Robust and Noninvasive Measurement of Renal Perfusion using Multi-Phase Pseudo-Continuous Arterial Spin Labeling

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Target Audience: Clinicians and researchers interested in renal perfusion imaging with ASL.

Purpose: Arterial spin labeling (ASL) is an alternative method for measuring tissue perfusion, providing a noninvasive technique that avoids both intravenous injection of a gadolinium contrast agent and its potential associated complications. Most broadly applied to study cerebral perfusion, examples of renal ASL applications include animal model studies and clinical investigations ranging from renal dysfunction to mass characterization. Common ASL implementations include pulsed (PASL) and continuous (CASL) techniques. Pseudo-continuous ASL (PCASL) overcomes limitations associated with CASL, however it is sensitive to tagging loss due to the off-resonance field at the tagging plane. This can vary unpredictably, particularly in the application of renal ASL. Multiphase PCASL (MP-PCASL) provides a solution to this phase error problem[1]. In addition, application of ASL to the kidney is complicated by respiratory motion; different solutions have been employed to aid in tagged image alignment, including breath-hold and gated techniques during data acquisition and various registration methods during data processing. We present the application of 4-phase MP-PCASL to measure renal perfusion, augmented by a semi-automatic region-of-interest registration algorithm[2] to reduce motion artifact encountered during a breath-hold acquisition.

Methods: Acquisition: All experiments were performed on a 3T Siemens Skyra scanner with 18 ch. body coil using protocols approved by the local institutional review board. Informed consent was obtained from all volunteers. Prior to tagging, a fat-suppressed HASTE oblique coronal sequence was performed to obtain M0 data with TI of 10 sec.; this plane was placed through the long axis of the kidneys, with care to avoid the heart during ASL acquisition. The axial tagging plane was placed through the descending aorta just below the diaphragm, avoiding the heart to prevent unwanted blood signal saturation. ASL data was acquired in the same oblique coronal plane of the M0 image, with tagging phase offsets of 0, π/2, π, and 3π/2, using HASTE sequence with background suppression (BGS) applied between the bottom of the heart through the bottom of the kidneys. Tagging duration was 1500 msec, with post-labeling delay (PLD) of 1200 msec and associated inversion time (TI) of 2700 msec; BGS TI were 1500 and 2490 msec; TE = 24 msec and TR = 3600 msec. Breath-hold technique was used, requiring 16 seconds per ASL series acquisition. Images were acquired using a 128x128 matrix with 5 mm slice thickness for a pixel size of 3.125 x 3.125 x 5.000 mm. No signal averages were obtained.

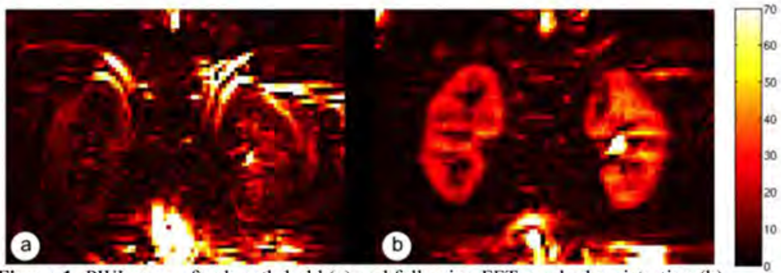

Figure 1: PWI maps after breath-hold (a) and following FFT-masked registration (b).

Analysis: ASL images were first aligned using a semi-automatic algorithm based on masked FFT registration[2]; given differential movement, ROIs for masked registration were selected for each kidney separately. By convention the tagged and M0 images were aligned to the 0-phase offset tagged image as reference. Perfusion weighted images (PWI) were then calculated. The complex vector for the MP-PCASL map was obtained using the 4 phases captured above in order to estimate the magnitude of perfusion weighted signal and the phase error, while a conventional PCASL map was derived from the 0 and π phase-offset images for comparison. Renal blood flow (RBF) estimates (units of ml/100gm/min) were obtained from the PWI maps using the kinetic ASL model[3] with tagging efficiency of 0.8.

Results/Discussion: Because the ASL maps are sensitive to even small offsets related to organ motion, masked object registration was applied prior to computing PWI maps. The effects are illustrated in Figure 1 panels (a) and (b), which compare PWI maps obtained from pre- and post-alignment ASL data. To illustrate the effects of phase-error encountered with standard PCASL technique, PCASL renal blood flow maps are placed alongside the MP-PCASL maps (Fig. 2a-b). A map and histogram of phase errors in the kidney mask are shown in Fig. 2c-d. The phase errors larger than 90° indicate that the off-resonance field at the tagging location may yield negative perfusion signal with the conventional PCASL, while MP-PCASL is insensitive to this issue.

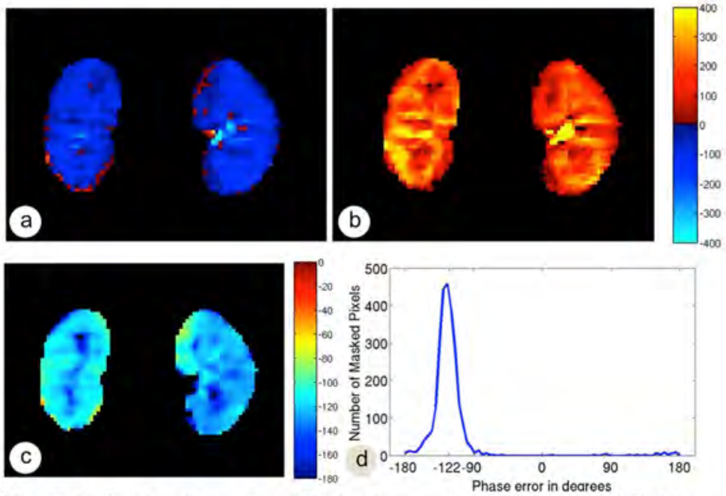

Figure 2: Renal perfusion maps calculated using PWI obtained by PCASL (a) and MP-PCASL (b). Units = ml/100gm/min. In this case, phase-error in PCASL results in negative perfusion values. (c) Map and (d) histogram of phase error.

Conclusion: We demonstrate that 4-phase MP-PCASL can provide an alternative method for assessing renal blood flow, along with post-acquisition semi-automated registration of ASL data using a recently described masked object registration algorithm[2]. The MP-PCASL approach decreases errors in the perfusion weighted imaging derived from standard PCASL in the context of reduced tagging errors associated with the off-resonance field at the tagging plane.

References: (1) Jung, et al., MRM, v64: p799, 2010 (2) Padfield, IEEE Trans on Image Process., 21(5):2706–2718, 2012 (3) Buxton et al., MRM;40(3):383-396, 1998