Noncontrast-Enhanced Four-Dimensional MR Angiography at 7T

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INTRODUCTION: Non-contrast enhanced time-resolved 4D MRA has been shown to be a valuable method for simultaneously assessing anatomic structure and dynamic filling of cerebral arteries (1,2). With these methods, vessel contrast is obtained by subtracting a labeled volume with a control similar to methods used for arterial spin label (ASL) perfusion imaging. Using blood as an endogenous tracer eliminates the need for exogenous contrast agents important for patients with contraindications.

Performing ASL 4D MRA at higher magnetic fields has multiple advantages including increased SNR, improved parallel imaging performance and longer longitudinal relaxation times (T1). The longer T1s would result in more persistent labeling allowing for improved visualization of distal vessels, especially in conditions of reduced flow. We show, for the first time, a strategy for performing 4D ASL MRA in the human brain at 7T and initial results demonstrating persistent labeling for visualization of distal arteries.

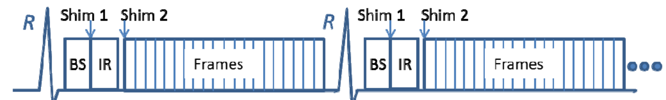

Figure 1: 4D ASL MRA sequence. The label volume is acquired with an inversion labeling (IR) pulse on and the control volume with the IR pulse off. Background suppression (BS) is applied in the imaging volume for label and control volume acquisitions. The locations for the dynamically applied B1+ shim solutions are shown by the labels "Shim 1" and "Shim 2".

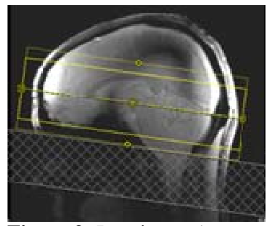

Figure 2: Imaging and saturation volume (yellow). Inversion region (hashed).

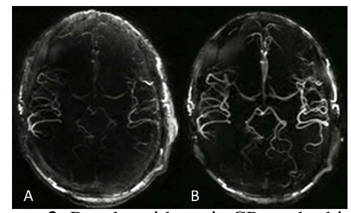

Figure 3: Results with static CP-mode shim (A) and dynamically applied B1+ shimming (B). Images are from at 0.78s and windowed individually for similar background contrast.

METHODS: Studies were performed on Siemens 7T whole body MRI scanner with a 16-channel transceiver TEM stripline array head coil driven by a series of 16, 1 kW amplifiers (CPC, Pittsburgh, PA). Non-contrast enhanced 4D ASL MRA was performed using an ECG-triggered, segmented, 3D acquisition using signal targeting with alternating radiofrequency (STAR) for spin labeling as previously described by Yu et al. (3). However, because of SAR limitations at 7T, a gradient echo readout was used instead of the balanced SSFP acquisition used at 3T (3,4). Label and control volumes were acquired with magnetization preparation immediately after the ECG R-wave and before the segmented readout used to generate the time resolved frames (**Fig. 1**). Compared to the labeled volume, the control volume used for subtraction was acquired without the IR pulse. Background saturation over the imaging volume was applied for both label and control volumes to decrease subtraction errors. The planning for the imaging and inversion volumes is shown in **Fig. 2**. The imaging parameters for the 4D ASL MRA acquisition consisted of the following: 220x188 mm FOV, 35 slices, 1.7 mm thick, in-plane resolution 1.2 x 1.0 mm, 4.6/2.1 ms TR/TE, 33% slice oversampling, 6/8 partial Fourier in slice and phase, GRAPPA R=2, 558 Hz/pixel bandwidth, 50 mm thick IR labeling volume and 7 degree excitation flip angle. Data was acquired with a total of 13 frames within 850ms (one R-R interval) and a temporal resolution of ~60 ms with a 5:53 acquisition time. Subsequent data was acquired with 26 frames over 1700 ms (two R-R intervals) with the same temporal resolution and an acquisition time of 12:23.

To address the challenges of B1+ homogeneity and efficiency at 7T, B1+ shimming was performed based on a small flip angle, calibration scan (5). Two B1+ shimming strategies were compared; **1)** a static approach which used a CP-like mode (6) over the entire brain for all RF pulses in the sequence, and **2)** a dynamic approach which used a separate B1+ shim optimized for efficiency (Shim1) for the IR labeling pulse and the CP-like mode for excitation and background suppression (Shim 2) (7). The dynamic application of these two shims during the sequence is shown in **Fig. 1**.

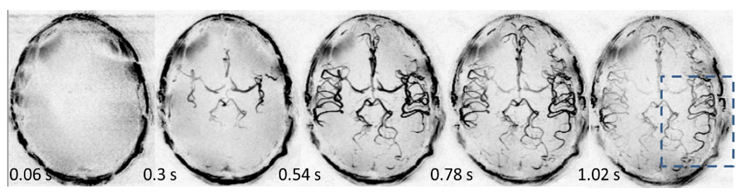

Figure 4: Volumetric MIPs at every 4th frame up to 1.02 s post labeling.

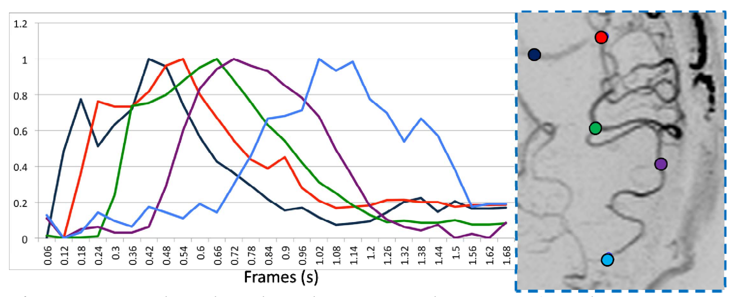

Figure 5: Normalized signal intensity over 2 RR intervals at 5 locations over all 28 frames encompassing 1.68 seconds after labeling. The zoomed region on which the ROIs are placed is demarcated in Figure 4 by the dashed blue lines in the last frame.

RESULTS/DISCUSSION: The CP-like mode provides reasonable transmit efficiency and homogeneity over the head and is a sensible solution for RF pulses applied within the imaging volume. Results using solely the CP-like shim for all RF pulses in the sequence are shown in **Fig. 3A**. As is typical for the close-fitting transceiver coil used in this work, the transmit field diminishes rapidly when moving into the cerebellum and below. At the location of the labeling volume, B1+ is appreciably weaker and thus benefits from its own shim focusing on optimized efficiency. Simply increasing the power for the labeling RF pulse with the CP-like solution is not a viable solution due to SAR constraints. By using an efficient solution optimized specifically on the labeling volume for the IR pulse and the CP-like mode for excitation and background suppression, far superior images were obtained (**Fig. 3B**). Higher labeling efficiency in the dynamically applied B1+ shimming strategy resulted in improved arterial blood labeling efficiency and correspondingly higher subtracted arterial blood signals, which improved the contrast between the vessels and surrounding tissue. Several volumes from the dynamically applied B1+ shimming acquisition acquired over 2 R-R intervals are shown in **Fig. 4**, demonstrating excellent time resolved volumetric MIPs (maximum intensity projections) as the label bolus passes through the vessels. The dynamic filling of arteries can be appreciated by observing the time course across all 28 frames from 5 selected regions of interest, **Fig. 5**. The persistence of the labeled spins can be observed in the time course of the most distal ROI out to a time of 1.56 ms.

By using a dynamic B1+ shimming approach improved labeling could be achieved while maintaining a relatively efficient and uniform transmit B1 over the imaging volume for background suppression and excitation. No attempt was made to optimize resolution and acquisition speed in the current study. However, isotropic data with 1 mm resolution has also been acquired with the same temporal resolution as described above in ~8 minutes (data not shown). Optimization of the sequence parameters and hardware could further improve upon these results and will be necessary prior to comparing with acquisitions using balanced SSFP readouts at lower fields (3,4).

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