Feasibility of Five-Minute Comprehensive Cardiac MR Examination Using Highly Accelerated Parallel Imaging with a 32-Element Coil Array

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Introduction: Cardiac MRI (CMR) is one of the most versatile means of noninvasive assessment of cardiovascular disease. A comprehensive cardiac exam usually occupies 30 minutes to 1 hour [1-3] and evaluates cardiac morphology, function, perfusion, coronary artery anatomy and myocardial viability. A large portion of the total scan time is devoted to anatomy- and physiology-specific scan planning. Repetitive breath–holds are generally required to examine the entire heart volume. Such procedures require substantial user interaction, and the resulting image quality tends to be operator dependent. Fast volumetric 3D and 4D imaging are desirable to reduce total scan time and minimize operator dependence as well as to improve the image quality and throughput. So far, rapid volumetric techniques have been limited either in spatial resolution, temporal resolution or volumetric coverage. With the combination of 32-channel receiver coils and advanced acceleration strategies, rapid comprehensive cardiac imaging becomes feasible. In this study, highly accelerated 3D and 4D imaging techniques for comprehensive cardiac imaging in a total time of 5 minutes were developed and assembled into a single streamlined protocol, which was evaluated for feasibility in healthy adult subjects.

Methods: Figure 1 outlines the imaging protocol used in this work. 10 subjects were examined using the following pulse sequences:

- 3D Perfusion imaging: an SR prepared TurboFLASH sequence utilizing TGRAPPA [4] with an acceleration factor of 4 in the phase encoding direction (PE) and 2 in the partition direction (PA) was used. Other sequence parameters are as follows: TI 110ms, TR 2.4ms, TE 0.9ms, FA 10°, Matrix 128x76x10, slice over sampling 20%, FOV 34x34x10cm^3, spatial resolution 2.6x4.4x10mm^3, BW 1392Hz/pixel, 40 repetitions, total acquisition time (TA) 36s. The total number of lines acquired was 76/4=19 phase encodes x 12/2=6 partition encodes; the data acquisition window per 3D volume was 273.6ms.
- 3D CINE imaging: A breath-held TrueFISP sequence using 2D TGRAPPA with an acceleration factor of 4 (PE) by 2 (PA) was employed, with the following parameters: matrix 192x192, FOV 34x34x10cm^3, slice thickness 5mm, partitions 20, number of lines per segment 18,TE 1.13ms, TR 3.1ms, BW 800Hz/pixel, temporal resolution 45.8ms,TA 18s.
- Whole heart 3D coronary MRA: A breath-held TrueFISP sequence was used with data acquired during diastole, 2D GRAPPA acceleration of 4 (PE) by 2 (PA), matrix 256x192x60, FOV 34X34X12cm^3, voxel size 1.3x1.7x2mm^3 reconstructed to 0.65x0.85x1.0mm^3. An additional short breath-held coil sensitivity calibration dataset was acquired. Total acquisition time for the two breath-holds was 50s.
- 3D myocardial viability imaging: A breath-held TrueFISP sequence was used with 2D GRAPPA acceleration of 4 (PE) by 2 (PA) with an additional coil sensitivity scan. Parameters: matrix 256x192x20, FOV 34x34x10cm^3, slice thickness 5mm, TI 250ms-300ms. TA 50s.
- The 5-min comprehensive cardiac examination was performed on a whole-body 1.5T MR scanner (Avanto, Siemens Medical Solutions, Erlangen, Germany) using a 32-element cardiac coil array (Invivo, Florida). Each contrast injection used a single dose (0.1mmol/kg) of contrast agent (Berlex Magnevist, Schering AG) at 5ml/s followed by a saline flush (20ml at 5ml/s). The first contrast injection, performed during subject preparation, is a loading dose to ensure sufficient enhancement by the time of the final myocardial viability scan.

Results: The left-hand panel of Figure 2 shows a representative Coronary MRA of the LCX and LAD obtained from a whole heart volume obtained in a total of 50 seconds using 8-fold acceleration. For comparison, the result of conventional whole heart coronary MRA acquired with a free-breathing technique in 8 minutes is shown at the right of Figure 2. Figure 3 shows reformatted short axis and 4-chamber views from a whole heart breath-held 3D CINE dataset (left and middle) and representative 3D myocardial viability image (right). Figure 4 shows representative whole heart perfusion images before contrast arrival, during RV enhancement, during LV enhancement, and during myocardial enhancement.

Discussions: Comprehensive cardiac MR examination in a short sequence of breath-holds has been demonstrated using highly accelerated parallel imaging, each breath-hold is restricted within 20 seconds, so as not to exceed the breath-holding capacity of the target patient population. Therefore, total examination time from the start of the first scan to the end of the last; including suitable rest periods and injection time, is approximately 5 minutes. Eightfold accelerations approach the maximum practical capability of the coil array used here. However, we are currently exploring complementary acceleration techniques such as compressed sensing, which are expected to enable acquisition of more nearly isotropic datasets for improved reformatting, as well as elimination of separate breath-holds for sensitivity calibration data.

References: [1]. Plein S, et al., Radiology 2002; [2].Foo TK, et al., Radiology 2005; [3]. Gutberlet M, et al, Invest Radiol 2006; [4] Breuer FA, et al. MRM 2005.

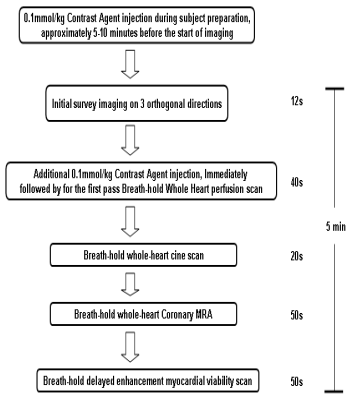

Figure 1: Target protocol used for comprehensive cardiac exams

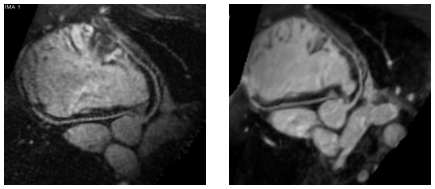

Figure 2: Left: MRA of the LCX and LAD obtained from a breath-held whole heart volumetric dataset; Right: MRA of the LCA and LAD using a free breathing scan lasting 8 minutes.

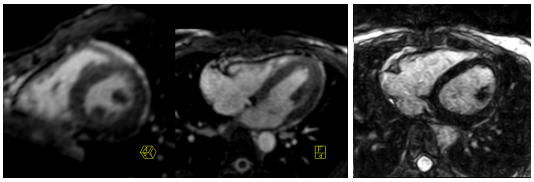

Figure 3: Representative 3D CINE (Left: reformatted short axis view; Middle: reformatted 4-chamber view) and 3D myocardial viability (right) images obtained from whole heart imaging with 8-fold acceleration.

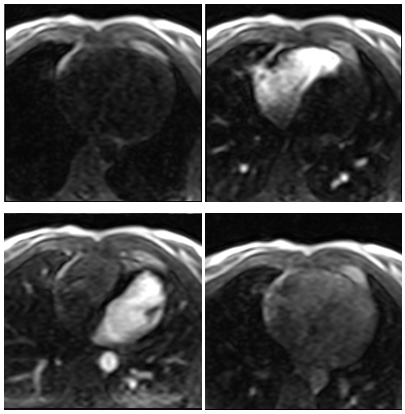

Figure 4: Representative perfusion images at pre-contrast, RV, LV, and myocardial enhancement time points.