

Improved Human Carotid Intraplaque Hemorrhage Imaging using a Slab-selective Phase-sensitive Inversion-recovery (SPI) sequence

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Introduction: Intraplaque hemorrhage (IPH) plays a critical role in the evolution of carotid atherosclerotic disease. Among techniques [1-3] proposed for in vivo IPH imaging, MP-RAGE currently provides the highest sensitivity and specificity for in vivo IPH detection [4] at 3T. However, contrast between IPH and vessel wall is still limited on MP-RAGE. In addition, MP-RAGE provides unsatisfactory blood suppression. The main causes of these limitations are 1) MP-RAGE utilizes only the magnitude information of the MR signal and discards the MR signal polarity information and 2) IPH contrast and blood-suppression efficiency cannot be independently optimized. Phase-sensitive imaging has been used to retrieve the polarity information in MR images [5]. In this study, a Slab-selective Phase-sensitive Inversion-recovery (SPI) technique, which combines both phase sensitive (PS) imaging and a specially designed IR turbo field echo (TFE) sequence, is proposed to improve the IPH contrast and blood suppression efficiency in human carotid IPH imaging.

Methods and Materials: Pulse sequence In phase-sensitive images, blood inversion is preferred over saturation because inverted blood magnetization will show a strong 'negative' signal in the reconstructed images and thereby considerably improve lumen/wall boundary delineation. The SPI sequence is shown in Fig. 1. The two primary differences compared to the MP-RAGE sequence are: 1) the original IR pulse is now applied as slab-selective so that only static tissue in the imaging slab experiences repetitive IR pulses (Fig.1b); and 2) a 2nd IR pulse (IR_{blood}) was added to be applied upstream of the imaging region so that blood inverted by only one IR pulse flows into the imaging region. Optimization of sequence timing, the thickness and spacing of the IR_{blood} slab ensures that inflowing blood is not saturated by repetitive inversion in the imaging region. Accordingly imaging parameters of SPI were optimized to achieve optimal IPH contrast and sufficient blood suppression using Bloch equation simulation. Simulation indicated that compared to MP-RAGE, the IPH-wall contrast can be significantly increased, as well as wall-lumen contrast.

Study Population In this Institutional Review Board approved study, 17 patients with diagnosed carotid atherosclerotic plaque were recruited after informed consent. Six patients had carotid endarterectomy and the remaining 11 patients had only in vivo scans.

Ex vivo validation and IPH CNR comparison All MR scans were conducted in a 3T clinical scanner (Philips Achieva, R2.6.1, Best, the Netherlands). The imaging parameters used for both MP-RAGE and SPI sequence were the same [3], except SPI used optimized $TI=400ms$. All MR images were reviewed for the presence or absence of IPH and then compared to the matched histology for agreement test. A separate set of contours were drawn on the MR images by referencing to the histology for IPH CNR comparison. Contours were then transferred to the corresponding MP-RAGE images for comparison.

In vivo IPH CNR and blood suppression comparison MR scans were acquired on the same scanner with carotid coil. Both SPI and MP-RAGE images were acquired in the axial orientation around the carotid bifurcation using the exact parameters as the ex vivo scans. The MR images were first matched and contoured for IPH, lumen and wall. IPH CNR was quantified and blood/lumen CNR was used to quantify blood suppression efficiency.

Statistical Analysis Cohen's Kappa was used in the ex vivo IPH/histology identification agreement study. In the ex vivo and in vivo CNR comparison studies, paired Student's t-test was used.

Results: Ex vivo validation and IPH CNR comparison: SPI images, demonstrated markedly improved IPH contrast when compared to MP-RAGE (Fig. 2). Quantitatively, both SPI and MP-RAGE were found to provide accurate IPH identification when compared to the histology (SPI: 0.817, MP-RAGE: 0.75). In CNR comparison, SPI demonstrated a significantly improved CNR for IPH when compared to the corresponding MP-RAGE images (MP-RAGE: 22.8 ± 12.0 , SPI: 26.1 ± 14.0 , $p=0.01$).

In vivo IPH CNR and blood suppression comparison Consistently improved IPH delineation and blood suppression were identified on the SPI images, when compared to the MP-RAGE images (Fig. 3). On quantitative comparison, SPI again demonstrated a significantly improved IPH CNR (MP-RAGE: 7.95 ± 5.11 , SPI: 10.24 ± 2.16 , $p=0.01$), when compared to MP-RAGE images. Significantly improved blood suppression was also found on SPI (MP-RAGE: 4.19 ± 2.72 , SPI: 11.76 ± 4.28 , $p<0.01$).

Conclusion: In conclusion, SPI proposed in this study improved IPH imaging in carotid atherosclerotic plaque. Significantly improved IPH contrast and blood suppression were found in the in vivo atherosclerotic patient scanning. This technique can also be potentially applied to other vascular beds for IPH detection with proper optimization of imaging parameters.

References:

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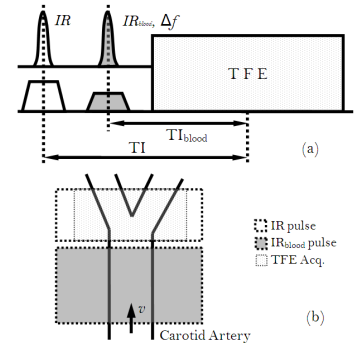


Fig. 1 Diagram for SPI sequence – the pulse sequence (a) and the geometry setup (b) are shown to illustrate the location of RF pulses. The specimen was scanned ex vivo.

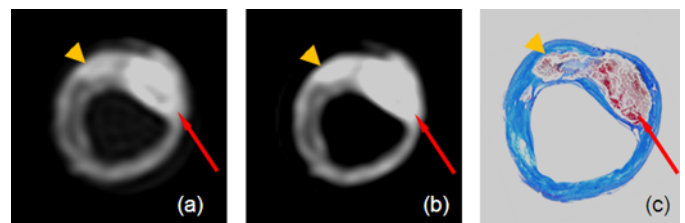


Fig. 2 Ex vivo imaging comparison between MP-RAGE (a), SPI (b) and histology (c). Both MP-RAGE and SPI identified the IPH region accurately (arrows). SPI, however, demonstrated improved CNR between IPH and the rest of the vessel wall (arrowheads).

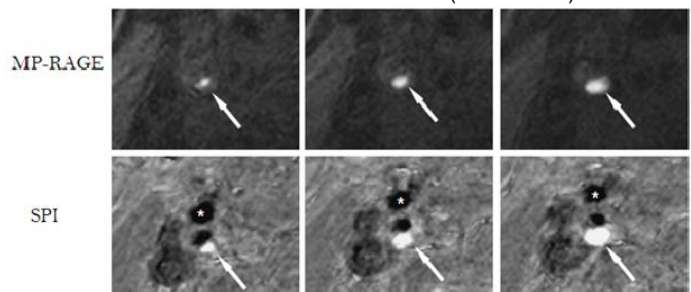


Fig. 3 In vivo comparison between MP-RAGE and SPI images of an atherosclerosis patient with IPH. Improved artery lumen visualization (asterisks) as well as IPH (arrows) contrast can be seen on SPI images.