Fast Simultaneous Non-contrast Angiography and intra-Plaque hemorrhage (fSNAP) imaging for atherosclerotic disease with low-resolution reference scan and corrected phase sensitive reconstruction

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Introduction The Simultaneous Non-contrast Angiography and intra-Plaque hemorrhage (SNAP) sequence has been proposed for imaging both luminal stenosis and intraplaque hemorrhage in subjects with carotid atherosclerosis in one scan by using the phase-sensitive inversion recovery (IR) technique [1]. Benefiting from the phase-sensitive reconstruction process, the blood signal presents only negative signal, while all other tissues in the SNAP sequence present T1-weighted positive signal. The T1-weighted positive SNAP signals provide an intraplaque hemorrhage detection tool with good blood suppression. Additionally, negative SNAP signals provide a unique way of discriminating non-contrast MR Angiography (MRA) images. However, the phase-sensitive reconstruction in the SNAP sequence requires a full-resolution reference scan, and essentially doubles the scan time. In this study, we propose a fast SNAP (fSNAP) sequence with low resolution reference scan and a corrected phase-sensitive reconstruction to speed up the acquisition without compromising the image quality.

Methods In the SNAP sequence, phase-sensitive reconstruction is the key to obtain MRA and high contrast of intraplaque hemorrhage simultaneously. In MR acquisition, background phase always exists because of non-uniform coil receive patterns, readout gradient delay, B0 inhomogeneity, eddy currents, and more. To eliminate the background phase, SNAP utilizes a full-resolution reference acquisition ref at a different Inversion Time (TI) (Fig. 1a). Then the phase-sensitive reconstruction can be generated as

\[ I = \text{real}(\text{IR} \cdot \text{ref}^*) \]

where \( \text{ref}^* \) is the complex conjugate of ref.

Low-resolution Phase-sensitive reference: In this study, we propose to use a separate low-resolution reference scan instead of the full-resolution reference scan to speed up the acquisition, as shown in Fig. 1(b). However, in the proposed fSNAP sequence, the original phase-sensitive reconstruction will fail because there is a background phase difference \( \phi \) caused by different slice and phase selective gradients between IR and ref acquisition, as demonstrated in Fig. 2a. To address this phase change, we proposed an automatic correction algorithm based on a reasonable assumption that \( \phi \) is approximately a small constant within a small region of the same tissue. The corrected phase-sensitive process is as follow: (1) calculate the intermediate IR image with zero-padding interpolated Ref: \( I_{\text{corr}} = \text{IR} \cdot \text{ref}^* \), where \( n \) is the iteration index, starts from 1; (2) segment lumen regions with negative signal on \( I_{\text{IR}} \); (3) calculate the \( n \)th phase correction \( \phi_n \) in the segmented lumen regions; (4) correct IR image with \( \phi_n \); \( I_{\text{corr}} = \text{IR} \cdot e^{-\phi_n} \); (5) if \( \phi_n \) is small enough, output the reconstructed IR image by \( I_{\text{corr}} = \text{real}(\text{IR}_{\text{corr}}) \), else not, repeat step 1-4 for \((n+1)^{th}\) iteration.

After IRB approval and informed consent was obtained, we tested the fSNAP sequence on one healthy volunteer and one subject with carotid atherosclerotic plaque with intraplaque hemorrhage. A whole body 3T scanner (Philips Achieva, the Netherlands) and a custom 8-channel carotid coil were used. As a reference, the original SNAP sequence was scanned, with imaging parameters: TI 500ms, TR 10ms, IRTR 2000ms, FA 11º/5º, FOV 250×160×32mm², resolution: 0.8x0.8x0.8mm³, fatsat, 2 nex, turbo factor 100. The total imaging time was 5min17sec. In the fSNAP sequence, a separate low-resolution ref scan enabled the IR to be acquired with TI 400 ms and turbo factor 160 for a reduced imaging time of 3min20sec. All other parameters remained the same. The scan parameters for the separately acquired ref image were: TR 10ms, FA 5º, FOV 250×160×32mm², resolution: 0.8x1.6x1.6mm³, fatsat, 2 nex, imaging time 40sec. The proposed reconstruction algorithm is implemented in Matlab (R2007b). A total imaging time reduction of 1 min 17sec (~25%) was achieved.

Results As shown in Fig.2b, the fSNAP sequence and corrected phase-sensitive reconstruction successfully produced high-contrast MRA of the carotid artery. Compared with original phase-sensitive reconstruction (Fig.2a), the proposed corrected phase-sensitive reconstruction method did not suffer artifacts caused by background phase difference, showing much better MRA with fine arterial structures. Additionally, Fig. 3b shows intraplaque hemorrhage (solid white arrows) exhibiting high signal in reconstructed fSNAP image, similar to the image of SNAP (Fig. 3a), demonstrating its value in clinical diagnosis.

Discussion A fast Simultaneous Non-contrast Angiography and intraPlaque hemorrhage (fSNAP) imaging technique with a low-resolution reference scan and corrected phase-sensitive reconstruction was proposed and validated to generate carotid MRA and detect intraplaque hemorrhage. By using a separate low-resolution reference acquisition, the scan time is reduced 25% without negatively impacting MRA quality, which makes the technique more robust to patient motion. Potentially, with the proposed automatic phase correction method, the imaging efficiency can be further improved by utilizing arbitrary k-space filling technique to speed up the IR acquisition and a SENSE or CLEAR prescan instead of an additional reference scan. Thus, fSNAP represents a robust, flexible, and efficient means of generating non-contrast MRA and detecting intraplaque hemorrhage.