Time-Resolved Contrast-Enhanced Black-Blood Carotid Vessel Wall Imaging with SRDIR

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Introduction: Inflammation plays a critical role in various stages of the atherosclerotic plaque development [1]. Destructive enzymes and cytokines produced by inflammation at the core of the plaque lead to rupture of the fibrous cap of the carotid plaque, causing stroke [2]. Dynamic contrast-enhanced vessel wall imaging has been used to link the enhancement pattern to the extent of inflammation of carotid plaque [3]. However, the previous work used a bright blood technique, making it difficult to clearly draw the contour of the vessel wall [4]. Partial volume effects from the bright lumen may lead to errors in signal measurements from the vessel wall. In this work, we developed a time-resolved contrast-enhanced black-blood technique to overcome the limitation. In addition, an interleaved acquisition strategy was implemented to facilitate determination of K^{trans} (transfer constant), etc.

Theory: An SRDIR (Saturation Recovery + Double Inversion Recovery) sequence was designed to achieve two aims: 1) To create T_1-weighting for vessel wall so that the signal intensity of the vessel wall reflects contrast concentration; 2) To consistently null the blood with a fixed inversion time TI despite the rapidly changing blood T_1 during the wash-in and wash-out periods of contrast media. During each heartbeat, after the ECG-trigger and a delay time (TD), a 90^0 non-selective saturation pulse is applied. After a delay of TI_1, a DIR preparation (a non-selective inversion pulse immediately followed by a slice-selective inversion pulse) will be applied. Data acquisition starts after another delay time of TI_2. With these preparations, magnetization of the stationary tissue in the imaging plane, including the vessel wall experiences saturation recovery only and is T_1-weighted. Tissues outside the imaging plane, flowing blood in particular, will undergo both SR and IR preparations, which have a wider range of T_1 nulling compared to single IR pulse [5]. As shown in Fig. 1, an appropriate combination of TI_1 and TI_2 is the key to consistent blood nulling because blood T_1 changes dynamically after contrast injection. An additional benefit of the SR preparation is that signals from both vessel wall and blood become insensitive to arrhythmias. To permit K^{trans} and V_p (fractional plasma volume) calculation, which needs blood signal to provide arterial input function, the black-blood acquisition is interleaved with a bright-blood acquisition where only SR preparation is applied and T1-weighted blood signal will be measured.

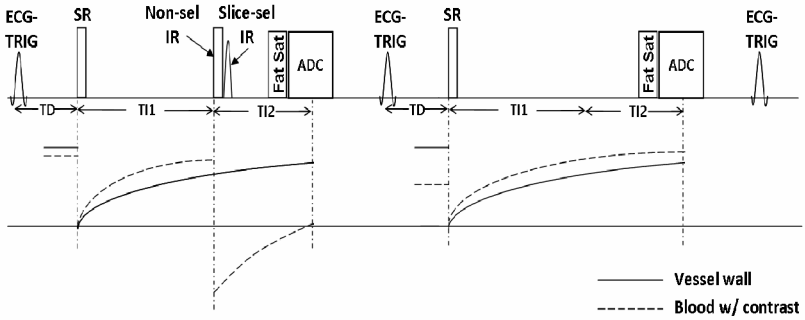

Fig. 1 A 90° pulse is applied after an appropriate trigger delay time (TD) in each cardiac cycle. A time delay TI_1 is allowed after the saturation pulse, which is followed by a double-inversion pulse and another time delay TI_2. This sequence is designed to be interleaved to allow both black-blood and bright -blood images to calculate K^{trans} and V_p.

Methods: Five healthy subjects were scanned on a 3.0T MR system (Verio, Siemens) using a 4-channel carotid coil. An ECG-triggered, 2D segmented gradient-echo sequence was used for data acquisition. 0.2 mmol/kg of contrast (OptiMark) was injected at a rate of 0.2 ml/s and followed by 20 ml saline solution. Parameters used were: TE = 2.2 ms, flip angle = 25°, FOV = 258 x 258 mm^2, spatial resolution = 1.0 x 1.0 x 2.0 mm^3, transversal view, 30 k-space lines per cardiac cycle, bandwidth of 605 Hz/pixel. The temporal resolution is ~30 s. TI_1 and TI_2 was chosen to be 670ms and 40ms respectively based on simulation to null the blood during contrast injection consistently.

Results: Fig. 2 shows example images from one volunteer during the contrast injection at different time frames (a, b, c and d are the 5^{th}, 8^{th}, 9^{th} and 13^{th} frame acquired after the contrast injection). Irrespective of the T_1 of the blood, blood signal is dramatically suppressed which creates sufficient contrast between vessel wall and lumen. Some residual blood signal can still be observed in the first several frames since blood T_1 is significantly short at the beginning. However, good separation between vessel wall and lumen is maintained. Fig.3 illustrates the significant blood suppression during the contrast injection. Figs. 4 shows the images collected in an interleaved fashion at multiple time frames from another volunteer. (a, c and e are the 1^{st}, 5^{th} and 8^{th} images from the dark-blood measurement while b, d and f are the corresponding bright-blood measurement). K^{trans} and V_p calculated from the volunteers are 0.01 min^{-1} and 0.25, which are in agreement with previous studies [3,4].

Discussion and Conclusions: A T_1-insensitve 2D black blood imaging technique, SRDIR-prepared gradient-echo sequence, was developed for investigating the contrast dynamics in the carotid vessel wall. Quantitative indices such as K^{trans} and V_p can be calculated for evaluating inflammation. Further carotid disease patient studies are needed to validate this technique.

References 1. Ross R. N Engl J Med 1999 ; 2. Falk E, et al. Circulation 1995 ; 3. William S. Radiology, 2006 4. Dong Li, et al, Radiology 2001; 5. Deshpande VS, et al. Magn Reson Med. 2003;

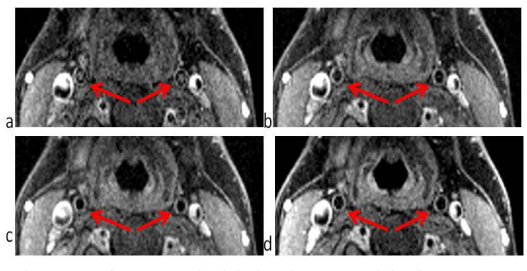

Fig. 2. Four frames acquired during the contrast injection process, red arrows point to the carotid vessel walls.

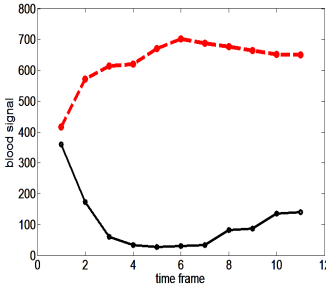

Fig. 3. Blood signal changes during contrast injection. Red line: SR-prepared (bright-blood); black line: SRDIR prepared (black-blood)

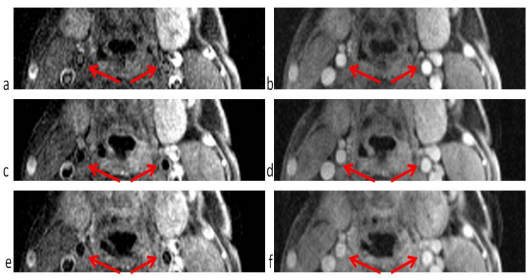

Fig. 4. Three frames acquired during the contrast injection process with the interleaved scheme.