Balanced SSFP Spin-Labeled Angiography Using Sparse Data: Optimization and Application to Supraaortic Vessels

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Introduction: Although contrast-enhanced magnetic resonance angiography (CE-MRA) remains the technique of choice for evaluating the blood vessels of the head and neck, it is now frequently contraindicated in patients with renal insufficiency at risk for nephrogenic systemic fibrosis. Pulsed arterial spin-labeled (ASL) angiography has long been proposed as a method for unenhanced MRA [1] that may provide better contrast than well-established unenhanced methods of 2D and 3D time-of-flight (TOF) angiography. Due to the presence of flow artifacts in stenotic vessels containing rapid blood flow, however, it remains challenging to robustly combine the pulsed ASL method with a balanced steady-state free precession (bSSFP) readout. Here we sought to optimize a 3D bSSFP-based pulsed ASL technique in a flow phantom, and apply the optimized technique to image the carotid and intracranial arteries. Furthermore, the technique was based on sparse data to improve parallel imaging reconstruction quality [2].

Methods: The pulsed ASL MRA sequence consisted of an ungated segmented 3D bSSFP readout, with each slice-encoding step (k_z) acquired in a single shot. Imaging was performed on a 32-channel 1.5 T MR system (Avanto, Siemens Healthcare). Typical imaging parameters for carotid and *intracranial* MRA were: coronal slab orientation; non-selective RF excitation; inversion RF label applied axially inferior to the vascular segment (TI = 0.6-1.2 s); segment repetition time (TR) = 2.0s, bSSFP TR/TE/flip = 2.7*(3.0)*ms/1.3*(1.4)*ms/90°, matrix = 320x256; FOV = 320x256*(256x205)*; BW = 1100*(788)* Hz/pixel; slab thickness = 412(*390*) mm; acquired/reconstructed resolution = 1.0x1.0x2.0/1.0 *(0.8x0.8x1.6/0.8)* mm^3; scan time = 5*(6)* min; The inversion label was applied before the acquisition of every other k_z step to create a sparse 'ghost' angiogram.

Flow Phantom Experiment: A phantom study was performed to investigate the flow sensitivity of the technique to the parallel acceleration factor (PAF). A cylindrical tube phantom with 50% stenosis (normal/stenotic diameter = 6.35/3.18 mm), was filled with a blood mimicking fluid (40% glycerol and 60% water; T1/T2 = 850/170 ms), and was connected to a pump (CompuFlow 1000MR, Shelley Medical) generating a carotid flow waveform (Fig. 1) with peak velocity of 43 cm/s at a frequency of 70 beats/min.

Human Imaging: Based on the results of the phantom study, an optimal configuration of the 3D bSSFP pulsed ASL sequence was applied to image the carotid and intracranial vessels of 5 volunteers and of 2 patients with carotid arterial disease; nonetheless, the TI and the use of PF acquisition were varied to examine their effects in vivo. The benefit of selective presaturation [3] of the arterial segment was also examined. Contrast between arterial signal (S_a) and background signal (S_b) was computed as S_a/S_b-1.

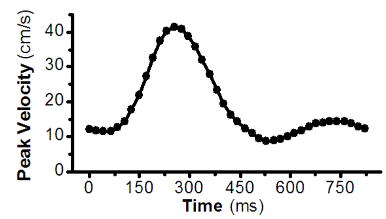

Figure 1. Carotid flow waveform used in phantom experiment as measured by phase-contrast 5 cm proximal to the stenosis.

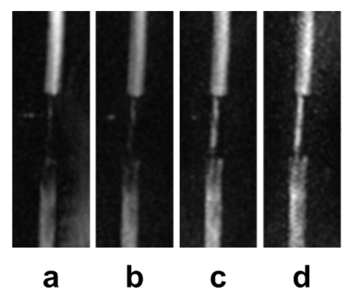

Figure 2. Images of the stenotic segment of the vascular phantom obtained with use of no parallel acceleration **(a),** and with PAFs of 2 **(b)**, 4 **(c)**, and 8 **(d)**.

Results: Flow Phantom Experiment: Figure 2 shows the results of the flow phantom study. Due to accelerating flow with peak velocities exceeding 1 m/s at the location of stenosis (not shown), signal void was observed without the use of parallel imaging acceleration. Abbreviation of the echo train with the use of increasing PAF, however, progressively improved the depiction of the stenotic segment.

Human Imaging: Figure 3 shows results of the technique applied for imaging the carotid and intracranial vessels in healthy volunteers. The extracranial carotid arteries and intracranial vessels were seen with excellent contrast. Figure 4 show the results of the technique (TI = 900 ms) in a patient with a history of stroke. A mild stenosis was seen at the carotid artery bulb (arrow), and close correspondence was observed with 3D time-of-flight (Fig 4b). Presaturation of the carotid arteries improved arterial-to-background contrast by 72% ($P < 0.001$). In the carotid/intracranial arteries, inversion labeling times (TI) of 900 ms and 1200 ms provided 75%/79% and 55%/55% of the contrast observed at a labeling time of 600 ms**.**

Conclusion: Pulsed ASL MRA of the extracranial carotid and intracranial arteries using a bSSFP readout benefits from presaturation and an abbreviated echo train made possible by the use of parallel and/or partial Fourier acquisition. Further work is needed to determine the accuracy of the method in patients with vascular disease.

References: **[1]** Dixon et al. MRM 1986;3:454-462. **[2]** Blaimer et al. ISMRM 2007 #749 **[3]** Sardashti et al. MRM 1990;15:192.

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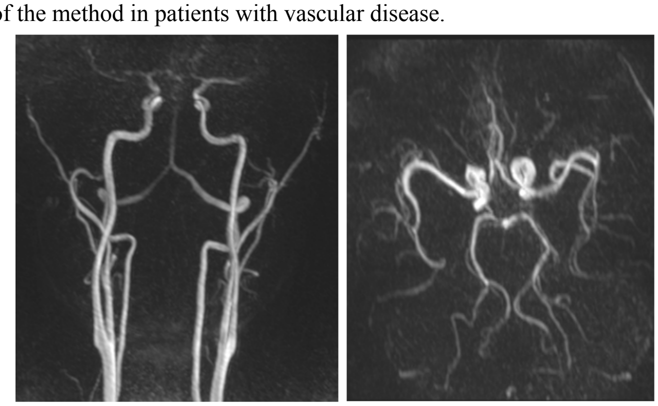

Figure 3

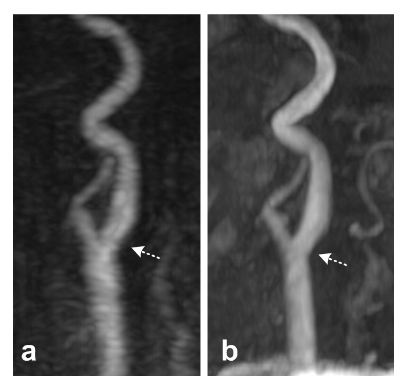

Figure 4