Accurate quantification of blood perfusion in the kidney using pseudo-continuous arterial spin labelling: an optimisation and reproducibility study

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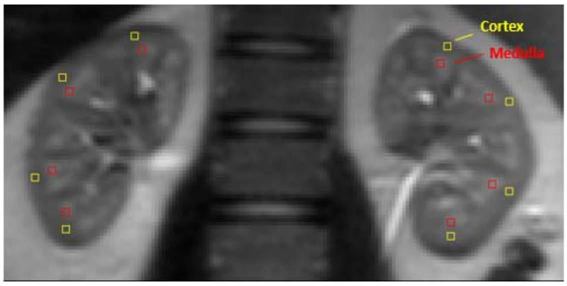
Target Audience: physicists and radiologists with an interest in assessing kidney function and/or applications of pCASL.

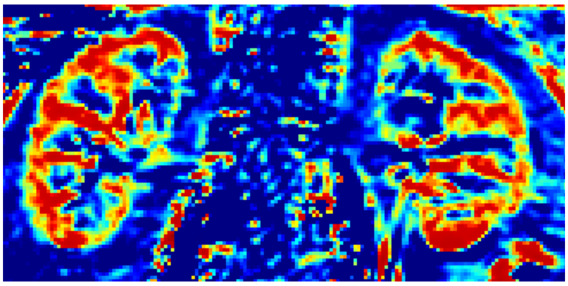
Purpose: The accurate quantification of blood perfusion in the kidneys without using exogenously administered Gd-based contrast agents (with contraindications for renal patients) has potential application across a broad spectrum of renal problems. The pseudo-continuous arterial spin labelling (pCASL) technique has been well-established as a reliable quantification method for assessing cerebral perfusion given its superior SNR compared to other ASL techniques [1], however its use outside of the brain is subject to additional magnetic susceptibility-related distortions and motion artefact arising from breathing in the thorax/abdomen regions [2]. The predominance of published kidney ASL studies have used the FAIR-ASL approach [3,4], and hence the potentially superior SNR afforded by the pCASL technique could offer significant benefits to the quantification accuracy of perfusion measurements in this technically-challenging area. The aim of this project was to implement an SNR-optimised pCASL technique in the kidneys, with sufficiently high spatial resolution to allow for accurate delineation of cortical and medulla regions, and to assess the reproducibility of these measurements in a cohort of healthy volunteers.

Methods: 15 healthy controls (age = 32±12 yrs, 4 male) were scanned using a 3T Philips Achieva TX system and a 32-channel array coil. All scanning was performed with informed consent and ethical approval from the local Institutional Review Board. A high spatial resolution pseudo-continuous ASL sequence was optimised through careful tailoring of the following acquisition parameters: the image readout sequence (EPI versus single shot TSE), voxel resolution (37.5-160 mm^3), receiver bandwidth (290-3037 Hz), label duration (500-2000 ms) and label delay (500-2000 ms). In all cases, 16 label/control image pairs were acquired, with the labelling plane positioned perpendicular to the aorta above the kidneys, and the image plane orientated coronally-oblique. Two breathing strategies were investigated: timed breathing (where the subjects were trained to time their breathing to coincide with the 6-second cycle of the label/control image pair acquisition), and multiple breath-hold acquisitions (label/control image pairs acquired in breath-holds of duration 6-12 s, depending on the pCASL label duration/delay times). To further minimise motion-induced errors, B-spline image registration was performed on all images prior to fitting to the standard pCASL perfusion model. Four of the volunteers were scanned on two different days using the final optimised TSE breath-hold protocol, with three repeat acquisitions on each day, to allow for an assessment of the intra- and inter-session reproducibility. A one-way ANOVA analysis was used to calculate the mean within-subject variance and coefficient of variance (CV), while Bland-Altman plots were used to determine the long-term repeatability of the measurements.

Results: 2D and 3D EPI readout acquisitions suffered from considerable geometric distortion which could not be completely eliminated despite using higher-order shimming and minimised TE values. A 2D ss-TSE single slice readout acquisition produced consistently-high quality images and was consequently used throughout. The breath-hold approach gave the least motion artefacts (taking approximately 5 mins to acquire all 16 label/control image pairs). A SNR of 56±3 was achieved in label and control images with a voxel resolution of 2.5 x 2.5 x 6 mm^3 and a receiver bandwidth of 3037 Hz. A representative label image from one volunteer is shown in the figure (left) demonstrating the distinct contrast between cortex and medulla areas. Regions of interest used for the perfusion measurements are also shown. The right figure is the corresponding perfusion map - the mean perfusion value measured in the cortex was 293 ± 44 ml/100g/min and 139 ± 20 ml/100g/min in the medulla, with optimal values for both the label duration and label delay found to be 1.5 s.

Reproducibility: The within-subject variance was found to be 19.4 / 24.1 ml/100g/min for the left / right kidney respectively. The average perfusion results of all three scans obtained on both scanning sessions had a mean value of 302 ml/100g/min, with a CV of 6.8% for the left cortical region and 7.5% for the right cortical region. The dispersion of perfusion measurements were all within the limits of agreement, as demonstrated in the Bland-Altman plot used to assess the long-term reproducibility.





Discussion/Conclusions: This study demonstrates that it is possible to perform sensitive and reproducible measurements of blood perfusion in the kidney using the pCASL technique, with a spatial resolution sufficiently high to allow for separation of medulla from cortical regions. Given the significant differences in perfusion values in these areas (as shown here and in previous studies), the ability to resolve them in a perfusion map will be critical in a clinical assessment of perfusion.

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References: 1. Alsop D.C. et al, Mag Reson Med, in print, 2014. 2. Gardener A.G. et al, Mag Reson Med 63, 1627-1636, 2010. 3. Karger N. et al, Magn Reson Imag 18, 641-647, 2000. 4. Cutajar M. et al, Magn Reson Mater Phys, 25, 145-153, 2012.