: Planning steps using a) Regular Cine, and b) Proposed technique. Each line represents how the operator continued to the next step.

Inter- and intra-observer variability: To assess the reproducibility of the proposed sequence, five volunteers were randomly selected to have the planning procedure by four different operators (observers). Each operator repeated the planning procedure four times, two times using regular cine and two times using the proposed sequence (FIP), independently. For each observer, the angle and distance were calculated between each of the following pairs of image sets: the two acquisitions using the regular cine (cine/cine), the two acquisitions using the proposed sequence (FIP/FIP), and (cine/FIP). ANOVA test was then applied to determine the agreement between those pairs. The same procedure was repeated for each volunteer to test the inter-observer variability. Then, for each subject, the agreement between the observers on the final slices was also statistically analyzed. The following acquisition parameters were used for the proposed technique: FOV, 256×256mm^2; Excited region width, 200mm; matrix size, 64×64; last flip angle [2], 30°; slice thickness, 10mm; in-plane spatial resolution, 4×4 mm^2. For each cardiac phase, two demodulation images were acquired, for each one 3 spirals were used with acquisition window of 7msec. This results in a temporal resolution of 42msec. Depending on the heart rate, 17-25 cardiac phases were acquired. The total scan time was 0.7-1.0 sec.

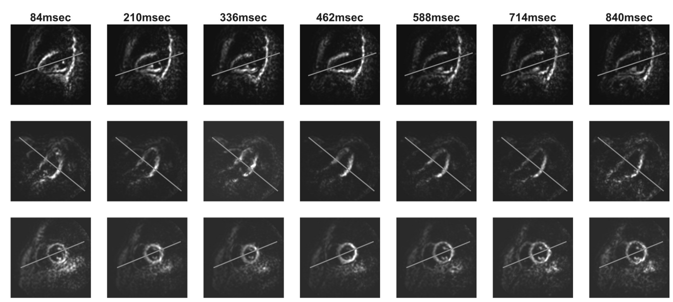

Figure 3: Representative cardiac phases for planning using the proposed technique. Columns represent time frames while rows show different planning slices (pseudo 2-Chamber, pseudo 4-Chamber, and Short-axis).

Results and Discussion: Fig. 2 shows representative results for the planning steps for one of the volunteers. While the regular cine images have better resolution and more details, the images from the proposed technique have enough details for adequate planning. The black blood feature allows for better recognition of the ventricles. Fig. 3 shows the complete cardiac phases of each of these planning steps. The interleaving between the two demodulation images helped in getting clear images over the whole cardiac cycle, either during relaxation (where the first demodulation image has more information) or during contraction (where the second one has clearer ventricle view). The angle between each two final targeted slices was 4.6±3.4° and the average distance was 2.4±1.9mm. Table 1 shows the ANOVA test results for the inter- and intra-observer reliability. The test shows no significant difference between the final targeted plans obtain using the regular cine and the proposed technique. For the same operator, planning time was reduced from 5±2min using regular cine images for planning to 2.2±0.7min using the proposed protocol.

	Inter-observer				Intra-observer			
	Angle		Distance		Angle		Distance	
	Mean (°)	SD (°)	Mean (mm)	SD (mm)	Mean (°)	SD (°)	Mean (mm)	SD (mm)
Cine-Cine	4.9	2.5	2.2	1.6	4.8	3.4	1.5	1.1
FIP-FIP	5.7	2.3	3.1	1.9	3.5	0.8	1.3	0.9
Cine-FIP	4.8	2.6	2.9	1.7	5.3	1.7	1.7	1.1
p-Value	0.34		0.43		0.53		0.59	

Table 1: Inter- and Intra- observer results using ANOVA test for both the angle and average distance between each two corresponding slices.

Conclusion: With a relatively low spatial resolution (4mm), the proposed protocol can be used for free-breathing cardiac imaging planning. This helps to reduce the overall scan time and the number of breath-holds during the exam which is especially important for dyspneic patients.

Acknowledgment This work was supported in part by grants from the national institute of heart, lung and blood R01HL072704 and R01HL61912, and Donald W. Reynolds Foundation grant.

References:

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