

PROSTATE PERFUSION USING ARTERIAL SPIN LABELING: INITIAL EXPERIENCE

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Introduction: Abnormal prostate perfusion is one of many markers of prostate cancer (1,2). It has the potential to be a valuable physiological index for the diagnosis, prognosis and therapeutic monitoring of prostate cancer. Arterial spin labeling (ASL) imaging is a non-invasive, non-radioactive and non-contrast enhanced method to measure perfusion, significantly benefitting prostate cancer patients with renal dysfunction or other contraindications to the use of MR contrast-agent. If a feasible method in the prostate, ASL would be more suitable for repeated perfusion studies in the longitudinal evaluation of tumor angiogenesis or treatment response. The challenges with ASL include limitations in SNR which is exacerbated by the relatively slow flow of blood into the prostate from multiple feeding vessels (3). The purpose of this study was to evaluate the feasibility and determine optimal timing parameters for performing ASL with a surface array receive coil at 3T. To our knowledge, these are the first attempts at obtaining ASL results in the human prostate.

Materials and Methods: Seven healthy male adults (41 ± 14 years) participated in an IRB approved protocol after providing informed consent: two for sequence testing and five for multiple inversion perfusion studies using FAIR (4) with an echo planar imaging (EPI) readout. All studies were performed on a 3T Siemens TIM Trio, transmitting with the whole body coil and receiving with a combined body array anteriorly and selected channels of the spine array posteriorly. The following imaging parameters were used for ASL perfusion imaging: TR/TE = 3000/9 ms, FOV = 220 x 200 mm², matrix size = 64 x 64, in-plane imaging resolution = 3.44 x 3.44 mm², slice thickness/gap = 5.0/1.0 mm, number of slices = 5, phase oversampling = 10% with posterior-anterior direction, acquisition order = descending, GRAPPA iPAT factor = 2 with 24 reference lines, partial Fourier = 7/8, selective inversion slab = 50 mm, spatially-confined inversion slab = 230 mm, inversion times = {0.7, 1.0, 1.3, 1.6, 2.0} s, and shimming mode = advanced 3D shimming over whole imaging slab. Proton density images (M₀) were also acquired using the same EPI imaging parameters but with a longer TR (8 s). The number of acquired EPI volumes ranged from 240 to 300 across subjects. The order of inversion times used for perfusion imaging was randomized for each subject. As an anatomic reference, T₂-weighted images were acquired using turbo spin echo at the same slice locations as the ASL data.

Motion correction and co-registration were performed using SPM. Pairs of labeled and control images with sudden and/or large motions (>0.5 mm translation and 0.5 degree rotation) were excluded for the data analysis. For all subjects, 110 perfusion-weighted images were used for the final analysis. A single blood compartment model (5) was used for prostate blood flow (PBF) quantification (equation 1). The analysis of error propagation was performed to evaluate the measurement errors due to either random noise (or white noise) or temporal noise (or physiological noise) (equations 2 and 3, respectively). The random noise was estimated by using the standard deviation of the background signal on EPI images, and the temporal noise was estimated by using the standard deviation over time of the measured mean perfusion signals in the prostate.

$$PBF = \Delta M / (2M_0 \times BolusWidth \times EXP(-TI / T_{1b})) \quad [1]$$

$$E_{random} = \sqrt{2 / N_{voxel}} \times \sigma_{random} / (2M_0 \times BolusWidth \times EXP(-TI / T_{1b})) \quad [2]$$

$$E_{temporal} = \sigma_{temporal} / \sqrt{N_{PWI}} \quad [3]$$

where N_{voxel} represents the total number of averaged voxels, N_{PWI} the number of averaged perfusion weighted images. T_{1b} is assumed 1660 ms. BolusWidth is the utilized temporal bolus duration of labeled blood.

Results and Discussion: The perfusion-weighted imaging maps from one subject showed highest perfusion signals at 1.6 s (Fig. 1). The maximal group mean perfusion signal, with compensated T_{1b} relaxation decay, is 0.69 ± 0.08 (mean ± SE: %) (Fig. 2). Based on the fact that linearly interpolated perfusion signals at 0.8 s became significantly different from 0 ($p < 0.05$ from two tailed paired t test), the arterial transit time is assumed to be 0.8 s for all subjects. Quantitative prostate blood flow, random and temporal errors were calculated for each subject by using measurements at 1.6 s and assumed bolus duration 0.8 s (Table 1). Random error is less than 10% of PBF and more than three times lower than that of temporal error, which can be as high as 30% of PBF for specific subjects. The estimated PBF values from ROI's within the prostate are comparable with those measured by using other techniques: 23 ± 21 mL/100 cm³/min using dynamic contrast-enhanced MRI (1) or 15.7 ± 7.5 mL/100 cm³/min using ¹⁵O-water PET imaging (6).

Conclusion: Global prostate perfusion can be measured with ASL at 3T with a surface array coil. However, generating perfusion maps, as would be required to localize disease, is difficult due to the low SNR and high physiological noise. Increased SNR and reduced physiological noise could be accomplished with more averaging but scan times would become clinically impractical. A more practical solution would be the use of an endorectal coil which has the primary advantages of increased SNR and the promise of improved temporal stability. Furthermore, increased PBF estimation accuracy could be obtained in the future through single-subtraction quantification methods, such as FAIR with Q2TIPS (7).

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References: 1. Ludemann et al. Ann Biomed Eng 2009; 37(4): 749-762. 2. Buckley et al. Radiology 2004; 233 (3): 709-715. 3. Clegg EJ, et al. J Anat 1955; 89:209-217. 4. Kim et al. MRM 1995; 34(3):293-301. 5. Buxton et al. JMRI 2005;22(6): 723-726. 6. Inaba et al. J Urol 1992; 148(5):1457-1460. 7. Luh et al. MRM 1999; 41(6): 1246-54.

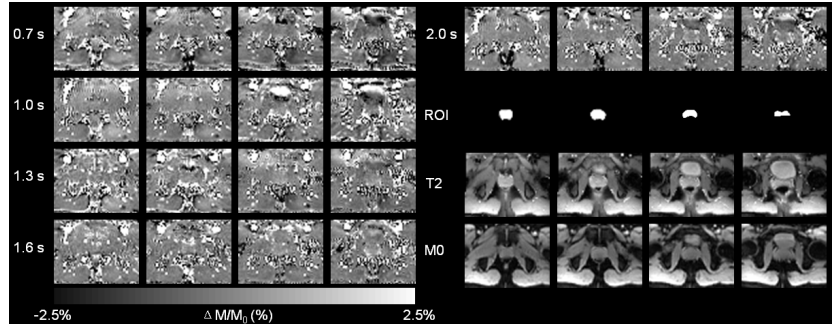


Fig. 1 One typical subject's perfusion-weighted imaging maps ($\Delta M/M_0$) acquired at different inversion times, co-registered ROIs and T₂-weighted images, and proton density images. ROIs were drawn on T₂-weighted images.

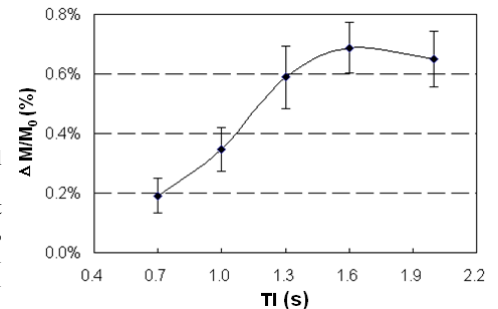


Fig. 2 Perfusion signal changes with inversion time (TI). Error bars represent standard errors.

Table 1 Measurements of prostate blood flow (PBF) and estimated measurement errors due to random and temporal noises

Subject No	Age (years)	Volume (cm ³)	PBF (mL/100 cm ³ /min)	Random Error (mL/100 cm ³ /min)	Random Error/PBF (%)	Temporal Error (mL/100 cm ³ /min)	Temporal Error /PBF (%)
1	29	12.3	32.3	1.8	5.7	4.8	14.9
2	29	11.2	21.4	1.4	6.6	4.5	21.1
3	39	10.0	29.6	1.8	5.9	2.5	8.4
4	57	17.8	30.1	1.1	3.8	7.5	24.9
5	65	16.8	15.6	1.4	9.2	5.7	36.6
Mean	44	13.6	25.8	1.5	6.2	5.0	21.2
SE	7	1.6	3.2	0.1	0.9	0.8	4.8