3D Radial Spin-Labeled MRA of the Extracranial Carotid Arteries: Optimization and Potential for Rapid Imaging

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Target Audience: Physicians and scientists who perform nonenhanced magnetic resonance angiography (NEMRA) of the carotid arteries.

Purpose: Arterial spin labeling (ASL) may provide better image quality and vascular coverage than time-of-flight techniques in the nonenhanced evaluation of carotid arterial stenosis[1,2]. However, the efficacy of ASL NEMRA depends on the labeling technique and timing, and it is unclear how these parameters affect signal in the extracranial carotid arteries. *The purpose of this study was to optimize the ASL NEMRA technique by examining how various imaging parameters affect the depiction of the extracranial carotid arteries, and to explore the potential of very rapid imaging made possible by an undersampled 3D radial k-space sampling trajectory.*

Methods: This study was IRB approved and informed consent was obtained. Imaging was performed on a 32-channel 1.5T MRI system (MAGNETOM Avanto, Siemens Healthcare) using an investigational prototype ungated 3D radial balanced steady-state free-precession (bSSFP) ASL sequence providing 1 mm isotropic resolution over a cubic 25.6 cm field of view. Baseline sequence parameters were scan times of 4 min, repetition times (TR) of 2.0 s, bSSFP TR/TE/flip of 3.7 ms/1.8 ms/90°, 7680 views (undersampling factor of 13.4). Multi-element neck and head coils received the MR signal. General Study Design: An initial study (Experiment 1, n = 8 volunteers) examined the impact of labeling technique and timing, while a 2nd study (Experiment 2, n = 7) examined the impact of the sequence TR and RF energy configuration of the optimal labeling technique identified in Experiment 1. A 3rd study (Experiment 3) explored the feasibility of highly accelerated carotid ASL NEMRA providing scan times as short as 1 minute. Experiment 1: Two labeling methods were evaluated: [1] pseudocontinuous labeling (pCASL) alone, and [2] combined pCASL and pulsed ASL[3,4]; the latter referred hereafter as 'hybrid' ASL (hASL). With hASL, the impact of a post-label delay (PLD) period (ranging from 0.0 s to 0.6 s) was examined for reducing streak artifact and improving arterial contrast-to-noise ratio (CNR). Pseudocontinuous labeling was applied 5 cm below the carotid bifurcation; pulsed labeling (10 cm thickness) was applied axially below the pseudocontinuous labeling plane. Experiment 2: Using the optimal labeling approach identified in Experiment 1, the impact of the sequence TR (2.0 s, 2.5 s and 3.0 s) and RF energy configuration of the pCASL control phase (RF energy on or off) on arterial CNR were examined. To equalize scan times and total number of acquired views,128-192 views per shot were acquired in protocols with TRs of 2.0 s-3.0 s. Experiment 3: Using optimal parameters determined in Experiments 1 & 2, the feasibility of highly undersampled 3D radial ASL NEMRA providing scan times as short as 1 min (1920 views, undersampling factor of 53.6) was tested. Signal Analysis in Experiments 1 & 2: The CNR of the carotid arteries was measured at 6 locations and averaged ([1] origin of the common carotid artery (CCA); [2] CCA midway between the origin and bifurcation; [3] CCA proximal to the bifurcation; [4] internal carotid arterial (ICA) bulb; [5] mid-cervical ICA; and [6] petrous ICA).

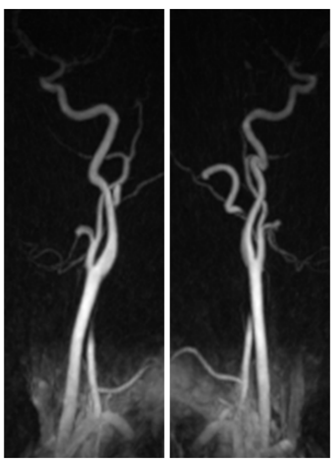

Figure 1. Typical image quality provided by hASL carotid NEMRA (oblique sagittal MIPs).

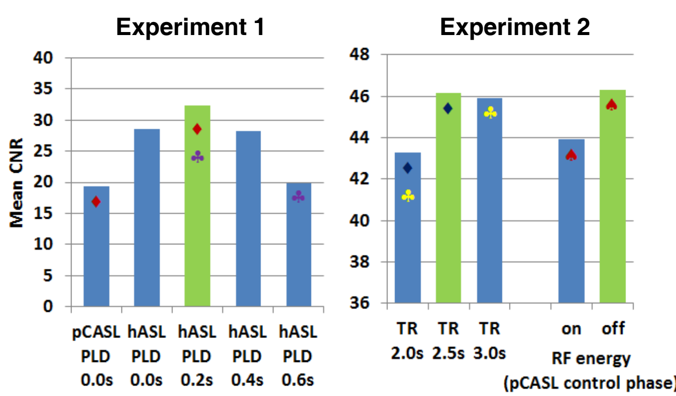

Figure 2. Results of Experiments 1 and 2. hASL NEMRA configured with a TR of 2.5-3.0 s, a PLD of 0.2 s, and without RF energy during the pCASL control phase optimized carotid CNR. Optimal configurations are shown in green. Colored symbols denote pair-wise statistically significant differences ($P < 0.05$).

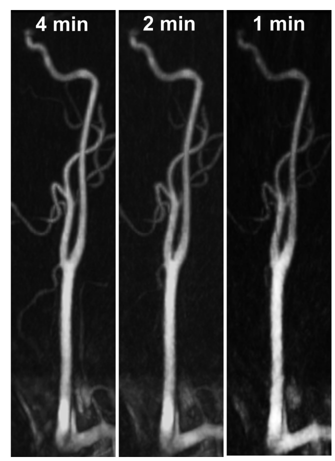

Figure 3. Results of Experiment 3. Ultrafast hASL carotid NEMRA is feasible in scan times of 1-2 mins.

Results: The 3D radial bSSFP ASL technique depicted the carotid arteries over long lengths with excellent arterial contrast (**Figure 1**). Carotid arterial-to-background CNR was optimized with the use of hybrid spin labeling, a 0.2 s quiescent delay prior to imaging, repetition times of 2.5-3.0 s, and when the RF energy of the pseudocontinuous control phase was turned off (**Figure 2**). Initial tests revealed scan time could be drastically reduced to as short as 1 minute (**Figure 3**).

Discussion: We optimized ASL MR angiography of the extracranial carotid arteries using a hybrid labeling scheme and a 3D radial bSSFP readout at 1.5T. Using an optimal implementation (hybrid ASL, post-label delay of 0.2 s, sequence TR ≥ 2.5 s, no RF energy during the pCASL control phase), NEMRA of the carotid arteries with 1 mm spatial resolution was feasible in scans times as short as 1 minute. Our results should help optimize the use of ASL nonenhanced MRA in the carotid arteries. Future studies will test the technique in patients with carotid stenosis with reference to alternate established techniques.

Conclusion: Optimized hybrid arterial spin labeling with an undersampled 3D radial bSSFP trajectory enables time-efficient, high-contrast imaging of the extracranial carotid arteries in as short as 1-2 minutes. Pending further validation, the method has the potential to become a useful diagnostic test for patients with carotid artery stenosis, and may have particular appeal in the rapid imaging of patients with acute stroke.

References: (**1**) Dixon et al. *Magn Reson Med*. 1986; 3:454-62. (**2**) Koktzoglou et al. *J Magn Reson Imaging*. 2011; 34:384-94. (**3**) Robson et al. *Radiology*. 2010; 257:507-15. (**4**) Wu et al. *Magn Reson Med*. 2013; 69:708-15.