Quantitation of renal perfusion in an animal model at 3T: A comparison between ASL and DCE-MRI

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Introduction: The assessment of kidney function by measuring renal microvascular perfusion is crucial to diagnose and treat renal diseases at an early stage of progression. MRI provides two techniques to assess renal perfusion: Dynamic contrast-enhanced (DCE)-MRI and arterial spin labelling (ASL). DCE-MRI involves the injection of a contrast agent to measure the renal blood flow (RBF). However, recently, cases of nephrogenic systemic fibrosis (NSF) were associated with the administration of gadolinium based contrast agents in renal MRI [1]. Therefore, it is the advantage of ASL to be a completely non-invasive method that uses magnetically labelled protons in arterial blood as an endogenous tracer. In the last years several studies have shown the feasibility of renal perfusion measurements with ASL [2,3]. However, regarding the quantitation of blood flow with ASL, there is a number of challenges and aggravating issues like movement from respiratory-related motion or the low SNR of the perfusion signal. The objective of this study was to establish ASL for renal perfusion measurement in rats with unilateral ischaemic acute renal failure (ARF) at a 3T clinical whole body scanner and to compare the estimates of a pulsed ASL experiment against those obtained by DCE-MRI.

Material and Methods: A total of six male Lewis rats (260g – 290g) were examined, five of which had an ischaemic ARF of the left kidney. All procedures conducted with the animals were approved by our institutional animal committee. All measurements were performed on a 3T Magnetom Tim Trio (Siemens Healthcare, Erlangen, Germany) using an eight channel receive-only volumetric rat array (RAPID Biomedical GmbH, Rimpar, Germany) for signal detection.
ASL measurements were performed using a FAIR-TrueFISP sequence [3] imaging a single axial slice of 4mm thickness including both kidneys. Images without magnetic preparation M_0, with global inversion (ns-IR) and with slice-selective inversion (ss-IR) were recorded in an interleaved manner and an inter image time of 6s. Overall, 90 images were acquired. The ss-IR slab had a thickness of 8mm and covered the imaging volume completely and symmetrically. True-FISP parameters were: TE/TR/TI/FA = 2.72ms/5.44ms/1.2s/70°, BW = 651Hz/pixel, matrix = 256 x 256, FOV = 140 x 140mm² and a PAT acceleration factor of 3. The total measurement time was 9 min. Immediately after the ASL measurement DCE-MRI was performed using a time-resolved angiography with stochastic trajectories (TWIST) [4] sequence with the following parameters: TR/TE/FA=3.4ms/1.4ms/20°, matrix = 192 x 84, FOV = 114 x 50mm², a PAT acceleration factor of 2 and 28 slices. The nominal temporal resolution was 0.9s per volume. Images were continuously acquired for 6 minutes. After the 15th volume, 0.05ml of contrast agent (Dotarem, Guerbet, France) was manually administered in the femoral vein, followed by a saline flush.
ASL perfusion maps were calculated with an in-house MATLAB script (The MathWorks, Natick, MA, USA), averaging the images and calculating the ΔM image by subtracting the average ss-IR from the average ns-IR image. Perfusion maps were calculated on a pixel-by-pixel basis according to the following equation [2] for the perfusion rate f: $f = \frac{\lambda}{2TI}\frac{\Delta M}{M_0}\exp\left(\frac{TI}{T_1}\right)$.

The blood-tissue water partition coefficient λ was set to 0.8 ml/g [5] and T_1 =1.14s [6]. Quantification of DCE-MRI was performed using a pixel-by-pixel deconvolution [6] approach. The arterial input function was determined by placing a region of interest (ROI) in the abdominal aorta. All data were normalized by subtracting the mean intensity of 15 baseline volumes, and a linear relationship of the contrast agent concentration to the measured signal intensities was assumed. The cortical RBF was assessed by drawing a ROI into the DCE and ASL perfusion maps depicting the kidney cortex. Both left and right kidney of each rat has been evaluated. A paired t-test was applied to compare the estimates of ASL and DCE and healthy and diseased kidneys, respectively.

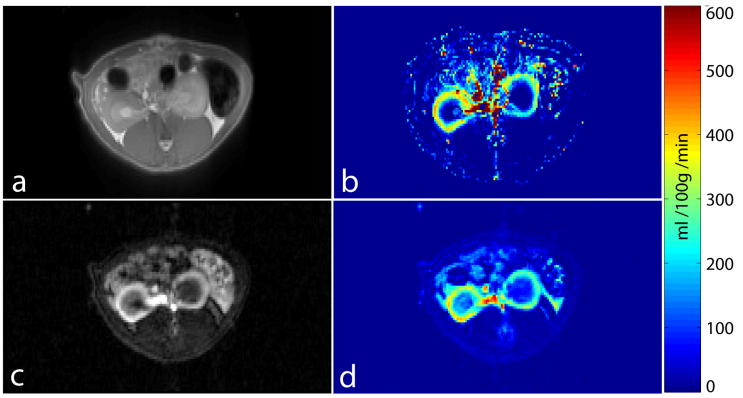

Fig. 1: *The upper row shows a TrueFISP M_0 image* ***(a)*** *and the corresponding perfusion map* ***(b)*** *from a representative ASL measurement. Image* ***(c)*** *shows a TWIST post contrast agent image of the same rat and the same slice. The corresponding DCE perfusion map is shown in* ***(d)****.*

Tab. 1: *Cortical RBF in ml/100g/min as estimated from ASL and DCE measurements.*

Rat	ASL		DCE	
	left (ARF)[1]	right (healthy)	left (ARF)[1]	right (healthy)
1	289	504	430	470
2	456	634	262	365
3	191	344	346	449
4	(295)[2]	304	(395)[2]	414
5	374	462	243	302
6	269	371	266	335
Mean	316±102	416±124	309±78	390±60

[1]Kidneys with ischaemic acute renal failure, except for rat 5.
[2]This value was included in the calculation of the mean blood flow of the healthy kidneys and excluded when calculating the mean perfusion of the left (ARF) kidneys.

Results: Table 1 shows the cortical RBF of each rat and laterality as estimated with both DCE and ASL. The mean perfusion estimates of the left kidneys (ARF) were found to be 316±102ml/100g/min (ASL) and 309±78ml/100g/min (DCE). For the right (healthy) kidneys we found 416±124ml/100g/min (ASL) and 390±60ml/100g/min (DCE). Both pairs of values are in close agreement and show no statistical differences. Furthermore, the perfusion estimates between healthy and diseased kidneys are significantly different ($P<0.01$) in both methods. However, this difference is less pronounced for the DCE measurements, whereas the inter animal variations are higher for the ASL estimates. Figure 1 shows one representative image from a DCE and an ASL measurement and the corresponding perfusion maps. All images show the same rat and the same slice.

Discussion: The agreement between the estimates of both methods shows that ASL is capable of measuring renal perfusion quantitatively. Most important, both methods express the reduced blood flow in the kidney with ischaemic ARF, leaving it open to physicians to choose ASL, especially for patient with an increased risk for NSF. So far, to our knowledge, only one other study directly compared absolute RBF estimates assessed with ASL and DCE [7]. The reported results for the cortical RBF in rabbits (328±59ml/100g/min (ASL) and 357±96ml/100g/min (DCE)) are similar to our estimates. However, only one healthy kidney per animal has been examined. The ASL measurements might benefit from applying background suppression techniques to increase SNR or by using respiratory triggering to ensure the congruency of ss-IR and imaging slab. Although the profile quality of the ss-IR pulse was checked in an oil phantom, it might be corrupted in the abdomen due to air-tissue transitions that cause magnetic field inhomogeneities. In conclusion, we showed that absolute quantitation of cortical RBF is in agreement between ASL and DCE. Furthermore, both methods provided significantly different values between healthy and diseased kidneys.

References: [1] Broome DR, Eur J Radiol 2008, 66(2):230-234 [2] Song R et al., MRM 2010; 64(5) :1352-1359 [3] Martirosian P et al., MRM 2004; 51(2):353-361 [4] Song T et al., MRM 2009, 61(5):1242-1248 [5] Roberts DA et al., Radiol 1995; 196:281– 286 [6] de Bazelaire CM et al., Radiol 2004, 230:652-659 [7] Sourbron S, Phys Med Biol 2007, 52(2):429-47 [8] Winter JD et al., JMRI 2011, 34(3):608-615