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 0 in fig 1). Imaging parameters were adjusted such that the first image (I1) is T1-weighted and the second image (I2) is PD weighted. Image reconstruction: Defining the acquired image as I(x,y) = |I(x,y)|P(x,y)e^{iθ(x,y)} where P(x,y) is the polarity function which takes values (-1 or +1) depending upon the longitudinal magnetization and θ(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 I1(x,y) and I2(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 S1(x,y) = P(x,y)|I_1(x,y)| and PD-weighted corrected real image is obtained as S2(x,y) = P(x,y)|I_2(x,y)|. Since blood is inverted in I1, voxels corresponding to blood take value of -1 in P(x,y). Thus bright-blood MRA can be generated as the negative part of S1(x,y) (fig 2) for stenosis assessment similar to [2]. Additionally S2(x,y) produces black-blood PD-weighted vessel wall image (fig 2) for plaque burden assessment. The reconstruction of S(x,y) can be further improved by using region growing segmentation of P(x,y) with seeds selected based on I1(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 S1(x,y) for IPH detection, 2) S1(x,y) < 0 providing bright-blood MRA, 3) I2(x,y) providing gray blood MRI, 4) PD-weighted S2(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 I1(x,y) and I2(x,y). Corresponding S1(x,y) and S2(x,y) were calculated using the above equations. S2(x,y) reconstruction using a region growing segmentation for determining S(x,y) provided an improved PD-weighted image (S2(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 S2(x,y), stenosis using S1(x,y) < 0, IPH using S1(x,y) and JCA using S2(x,y) and I2(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.


Figure 1: Sequence is based on the SNAP method [2] with a highly T1-weighted I1(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 I2(x,y).

Figure 2: T1-weighted S1(x,y) and S2(x,y) corresponding to I1(x,y) and I2(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 S2(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.