Dual Contrast Vessel Wall MRI using Phase Sensitive Polarity Maps

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Introduction: Thromboembolism from carotid atherosclerotic plaque is a major cause of mortality and morbidity from stroke. Carotid plaques that are most likely to cause thromboembolism exhibit high-risk features such as stenosis, large plaque burden, intraplaque hemorrhage (IPH) and juxtaluminal calcification (JCA) [1]. Currently vessel wall MRI for identification of such high-risk plaques requires the use of multiple sequences to determine each of the components. However clinical application of a multi-contrast protocol with several sequences may not be clinically feasible due to limited scan times. Recently a phase-sensitive inversion-recovery (IR) based sequence (SNAP) [2] was proposed to simultaneously identify stenosis and IPH. However the highly T1-weighted images of the SNAP method do not provide information about plaque burden or JCA. In this work we extend the SNAP reconstruction to include a black-blood proton density (PD) weighted image for plaque burden and JCA assessment.

Aims: 1) To develop a dual contrast vessel wall MRI imaging method to provide stenosis assessment using bright blood MRA and plaque burden assessment using black-blood MRI, 2) To use the sequence to identify high risk plaque constituents related to symptoms: IPH and JCA.

Materials and Methods: ***Image Acquisition:*** Imaging parameters were similar to [2]: TR/TE 10/4ms, TI 500ms, Resolution 0.8x0.8x0.8mm, FOV (coronal) 16x16x3.2cm, turbo factor 98, scan time 5 min. Two images were acquired after one IR pulse. Acquisition flip angles were 11 and 5 degrees respectively (corresponding to α and θ in fig 1). Imaging parameters were adjusted such that the first image (I_1) is T1-weighted and the second image (I_2) is PD weighted. ***Image reconstruction:*** Defining the acquired image as $I(x,y) = \|I(x,y)\|P(x,y)e^{-\emptyset(x,y)}$ where $P(x,y)$ is the polarity function which takes values (-1 or +1) depending upon the longitudinal magnetization and Ø(x,y) is the total background phase due to factors such as flow, susceptibility, gradient group delays etc. $P(x,y)$ can be calculated using $I_1(x,y)$ and $I_2(x,y)$ as

$$P(x,y) = \frac{I_1(x,y)I_2^*(x,y)}{\|I_1\|\|I_2\|}$$

where * represents complex conjugation. T1-weighted corrected real image is then obtained as $S_1(x,y) = P(x,y)\|I_1(x,y)\|$ and PD-weighted corrected real image is obtained as $S_2(x,y) = P(x,y)\|I_2(x,y)\|$. Since blood is inverted in I_1, voxels corresponding to blood take value of -1 in $P(x,y)$. Thus bright-blood MRA can be generated as the negative part of $S_1(x,y)$ (fig 2) for stenosis assessment similar to [2]. Additionally $S_2(x,y)$ produces black-blood PD-weighted vessel wall image (fig 2) for plaque burden assessment. The reconstruction of $S_2(x,y)$ can be further improved by using region growing segmentation of $P(x,y)$ with seeds selected based on $I_1(x,y)$. ***Patient image review:*** Carotid MRI from 2 patients with 16-79% stenosis by doppler, was reviewed. Four images reconstructed from the single acquisition were used for identifying high risk-plaque: 1) T1-weighted $S_1(x,y)$ for IPH detection, 2) $S_1(x,y) < 0$ providing bright-blood MRA, 3) $I_2(x,y)$ providing gray blood MRI, 4) PD-weighted $S_2(x,y)$ providing black-blood MRA. Wall boundaries, IPH, JCA were compared to traditional multi-contrast carotid MRI [1] (MP-RAGE, T1w TSE, PDw TSE and 3D-TOF).

Results: $P(x,y)$ was derived from $I_1(x,y)$ and $I_2(x,y)$. Corresponding $S_1(x,y)$ and $S_2(x,y)$ were calculated using the above equations. $S_2(x,y)$ reconstruction using a region growing segmentation for determining $P(x,y)$ provided an improved PD-weighted image ($S_2(x,y)$) as shown in fig 2.

Patient comparison (fig 3) showed that all four components reflective of high-risk plaque can be identified: plaque burden and stenosis using $S_2(x,y)$, stenosis using $S_1(x,y) < 0$, IPH using $S_1(x,y)$ and JCA using $S_2(x,y)$ and $I_2(x,y)$.

Discussion and Conclusions: We have extended the SNAP method to include PD-weighted contrast for identification of plaque burden and JCA. Thus using a single acquisition coupled with the reconstruction and analysis procedure described above, multiple major high-risk carotid plaque components can be detected. **References:** [1] Saam Radiology 2007; 244(1):64-77, [2] Wang MRM 2013; 69(2):337-45

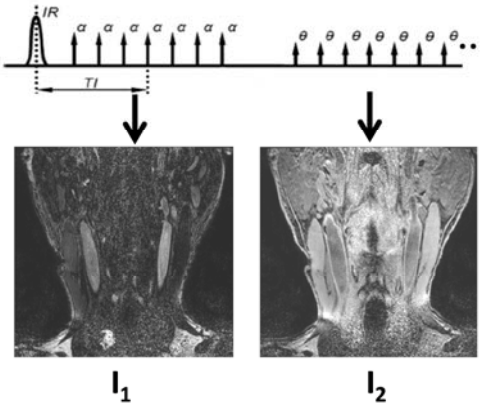

Figure 1: Sequence is based on the SNAP method [2] with a highly T1-weighted $I_1(x,y)$ acquired after a slab-selective inversion with linear encoding and flip angle α. The acquisition is repeated with a small flip angle θ after signal recovery to acquire the PD-weighted $I_2(x,y)$

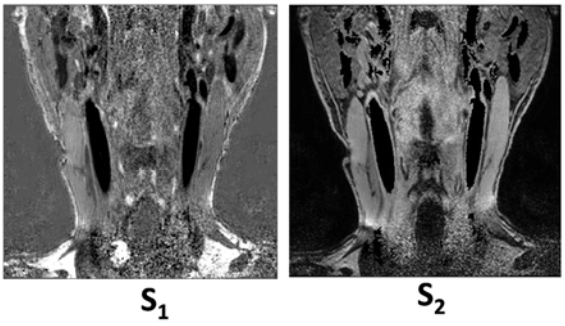

Figure 2: T1-weighted $S_1(x,y)$ and $S_2(x,y)$ corresponding to $I_1(x,y)$ and $I_2(x,y)$ in fig 1 are reconstructed using the polarity map $P(x,y)$. Note the vessel boundaries (lumen and outerwall) are clearly observed on $S_2(x,y)$

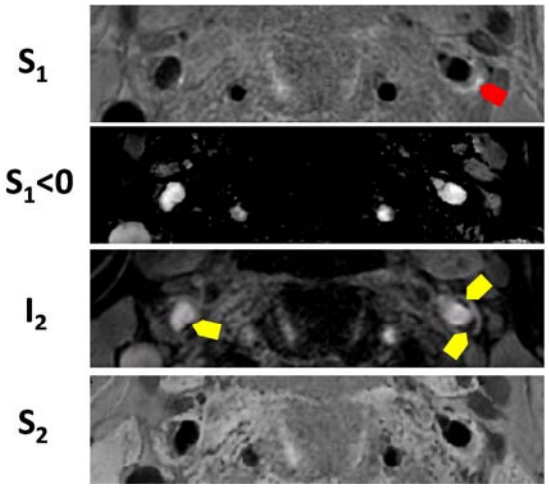

Figure 3: High risk plaque identification using four images reconstructed from a single sequence on a patient. Red arrows show IPH and yellow arrows show JCA.