Arterial Spin Labeling Angiography without the Need of Subtraction using a Triple Inversion Recovery Prepulse

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INTRODUCTION: Arterial Spin Labeling (ASL) is a well-known technique for the non-invasive acquisition of angiograms without the need of a contrast agent [1][2]. ASL angiography is still clinically underused because of several challenges [3]: ASL requires two acquisitions (labeled and non labeled dataset) thereby doubling scan time. The need of subtraction increases the sensitivity to spatial misregistration and the need to select an optimal inversion delay for best blood-to-background contrast introduces some "operator dependence". An alternative technique not requiring image subtraction has been proposed [4]. This approach is based on a double inversion (DIR-ASL) prepulse and provides good background suppression if the surrounding tissues have similar T1 values. However, DIR-ASL has only one optimal inversion delay and thus there is a trade-off between background suppression and visualized vessel extent. Our goal was to develop an ASL technique with improved background suppression and without the need of subtraction. **METHODS:** The proposed method is a Triple Inversion Recovery sequence (TIR-ASL), which provides excellent background signal suppression according to our simulations (Figure 1). The first pair of RF pulses consists of a non-selective inversion RF pulse followed by a selective reinversion pulse and a navigator-restore pulse. The second pair of RF pulses consists of a non-selective inversion pulse followed by a navigator-restore pulse. With this configuration, the upstream labeled blood only "experiences" the second non-selective inversion recovery (IR) pulse, while the static tissue "experiences" both non-selective IR pulses. The steady state Mz magnetization of static tissue immediately before the imaging sequence and with a single echo acquisition (flip angle = α) is shown in Eq-1 (modified from [5]). The labeled blood only experiences the second non-selective IR pulse. However, blood experiencing the labeling pulse is a mix of "fresh blood" and blood that has already experienced an inversion pulse in the previous cardiac cycle. The Mz magnetization of blood therefore will be between the steady state (Eq-2) and the free relaxation magnetization of an inversion recovery prepulse (Eq-3) (Figure 1). With the right choice of TI1 and TI2, signal from static tissue can be suppressed over a wide T1 range while maintaining the signal of labeled blood (Figure 1). To find the optimal inversion times we solved an optimization model, which maximized the difference magnetization of labeled blood and static tissue. To correct for the data acquisition on signal behavior, we simulated the pre-pulse together with a TFE acquisition with 20 RF excitations with a flip angle of 30º. In this optimization model, the restriction [i] allows nulling the background signal. ξ (arbitrary units) provides an additional degree-of-freedom and to select the strength of background signal suppression. Restriction [ii] restricts the prepulse to one RR interval (Figure 1). In the optimization model, we modeled the magnetization of labeled blood according to the free relaxation equation (Eq-3). The TIR-ASL pre-pulse was implemented on a 1.5T Achieva Gyroscan MR scanner (Philips Healthcare, Best, NL) and tested in 5 subjects. For comparison, we acquired three Double Inversion Recovery (DIR) renal angiograms using three inversion times (TI) of 300, 450 and 600 ms while maintaining all other imaging parameters. **RESULTS:** We identified a set of inversion delays (TI1 and TI2) that provided the optimum solution for different ξ. For the TIR-ASL acquisition we used the following optimal parameters (ξ=10): (TR/TI1/TI2): 1000/424/146 ms and 900/380/131 ms. Renal arteries including small branches were successfully visualized in all subjects. The scout scan and the maximum projection angiogram (MIP) of a representative volunteer are shown in Figure 2. Improved background suppression was observed with TIR-ASL compared to DIR-ASL (Figure 3) with an approximate 2-fold increase in contrast-to-noise ratio (Figure 4). **CONCLUSIONS:** We successfully demonstrate a new ASL approach for non-contrast enhanced MR angiography with excellent background tissue suppression and without the need for subtraction. In comparison to DIR-ASL, TIR-ASL yielded better background suppression and improved vessel delineation. **REFERENCES:** [1] Nishimura DG MRM 1989 [2] Stuber M MRM 2002 [3] Miyazaki M Radiology 2008 [4] Katoh M JMRI 2008 [5] Yarnykh V MRM 2002

$$M_z^{static\ tissue} = \frac{1-\exp(-TR/T_1)-2\cdot\exp(-TI_2/T_1)\cdot[1-\exp(-TI_1/T_1)]}{1-\exp(-TR/T_1)\cdot\cos(\alpha)} \quad \text{Eq [1]}$$

$$M_z^{labeled\ blood} = \frac{1+\exp(-TR/T_1)-2\cdot\exp(-TI_2/T_1)}{1+\exp(-TR/T_1)\cdot\cos(\alpha)} \quad \text{Eq [2]}$$

$$M_z^{labeled\ blood} = 1-2\cdot\exp(-TI_2/T_1) \quad \text{Eq [3]}$$

$$MAX\left[\int_{T_1\ minimum}^{T_1\ maximum}\left(M_z^{labeled\ blood}-M_z^{static\ tissue}\right)\right]$$

$$s.t.$$

$$[i]\quad \int_{T_1\ minimum}^{T_1\ maximum} M_z^{static\ tissue} \le \xi$$

$$[ii]\quad TI_1+TI_2 \le TR - Imaging\ acquisition\ duration$$

Figure 1- TIR-ASL sequence. nsIR: Adiabatic Non-Selective Inversion Pulse. sIR: Selective Inversion Pulse, NR: Navigator Restore Pulse. N: Navigator, AQ: Acquisition.

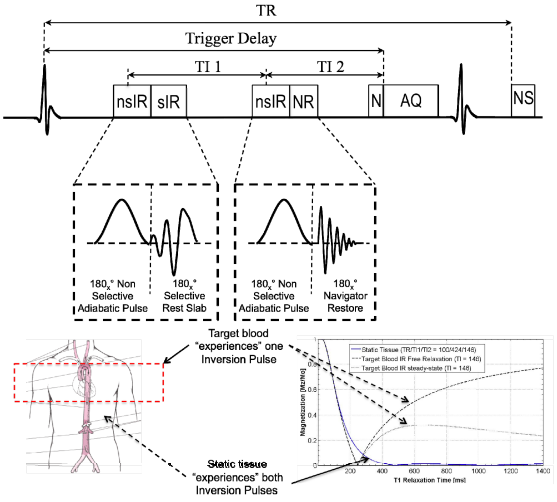
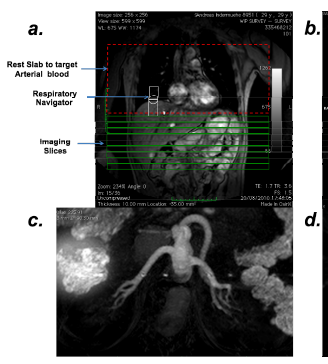


Figure 2- In vivo result with TIR-ASL (TR/TI1/TI2 = 1000/424/146 ms)
a- Planning procedure; b-, c- and c- MIPs of aorta and renal arteries



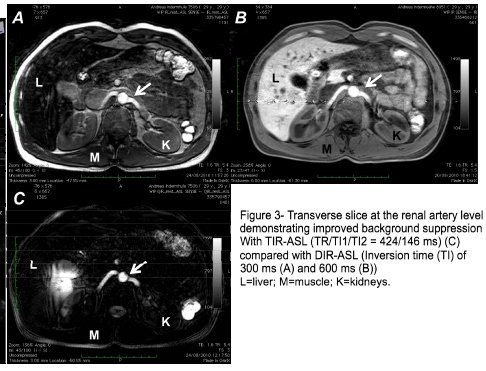


Figure 3- Transverse slice at the renal artery level demonstrating improved background suppression With TIR-ASL (TR/TI1/TI2 = 424/146 ms) (C) compared with DIR-ASL (Inversion time (TI) of 300 ms (A) and 600 ms (B)) L=liver; M=muscle; K=kidneys.

Figure 4- CNR of the labelled blood and background tissue (muscle, liver, blood) for TIR-ASL (1000/424/146 ms) and DIR (TI = 300, 450, 600 ms) (*)p<0.001