High Temporal Resolution Mouse Renal Blood Flow (RBF) Imaging with pseudo-continuous ASL (pCASL) at very High Field

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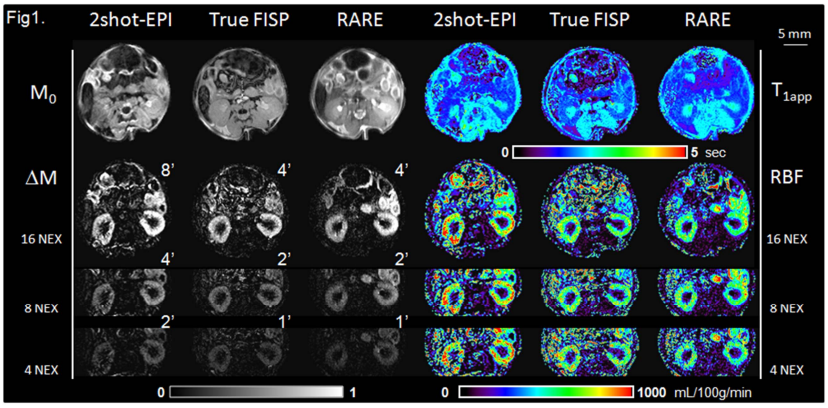
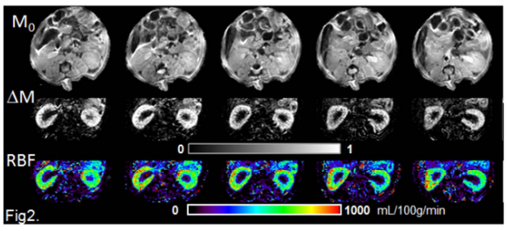
Target audience: people interested in a robust method able to non-invasively quantify mouse renal blood flow (RBF) in a very short scan time.

Introduction: Non-invasive and reliable assessment of the renal microvascular perfusion is a valuable tool for many diseases such as hypertension, ischemia or acute renal failure which have shown to be linked to damage or loss of renal microvessels. Arterial Spin Labeling (ASL), which offers simple quantification model and blood contrast specificity without any contrast agent injection had shown great potential for measuring renal blood flow (RBF) in humans and animal models. Most of the reported animal studies were performed with the moderately sensitive FAIR technique[1-3], which is limited to transverse imaging and which requires moreover the use of a RF coil able to cover a large volume of the animal for sensitivity concerns. A recent study compared the performance of the pseudo-continuous (pCASL) technique relative to FAIR for mouse renal perfusion, and concluded in pCASL superiority[4]. A segmented-EPI readout module was used for imaging, offering high SNR, but also high sensitivity to motion. In this study, we investigated more deeply mouse renal perfusion measurements using pCASL in combination with fast imaging (EPI, TrueFISP and RARE), with the aim of determining the most adapted protocol relative to sensitivity, robustness to motion, reduced scan time, multislice acquisition and imaging orientation.



Methods: Experiments were performed at 11.75T on a vertical MR system (Bruker, AV 500WB, transmit/receive volume coil:∅ 2cm, length 3cm) on anaesthetized mice (C57BL/6j, 10 weeks, weight 25±1g, N=5). pCASL experiments were performed with the unbalanced (ubpCASL) scheme[4,5] (b_{1ave}= 4.7 µT, G_{max}/G_{ave}=90/10 mT/m, Hanning pulse duration δ=200µs and repetition rate Δt=450 µs, labeling duration τ=3s and post-labeling delay, *w*=0.3s). The transverse labeling plane was located ~8mm above the imaging slab perpendicularly to the descending aorta. The pCASL preparation was combined with a 2-shot SE-EPI sequence (TE=9ms), a TrueFISP sequence (TE=0.8ms, TR=1.6ms, acquisition time 130ms, fa 70°, partial Fourier 1.6) and a RARE sequence (TE=2.4ms, TE_{eff}=28.8ms, RARE factor=64, Partial Fourier 1.7) for transverse and coronal single-slice and multislice imaging. Common parameters were: FOV 2.5x2.5cm^2, slice thickness 0.75mm, matrix 128x128 and fat sat. A total number of 16 NEX (control and label images) was acquired for each sequence. Quantitative RBF values were derived from the magnetization differences (ΔM) images and application of the classical CASL equation[6]. All the acquisitions were synchronized to the respiratory rate (80±10 bpm).



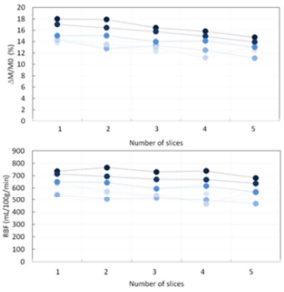
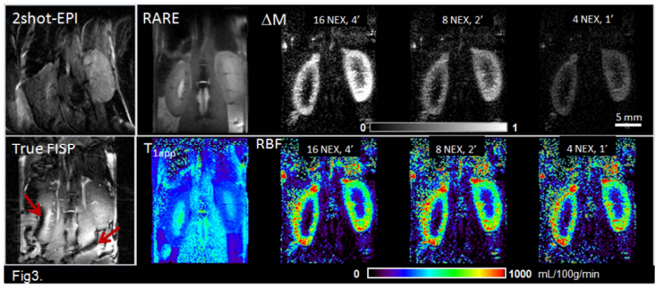


Fig2. Multislice pCASL-EPI images showing non-significant signal decrease across slices

Results and Discussion: Figure 1 shows typical transverse pCASL perfusion maps obtained with EPI, TrueFISP and RARE imaging for different total acquisition time (different number of NEX). Quantitative analyses were performed in the renal cortex. Due to segmentation of the readout, EPI was less efficient in terms of signal per unit of time (e.g. for 4' of acquisition, $\Delta M^{TrueFISP} \geq \Delta M^{RARE} > 1.5x\Delta M^{EPI}$). The percentage of signal change ($\Delta M/M_0$) was however slightly higher ($\Delta M/M_0^{EPI}$=18.5±2.0%, $\Delta M/M_0^{TrueFisp}$=16.4±1.5% and $\Delta M/M_0^{RARE}$=15.7±1.8%). This sensitivity difference could be explained by T_1 relaxation and flowing blood affecting differently the magnetization during the acquisition train length, very short for EPI (20ms) and relatively long for TrueFISP (130ms). Nonetheless, pCASL provided high sensitivity which allowed decreasing the number of NEX to 8 while preserving accurate RBF quantification for all the imaging modules (Fig 1): For instance, (mean±in-ROI variations) RBF^{RARE} / $RBF^{TrueFISP}$ values were measured equal to 586±90 / 600±140 mL/100g/min (16 NEX) and to 584±110 /584±130 mL/100g/min (8NEX). When decreasing the scan time to one minute (4 NEX) a loss of accuracy was observed for RARE (RBF^{RARE}=496±140 mL/100g/min), not for TrueFISP ($RBF^{TrueFISP}$=600±175 mL/100g/min). Since moreover, better robustness to motion was obtained with TrueFISP, this imaging readout should be preferred when single slice perfusion imaging is desired. For multislice imaging in a single session, the long acquisition train length of TrueFISP and RARE led to consistant loss of sensitivity across slices sequentially acquired (data not shown), unlike EPI, for which up to 5 slices can be acquired while giving uniform RBF values (Fig2). Coronal perfusion imaging can be performed since the pCASL control experiment does not affect the flowing blood, unlike the FAIR slice-selective inversion pulse. However, the imaging readout module should be carefully chosen. EPI distortions were too much pronounced despite the segmented acquisition (Fig3) and TrueFISP might present dark banding artifacts not-easily removable (Fig 3, red arrows). Alternatively, single-shot RARE offered images with good quality, with high contrast between renal structures (cortex, outer medulla and inner medulla) as well as decent robustness to motion (Fig3., clean subtraction signal on ΔM images). Quantitative coronal RBF maps highlighting highly perfused cortex and moderately perfused outer medulla could be obtained in 2' only (8 NEX).



Conclusion: pCASL with different imaging readouts was applied at very high field for quantitative mouse renal perfusion. The robustness to motion of TrueFISP was advantageous for single-slice transverse imaging, whereas for multislice imaging, the short acquisition train length of EPI was preferable to preserve the sensitivity across slices. For coronal imaging, single-shot RARE provided the best image quality. Overall, highly sensitive pCASL combined with fast imaging which allowed obtaining RBF maps with 200x200µm^2/pixel of spatial resolution in 2 minutes of scan time only, appeared as a robust method well suitable for studying mouse models of renal vascular diseases.

References**:** *[1] Martirosian P. et al, MRM (2004) [2] Winter J.D. et al., JMRI (2011) [3] Zhang Y. et al. Contrast Media Mol. Imaging 2012 [4] Duhamel et al., Proc. ISMRM2012 [5] Dai et al., MRM (2008) [6] Buxton et al., MRM (1998).*