Optimization of Non-Contrast Enhanced Time-SLIP for Carotid Artery Imaging

W. W. Orrison Jr. MD, MBA[1,2], E. J. Kelly, PhD[3], D. Moreau, RT [3], C. J. Roach[4,5], and E. H. Hanson MD, MPH[4,5]
[1]CHW Nevada Imaging Company, Las Vegas, NV, United States, [2]Touro University Nevada, Henderson, NV, United States, [3]Toshiba America Medical Systems, Tustin, CA, [4]University of Nevada Las Vegas, [5]Advanced Medical Imaging and Genetics (Amigenics)

Purpose

Three-dimensional (3D) time-of-flight (TOF) is commonly utilized for routine magnetic resonance angiography (MRA) studies of the neck; however there are temporal and spatial resolution limits that have been addressed with contrast-enhanced protocols. Due to the association of gadolinium based contrast media and nephrogenic systemic fibrosis (NSF) it has become increasingly important to replace contrast-enhanced MRA (CE-MRA) with non-contrast MRA angiography techniques when possible. Time-Spatial Labeling Inversion Pulse (Time-SLIP) [1-3] is a non-contrast technique that provides bright blood angiograms with comparable diagnostic quality of CE-MRA and has been well established for evaluating renal artery stenosis. Time-SLIP is based on an arterial spin labeling (ASL) technique and utilizes a selective tag pulse to magnetically label the blood as it flows into or out of an imaging region [1]. In addition, specification of the black blood time interval (BBTI) will control the delay time between the application of the tag pulse and the inflow of fresh unsaturated blood. The utility of Time-SLIP to produce bright blood 3D angiograms of the carotid arteries has previously been investigated [ref(s)]. However, the high flow speed of carotid artery blood, suboptimal tag placement, or BBTI selection along with poor cardiac synchronization can degrade image quality. The purpose of this study was to optimize tag placement and BBTI specifications to improve the resulting image quality of the 3D SSFP Time-SLIP protocol for carotid arteries.

Materials and Methods

The imaging protocol that incorporated the varied tag placements and BBTI specifications was completed on 5 volunteers. Subsequently, the revised Time-SLIP protocol parameters were added to 20 patient exams referred for clinical reasons to have a carotid non-contrast MRI/MRA study. All studies were performed on a 1.5T high performance scanner (EXCELART/Vantage/Titan $_{TM}$, Toshiba, Tokyo, Japan) equipped with the Speeder neck coil (Speeder neck coil$_{TM}$, Toshiba, Tokyo, Japan). Time-SLIP was utilized in conjunction with 3D Steady State Free Precession (SSFP) to produce a bright blood angiogram. Cardiac gating utilizing electrocardiography (ECG) was compared to photoplethysmography (PPG).The optimal Time-SLIP tag pulse placement enabled labeling and inflow of fresh blood from the heart while simultaneously suppressing the background signal. Incremental BBTI's from 800-1400ms was used for comparison as well as placing the acquisition window during systole versus diastole. Parallel imaging and segmentation were used to shorten the acquisition window. The varied Time-SLIP datasets were compared in terms of overall image quality, visualization of carotid arteries and background suppression. Time-SLIP sequence acquisition parameters were: TE/TR=2.6/5.2ms, Flip Angle = 120, Matrix = 256x256, Slice Thickness = 3mm (interpolated to 1.5mm), cardiac gating, parallel imaging factor = 2, BBTI = 800-1400ms, and CHESS fat saturation. Source and MIP images were qualitatively evaluated.

Results

All variations of the Time-slip acquisitions using PPG and ECG gating, tag pulse placements and incremental BBTI times were successfully accomplished. Image quality was compared between PPG and ECG gating and it was determined that ECG gating improved the precision of systolic versus diastolic acquisition times and enabled a priori determination of the acquisition window placement within the cardiac cycle. Imaging during systole resulted in brighter vessel to background contrast. The inherent delay of the PPG waveform prevented the determination of accurate systolic triggering times. Tag pulse placement was compared at three levels in the neck: at the level of the subclavian artery, below the aortic arch, and just below the carotid bifurcation and each placement allowed complete visualization of the carotid bifurcation. However, only the placement below the subclavian artery enabled full visualization of the carotid origins, which is necessary for overall radiologic assessment. 3D Time-SLIP datasets were acquired at incremental BBTI delays of 800-1400ms for determination of the optimal inflow effect and perceived contrast to noise ratios. For the tag placements just below the subclavian artery, a BBTI of 1200ms was found to be most robust (Figure 1). Image quality was excellent in all cases using this tag placement, a BBTI of 1200ms, and with systolic triggering using ECG gating.

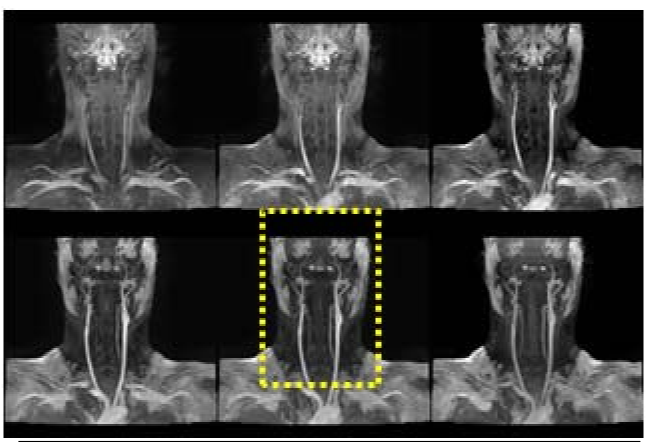

Figure 1. Depiction of the observed carotid artery signal compared with background suppression using BBTI delays of 800-1300ms, respectively (right to left, top to bottom). Qualitative assessments led to the conclusion that a BBTI of 1200 resulted in the highest image quality.

Discussion

This image optimization study demonstrated the feasibility and high likelihood of clinical utility for utilizing non-contrast Time-SLIP angiography of the carotid arteries. While conventional angiography techniques provides an accurate depiction of the carotid arteries and CE-MRA can provide high resolution images both studies increase risks for the patient compared to non-contrast Time-SLIP MRA. Non-contrast Time-SLIP MRA can provide a non-invasive high resolution image with lower costs and patient risk. Within the 3D Time-SLIP sequence, a spatially selective inversion-recovery pulse is placed before data acquisition, and blood flowing into the area of interest during the inversion time is depicted as bright while suppressed background signal recovers. Poor background suppression along with suboptimal carotid artery depiction were observed with the shorter BBTI's, while a longer BBTI improves carotid artery visualization. Although some background signal may recover with a longer BBTI the higher visualized contrast to noise results in the best image quality. When paired with imaging during systole, this study demonstrated that BBTI times of 1200ms-1300ms with ECG gating resulted in higher carotid artery visualization compared to PPG gating and lower BBTI times as determined by qualitative comparisons of both source and MIP images. Balanced SSFP MRA with a Time-SLIP allows excellent visualization of the external carotid artery system with good background suppression in less than three minutes. Clinical indications for this type study may include pretreatment screening. Future clinical studies will be necessary to establish how well 3D Time-SLIP carotid MRA compares with other non-contrast techniques such as Time of Flight and Phase Contrast MRA.

References

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