

Time-resolved Contrast-Enhanced Coronary Vessel Wall Imaging

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Introduction: Most acute coronary syndromes result from rupture of vulnerable plaques [1]. As a result, it's clinically very important to assess the vulnerability of coronary plaque. While studies have shown that inflammation plays a major role in plaque rupture, it is crucial to be able to evaluate the extent of inflammation of coronary vessel wall plaque. Contrast-enhanced studies have shown delayed-enhancement in several inflammatory vessel wall diseases, such as giant cell arteritis [2] and myocarditis [3]. Also strong associations between histological markers of inflammation and quantitative indices generated from dynamic contrast-enhanced carotid images in patients were demonstrated [4]. It is highly likely that the same mechanism will work in coronary wall. Delayed-enhancement and characterization of plaque component were successfully observed in coronary arteries after a delay time of one hour [5]. However, there have been no studies to demonstrate whether enhancement or characterization can be observed in very early-enhancement stage or to link the quantitative indices from dynamic contrast-enhanced images to inflammation in coronary artery. This is not a trivial task given the need for TI-independent black blood vessel wall imaging with high spatial resolution and temporal resolution. In this work, we modified the method proposed by Khaled Z [6] for dynamic contrast-enhanced coronary vessel wall imaging.

Theory: After a Double Inversion Recovery (DIR) preparation pulses, the vessel wall returns to the original magnitude while the flowing blood that does not go through the 2nd re-inversion recovers from the negative magnetization. At the beginning of contrast injection, the blood has shorter T1 due to high concentration of contrast, thus recovers faster (Fig1. Grey rectangle); as contrast washes out, the blood has longer T1 due to lower concentration of contrast and recovers slower (Fig1. Black rectangle). Using the phase-sensitive (PS) reconstruction method [7], we can identify the polarity information of the blood regardless of the TI and thus differentiate the coronary vessel wall and lumen. As a result, this can be a TI-independent vessel wall imaging technique to measure the quantitative indices during the dynamic contrast-enhanced process. But the limitation is that while contrast concentration is high, both blood and vessel wall will have positive magnetization and PS methods could not help to differentiate between them. However, one way to minimize the impact of this problem is to use TI that's as short as possible so that most of the time blood has negative magnetization.

The PS reconstruction is calculated by the following steps shown in Fig. 2: 1) Select the small rectangular area around vessel wall which covers mostly myocardium to provide high SNR phase information and crop out the region where coronary artery locates to avoid high variability (b). 2) Choose the high SNR data in both magnitude and phase image (c, d), 3) After unwrapping, utilize 2D polynomial weighted least square fitting with magnitude information (e) as weighting function to interpolate the crop-out-region phase (f) into the background phase (h). 3) Subtract (h) from the original phase (b) to get the true phase (g). 4) Recover the true polarity information by multiplying (a) with (g) and get the final polarity corrected image (i), where (i) is the enlarged image of corrected vessel wall compared to the original vessel wall image (k).

Methods: Four healthy subjects (2 Male, 2 Female) were scanned on 3.0T (Trio, Siemens) using a 32-channel coil (Invivo). An ECG-triggered, navigator-gated, 2D segmented DIR GRE sequence was used for acquisition to provide T1 weighting. Double dose of contrast was injecting at a rate of 2ml/s and followed by 15 mL of saline solution. Parameters used were: TE = 1.6 ms, trigger pulse = 1, TI = 240 msec, flip angle = 15°, FOV = 320x320 mm², resolution = 1 x 1 x 4.0 mm³, transversal view, 25 k-space lines per cardiac cycle, bandwidth of 605 Hz/pixel. The temporal resolution is 20~30 ms. Image processing was performed off-line using Matlab.

Results: Fig. 3 shows examples of the images from two volunteers during the contrast injection at different time frames. The upper row is before the PS reconstruction while the lower row is after the PS reconstruction. Figs. 3 (a), (b) and (c) are the 1st, 7th and 13th frame acquired after the contrast injection from one volunteer respectively; We can find the coronary vessel wall delineation improved in (f) and (g), but not so for image (e) because the blood has high concentration of contrast at the initial stage. (d) and (h) are the 2nd frame from another volunteer, where PS actually helps to null the blood and visualize the vessel wall. Fig. 4 shows the signal intensity curve of the vessel wall of one volunteer in the acquired 20 frames. The dynamic wash-in and wash-out process could be observed from this figure. The CNR has improved from 13.7±2.3 to 20.3±5.2 from pre-PS to post-PS averaged throughout all the frames.

Discussion and Conclusions: We developed a TI-independent 2D black blood imaging technique on coronary vessel wall during contrast injection by using PS reconstruction. Dynamic quantitative indices such as K^{trans} , V_p can be calculated from these measurements.

References 1. Virmani R, et al. J Am Coll Cardiol 2006; 2. Mahrholdt H, et al. Circulation 2004; 3. Bley TA, et al. AJR Am J Roentgenol 2005; 4. William S. Kerwin et al. Radiol 2006 ; 5. Yeon SB, et al. JACC 2007; 6. K. Z. Abd-Elmoniem, et al. MRM 2010. 7. Kellman P, et al. MRM 2002;47:372–383.

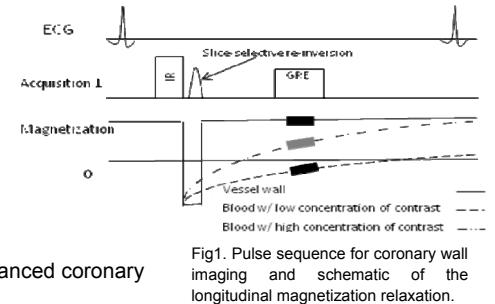


Fig 1. Pulse sequence for coronary wall imaging and schematic of the longitudinal magnetization relaxation.

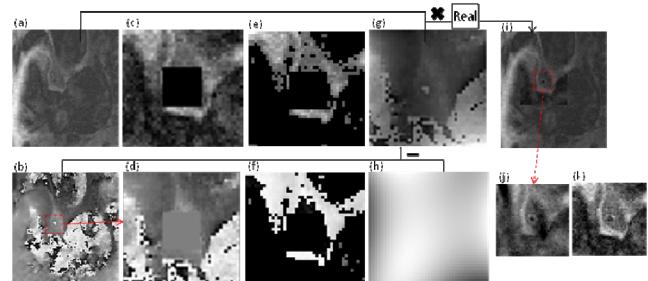


Fig 2. Illustration of reconstruction process for the DIR coronary vessel wall.

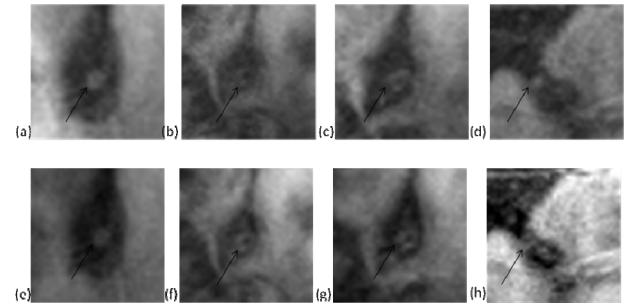


Fig. 3. Examples of the images from two volunteers at different time frames after contrast injection.

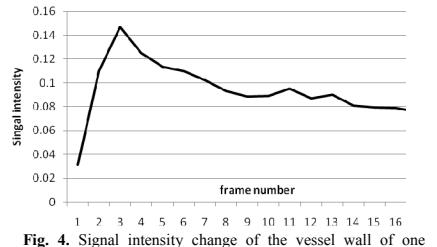


Fig. 4. Signal intensity change of the vessel wall of one volunteer.