Real-Time Cine Imaging at Peak Exercise Stress with a 32-Channel Cardiac Array, TGRAPPA, and Karhunen-Loeve Image Filtering

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Introduction: Exercise stress testing is widely used to diagnose coronary artery disease, and is preferred to pharmacologic stress because it links physical activity to symptoms of ischemia. Exercise testing also offers additional parameters of crucial diagnostic and prognostic value such as exercise capacity, blood pressure response, ECG changes, and the presence of symptoms such as chest pain during exercise. Exercise testing has not been successfully combined with cardiac MRI due to lack of compatible equipment, as well as the challenging imaging requirements. Stress cine imaging of cardiac function in multiple views must be completed within 60 seconds post-exercise to capture exercise-induced cardiac wall motion abnormalities, and repeated breath-holding is not feasible in patients at maximal cardiovascular stress. These factors necessitate the use of real-time cine imaging, but the rapid heart rates and heavy breathing associated with exercise stress require higher temporal resolution than is attainable by current methods. Our standard exercise stress protocol utilizes a 12-channel coil and parallel acceleration rate 4, resulting in temporal resolution of approximately 52 msec; further gain in temporal resolution is desired. We propose to use a 32-channel coil to enable higher acceleration rates, combined with optimal filtering based on the Karhunen-Loeve Transform (KLT) [1] to compensate for the increased noise level associated with higher parallel acceleration. Results obtained with this new protocol are compared to our standard methods and hardware to evaluate the impact on temporal resolution and SNR.

Purpose: To investigate the performance of real-time cardiac imaging immediately after maximal treadmill exercise by the combined application of a 32-channel cardiac array coil, TGRAPPA with rate 5 acceleration, and KLT filtering.

Materials and Methods: Six healthy subjects performed maximal exercise following the standard Bruce protocol on a modified treadmill positioned in the corner of the MRI room (Siemens 1.5T Avanto). The experimental setup and imaging protocol are described by Jekic et al. [2]. Immediately after exercise, the subject was escorted from the treadmill to the MRI table, the array coil was placed on the chest, and the previously prepared scan was started immediately using the “START” button on the magnet housing.

Real-time SSFP cine was performed in 3 subjects using TGRAPPA rate 4 with a standard 12-channel coil (Siemens Medical Solutions, Malvern, PA) and in 3 subjects using TGRAPPA rate 5 with a 32-channel coil (RAPID Biomedical, Columbus, OH). 1 vertical long-axis, 1 horizontal long-axis, and five short-axis slices were acquired with an acquisition time per slice of 1.38 seconds. The number of frames varied depending on the temporal resolution which differed somewhat among subjects with adjustment of the FOV. No breath-hold or ECG gating was applied. TGRAPPA and TSENSE were both evaluated prior to each study by asking the subject to breathe heavily to mimic chest wall motion during stress. TGRAPPA was chosen for exercise imaging because it provided superior artifact performance under conditions of heavy breathing.

SNR was quantified for each of the 7 slices in all 6 subjects. Signal was evaluated in a ROI within the blood pool that excluded papillary muscles. Noise measurement in parallel acquisition is challenging due to spatial variation in noise described by a coil geometry factor (“g-factor”) [3]. Significant motion from frame to frame precluded the use of subtraction methods of noise measurement [4]. Therefore, we used an alternative method for SNR measurement based on the eigenvalues of the KLT [5]. SNR was calculated in the unfiltered images as the ratio of the blood pool signal to the noise standard deviation of the entire image. The relationship between the SNR of KLT-filtered and unfiltered images is known [6] and was calculated based on the filter cutoff. A conservative filter cutoff of 0.5 was used, resulting in a SNR gain of $\sqrt{2}$ or 41%. We have previously shown that this cutoff results in insignificant loss of information or generation of artifacts in real-time cine images.

Results: Real-time imaging of cardiac function was successfully completed within 45±4 seconds from the end of exercise in all subjects. Quantitative results are displayed in Table 1, while an example filtered and unfiltered image is shown in Figure 1. The 32-channel coil at rate 5 provided improved temporal resolution of 43.7 msec compared to 51.1 msec with the 12-channel coil at rate 4, while maintaining spatial resolution without a significant change in SNR (mean 40.4 with the new method compared to 36.9 with the standard method; $p=0.3778$).

Table 1: Temporal resolution, spatial resolution and SNR of images acquired with 32-channel coil with TGRAPPA rate 5 compared to 12-channel coil with TGRAPPA rate 4

#Coil Channels	Rate	#Frames	TR (ms)	dx (mm)	dy (mm)	Signal	Noise SD	SNR
32	5	37	44.2	2.63	3.36	281	9.95	**39.9**
		32	43.4	2.75	3.52	242	9.65	**35.3**
		32	43.4	2.81	3.60	306	9.38	**45.8**
12	4	30	46.4	2.63	4.00	281	8.36	**33.9**
		26	52.8	3.13	4.00	208	5.67	**36.8**
		26	54.2	2.63	3.75	365	9.33	**39.9**

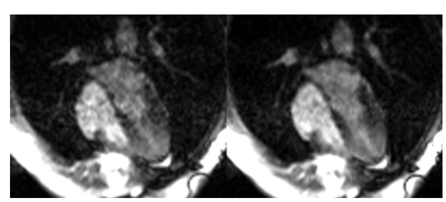

Figure 1: Horizontal long axis view at peak stress; filtered (left) vs. unfiltered (right) images acquired with TGRAPPA rate 5 and 32-channel coil

Conclusions: Temporal resolution demands for real-time cine imaging at peak exercise stress have motivated us to propose the combined use of a 32-channel coil with optimal filtering in the hope of increasing the acceleration rate from 4 to 5 without a penalty in SNR. This combination of improvements in hardware and image processing allows us to successfully increase temporal resolution without compromising SNR.

References:

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