Phase Sensitive Dual Inversion Recovery for Accelerated Multi-Slice Carotid Vessel Wall Imaging

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Target audience: translational and clinical scientists.

Purpose: Dual inversion recovery (DIR) [1] is a current standard of reference for magnetic resonance (MR) dark-blood vessel wall imaging. However, for ECG triggered DIR imaging, optimal lumen-to-vessel-wall contrast is difficult to obtain since the blood-signal nulling time (TI*) depends on both T_1 and the subject's heart rate [2]. Moreover, imaging at TI* limits the window of opportunity during which black-blood images can be acquired. This makes DIR imaging rather time-inefficient and multi-slice acquisitions, which are mandatory for sufficient volumetric coverage, lead to prolonged scanning times. The phase sensitive (PS) technique addresses these issues by exploiting information from the phase images [3,4]. A novel extension of PS-DIR for carotid vessel wall imaging is proposed that exploits the statistical distribution of the phase signal after DIR [5] to automatically segment carotid lumens and suppress their residual blood signal. In healthy adult human subjects, the performance of the proposed technique has been quantitatively ascertained and compared to that of conventional DIR imaging.

Materials and Methods: When imaging prior to TI* occurs, the DIR sequence produces phase values of 180° in voxels inside the lumen, which appears as a bright lumen surrounded by a dark rim (Fig.1A-solid arrow) in the magnitude image. For the PS algorithm, a region of interest (ROI) is drawn by the user on the magnitude image (dashed line-Fig.1A) that includes lateral carotid lumens and the surrounding tissue. On the phase image (Fig.1B), this ROI is used to obtain the relative phase histogram from which a Gaussian Mixture Model (GMM) [6] fits the phase values belonging to the lumen and tissue populations, respectively (Fig.1C). The posterior probability for the tissue class is computed on all phase values (Fig.1D) and used to extract the lumens (Fig.1E). This segmentation enables the classification of pixels that are assigned a zero signal intensity value in the magnitude image (=Phase Sensitive reconstruction (Fig.1F)). MR imaging was performed at 3T (Siemens Trio, Erlangen, Germany), with a dedicated 4ch carotid coil in 9 healthy adult volunteers with a Cartesian DIR-prepared segmented k-space gradient-echo sequence (216x240 matrix, 135x150mm FoV, 0.6x0.6x3mm spatial resolution, TR/TE=7.4/3.6ms, α=30°, 11 line/segment). Dual-inversion followed by imaging was repeated every 1000ms. In each subject images were acquired in an axial plane above the bifurcations for both internal and external carotids and at 11 time points after the DIR pulse (including TI*), with a 50ms increment. Quantitative image analysis was performed on all carotids for vessel wall/lumen contrast-to-noise ratio (CNR) and vessel wall sharpness (%VWS) using the Soap-Bubble tool [7]. Paired two-tailed Student's t-test was used to compare CNR in the PS-corrected and original images at all time points, whereas %VWS was compared between PS-DIR images at all TIs and DIR images at TI* only for standard-of-reference comparison. For 3-fold accelerated imaging, multi-slice imaging was implemented starting 100ms after the dual-inversion and preliminarily performed in 4 healthy adult subjects.

Results: CNR evaluation of all time points after the DIR pulse (Fig.2A), shows significantly improved performance of the PS method when compared to the DIR technique ($p<0.02$) while CNR for PS remains constant and TI-independent over a broad range of TI. Similar to CNR, %VWS is also TI-independent and higher than that for DIR at TI* ($p<0.05$). Example images of the left carotids are shown in Fig.2B where effective signal-nulling is obtained at several TIs using PS-DIR. In accordance with these findings, representative images of the left system from an accelerated 3-slice acquisition show effective blood-signal suppression at all anatomical levels (Fig.2C).

Discussion and Conclusion: A variant of the PS-DIR method has been successfully implemented and tested for carotid vessel wall imaging. It removes timing constraints related to inversion recovery and enhances lumen-to-vessel wall contrast. Preliminarily, this technique enabled a 3-fold increase in volumetric coverage at no extra cost in scanning time.

References: [1] Edelman et al Radiology 1991 [2] Fleckenstein et al Radiology 1991 [3] Huber et al InvestRadiol 2006 [4] Elmoniem et al MRM 2010 [5] Ahn et al IEEE 1987 [6] McLachlan JohnWiley&Sons, Inc 2000 [7] Etienne et al MRM 2002.

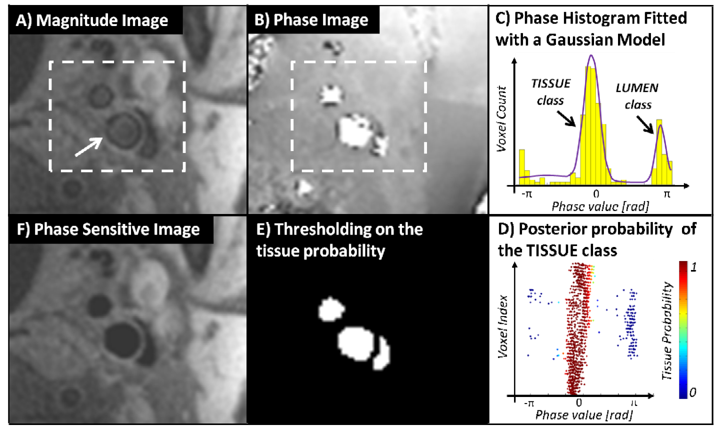

Figure 1 – PS-DIR Technique. *To correct for bright-blood lumen artifacts (A-arrow) an ROI is drawn on the magnitude image (dashed line - A) including carotid lumens and tissue. A Gaussian Mixture Model (GMM) is adopted to fit the phase histogram of the ROI (B) and to estimate the statistical distributions for the tissue and lumen classes (C). The posterior probability of the tissue class is then computed for all phase values (scatter plot-D) and thresholded to segment the carotid lumens (E). This segmentation is finally used to correct the magnitude image, resulting in an artifact-free Phase Sensitive reconstruction (F).*

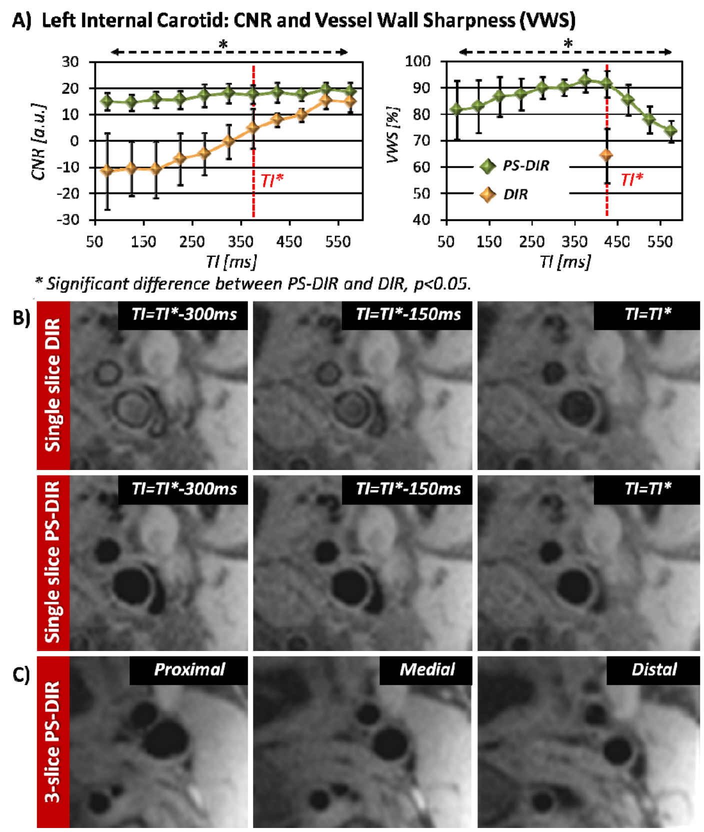

Figure 2 – In vivo human results for the left carotid arteries. A) Single-slice PS-DIR *analysis of CNR and %VWS at different TIs in 9 healthy subjects.* ***B)*** *Qualitative comparison of single-slice original (upper row) and PS-corrected (middle row) DIR in vivo images obtained at different TIs.* ***C)*** *Representative* ***3-slice PS-DIR*** *images. The PS-technique provides effective blood-signal suppression over a broad range of TIs and enables accelerated multi-slice imaging at no extra cost in scanning time.*