Carotid Multicontrast Atherosclerosis Characterization (MATCH) in a Single Scan: Technical Development and Preliminary Validation

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Introduction: The conventional MRI protocol for the characterization of atherosclerotic plaques involves a series of scans that provide multiple contrast weightings (e.g. T1-weighted, T2-weighted, and bright-blood, etc.) [1]. Despite the success in previous investigations, the multicontrast protocol has four major limitations: (a) the major part of the protocol, two-dimensional (2D) black-blood fast spin-echo imaging, has limited slice resolution; (b) multiple scans lead to a substantially long examination time (approximately 30 min); (c) image registration often needed due to interscan motion is time-consuming and sometimes unsatisfactory [2]; (d) compositional analysis requires image interpretation by a trained reader or specialized software. **The aim of this work was to develop a 3D MRI technique that acquires multiple image sets in a single 5-minute scan with distinct contrast weightings that help simplify compositional analysis in carotid plaques**.

Methods: *Sequence Design* The proposed sequence, called MATCH (Multicontrast Atherosclerosis Characterization), utilizes a spoiled gradient echo-based MRI acquisition combined with specialized magnetization preparative schemes. Multiple 3D image sets are collected in an interleaved scan with 4 TRs per cycle: the 1st TR provides hyper T1-weighted (T1w) contrast by using a nonselective inversion pulse and a blood-suppressing flow-sensitive dephasing (FSD) preparation [3]; the 2nd TR provides gray-blood lumen arising from both blood T1-recovery and in-flow fresh blood; the 3rd TR is for signal recovery without readout events, followed by the 4th TR for T2-weighted (T2w) contrast by using a long FSD preparation (T2-FSD). The three contrasts aims to identify the intra-plaque hemorrhage (IPH), juxtaluminal calcification (CA), loose matrix (LM), and potentially necrotic-rich lipid core (LC), respectively. With imaging parameters optimized by computer simulations (**Fig. 1**), **a proof-of-concept study was performed on 8 patients with known carotid plaques**. Further efforts were made to improve the T2w image quality and signal-to-noise ratio (SNR) as this contrast is more relevant to provide information on plaque geometry and structure. A variable-flip-angle (VFA) strategy using higher flip angles (FA ≥ 12°) is used in the T2w acquisition to generate more signals during the echo train (**Fig. 2**). **This refined protocol was tested on 6 healthy subjects**.

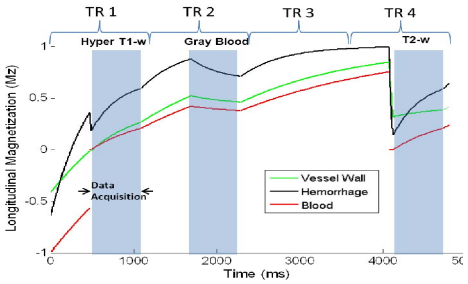

Fig. 1. *Computer simulations on longitudinal magnetization evolution in MATCH imaging*

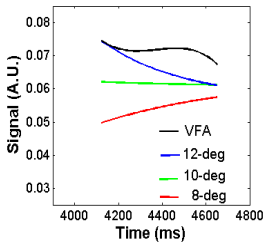

Fig. 2. *Signals on the T2w acquisition using different flip angles by simulations*

Human Study All studies were performed on a 3T system (Siemens Verio) using a carotid surface coil. In the patient study (**n = 8**), the MATCH technique was compared to the conventional multicontrast protocol with a matched imaging location and spatial resolution. The imaging parameters for MATCH imaging included: 55-62 lines per TR of 1200 ms, FA = 8°, in-plane resolution = 0.55-0.63 mm, 18 2-mm-thick slices, CHESS fat saturation, inversion time delay = 480 ms, m_1 = 945-1065 mT·ms²/m, FSD/T2-FSD duration = 18/40 ms, centric reordering, scan time = 5-6 min. In the healthy volunteer study (**n = 6**), four MATCH scans were conducted in a random order using FA = 8°, 10°, 12°, and VFA, respectively, for the T2w acquisition while keeping 8° for the other two. Some imaging parameters were slightly changed including FSD/T2-FSD duration = 17/45 ms, inversion time delay = 500 ms, resolution = 0.55 mm², lines per TR = 47, and scan time = 5:14 min.

Results: With MATCH, the three image sets were appropriately matched. A total of 12 locations with one of plaque components identified were assessed in the patient study. IPH (**Fig. 3a** arrows) appeared hyper-intense on the hyper-T1w image set, CA (**Fig. 3a** arrowheads) appeared as focal signal voids on gray-blood image set, and LM (**Fig.3b** dashed arrow) appeared hyper-intense on T2w but not on hyper-T1w. Compared with the conventional protocol, MATCH yielded better contrast ratio between the components and the normal vessel wall, markedly facilitating their identification (**Fig. 4**). No appreciable difference in the size of components was observed between the two protocols. In the volunteer study (**Fig. 5 a-e**), the use of VFA yielded a significantly higher vessel wall SNR, lumen SNR, and wall-lumen CNR than other choices ($p < 0.05$ for all, based on a *t*-test of 12 samples from 12 arteries).

Discussion and Conclusion: This preliminary patient study demonstrated that MATCH is a promising technique for an expedite and accurate characterization of carotid plaques. The novel technique is capable of generating three inherently registered 3D image sets with different component-relevant contrasts in a 5-min scan. The refined MATCH sequence can further improve the T2w image quality, thus facilitating carotid plaque assessment. A large-scale patient validation of the novel sequence is currently underway, using histology specimens as reference.

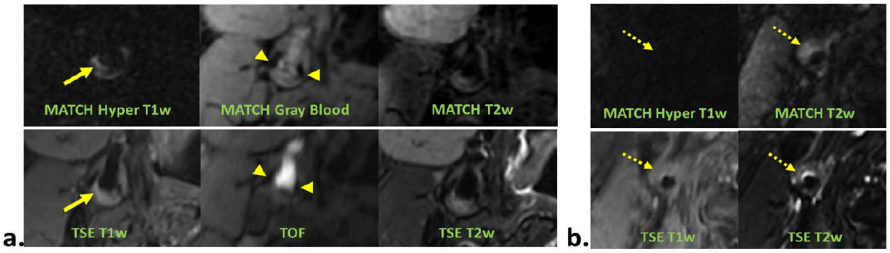

Fig. 3 *Representative images obtained using the MATCH and conventional protocols in two patients. Arrow: haemorrhage; Arrowhead: superficial calcification; dashed arrow: loose matrix.*

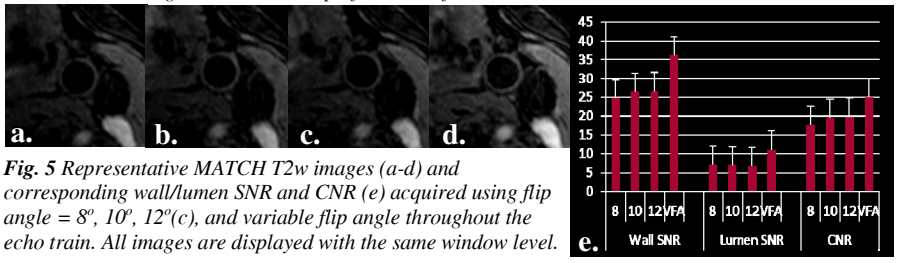

Fig. 5 *Representative MATCH T2w images (a-d) and corresponding wall/lumen SNR and CNR (e) acquired using flip angle = 8°, 10°, 12°(c), and variable flip angle throughout the echo train. All images are displayed with the same window level.*

References: 1. Yuan C et al. Circulation 2001;104:2051 2. Boussel L et al. Radiology 2009;252:789. 3. Fan Z et al. MRM 2009;62:1523.

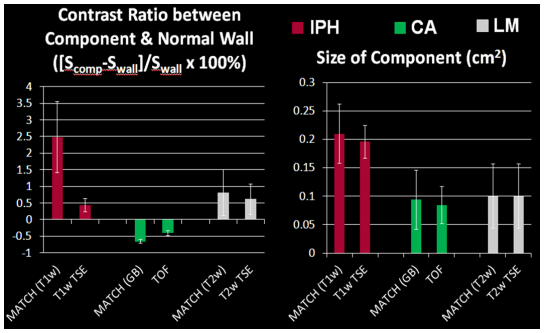

Fig. 4 *Quantitative comparison between the MATCH and conventional protocol. MATCH yields better contrast ratio between each of the target components and the normal vessel wall. The size of each of the components measured using the two protocols are comparable.*