Quantitative rat lumbar spinal cord blood flow measurements using multi-slice arterial spin labelling at 9.4T

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Target audience: Scientists interested in the metabolism and the hemodynamic of the central nervous system.

Purpose: The Arterial Spin Labelling (ASL) is a valuable tool in the investigation and the understanding of the central nervous system pathologies such as tumours, stroke, and neurodegenerative diseases. Whereas it has been extensively applied to the brain, only very few spinal cord (SC) ASL studies have been reported due to the experimental challenging difficulties [1,2]. The main pitfalls are its small size, the magnetic field inhomogeneities, and the physiological motion. To overcome these limitations many strategies were adopted. We showed previously a new approach which is adapted to the scanning of small structures like the spinal cord and optic nerve [3]. In brief, this sequence is based on the application of three slice selective RF pulses in three orthogonal spatial axes combined with a reduced FOV. The non-adiabatic slice excitation pulse is followed by an AFP RF pulse applied along the phase encoding axis and a second one applied along the readout axis. As a result, only a narrow cross section of the sensitive volume is selected (Fig1). Quantitative SC blood flow (SCBF) was efficiently measured using short TR pre-saturation FAIR sequence [4]. Multi-slice ASL acquisitions were adopted in order to cover a large region of the SC and to get a good time-efficiency. Q2TIPS was introduced to control the time duration of the tagged bolus and to improve the accuracy of perfusion quantification [5]. In this study, a new multi-slice ASL technique is detailed and applied to the study of rat spinal cord at 9.4T. Quantitative measurements of SCBF were performed using a pre-saturation FAIR Q2TIPS ASL technique based on the use of adiabatic RF pulses with a reduced FOV. In addition, diffusion weighted images (DWI) were acquired to get a good contrast between the grey matter (GM) and the white matter (WM) and match them with the SCBF maps.

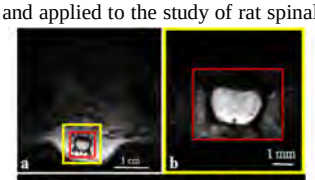

Fig1 Anatomical images of rat SC acquired with a standard GE (a) and EPI (b) sequences. The yellow and the red rectangles delineate the encoded reduced FOV and the selected volume of interest using adiabatic RF pulses.

Methods: Experiments were performed on anesthetized (isofluarne 2%) DA rat on a 9.4T Agilent scanner (Agilent Technologies, CA, USA) using transmit volume coil (Ø=72 mm) and two elements receive array coil (Rapid Biomedical). After a global manual shimming and based on fast localization imaging, the animal is positioned in such a way both the heart and the volume of interest are included in the volume coil. The surface coil was placed at the lumbar level. The non-selective pre-saturation was performed using 5 HS AHP RF pulses (T=4s, BW=12 kHz). The recovery time τ was set to 3.2s. Selective and nonselective inversions were performed with an adiabatic hyperbolic secant pulse (Slab thickness=20mm, BW=10 kHz, T=10 s). The TI1 and the TI2 of the Q2TIPS module were set to 1550ms and 1650ms, respectively. The equilibrium magnetisation, the inversion efficiency, and the tissue apparent longitudinal relaxation were estimated by fitting a slice selective inversion recovery data acquired with τ=10s and TI=0.1,1,2,and9s. 4 shots EPI readout technique was used to encode a FOV of 12x12mm^2. A sinc and two FOCI AFP RF pulses [6] were applied to select slices with a thickness of 2mm and an in-plane extent of 7x9mm^2 (Fig1). The slices were acquired sequentially with a gap of 2mm. In order to get contiguous slices, two sets of slices were acquired separately (Fig2.a). The inplane spatial resolution was 125x125um^2. The acquisition parameters were: TE/TR=20/5015ms, NEX=12, and the acquisition time=25 min. DWI were acquired using a slice selection and a spatial encoding schemes identical to those applied for the ASL method. The diffusion gradients were applied along the SC axis to get a good contrast between the GM and the WM. The acquisition parameters were: TE/TR = 31/2000 ms, δ/Δ =5/11 ms, b-value=300s/mm^2, Nex=8. In order to reduce movement artefacts, the breathing was checked in real time during the scanning. The timing was kept identical to avoid any variations in the signal intensity between the different saved images. The data were saved when both the inversion and the image acquisition were performed during the quiescent phase of the respiratory plateau. Otherwise, the data are not saved and the acquisition parameters were adjusted accordingly.

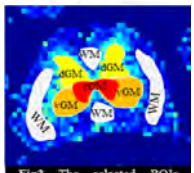

Fig3 The selected ROIs within the dorsal GM (dGM), ventral GM (vGM), central GM (cGM), and WM.

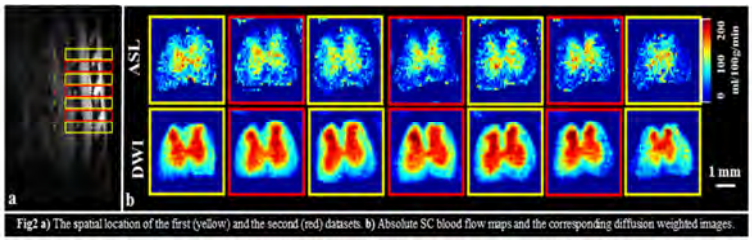

Fig2 a) The spatial location of the first (yellow) and the second (red) datasets. **b)** Absolute SC blood flow maps and the corresponding diffusion weighted images.

	Slice1	Slice2	Slice3	Slice4	Slice5	Slice6	Slice7	Mean
dGM	82.0±21.4	90.8±22.9	80.5±21.6	88.1±25.8	87.4±25.5	84.0±30.0	75.7±21.7	84.1±4.8
vGM	111.6±24.0	102.7±23.2	96.6±22.8	92.6±23.5	97.9±27.1	98.5±28.5	100.0±31.0	100.0±5.6
cGM	119.6±20.1	112.9±19.4	110.5±19.0	116.8±15.1	120.7±19.4	118.0±18.8	126.6±23.4	117.9±5.0
tGM	104.4±23.3	99.1±23.1	91.2±22.4	90.9±24.4	94.2±26.5	93.5±29.0	92.6±28.5	95.1±4.6
tWM	45.8±19.5	40.8±19.0	40.7±21.0	34.2±17.3	37.9±22.1	39.8±21.3	39.0±21.3	39.7±3.2

Table 1: The quantification results within the selected ROIs

Results: The typical SCBF maps and the DWI obtained at the lumbar level of the rat spinal cord are depicted at Fig2b. On both perfusion and DWI images, the typical butterfly shape of the GM is clearly visible. The averaged SNR within the GM and the WM were 3.8±0.5 and 2.0±0.2, respectively. The quantitative measurements within the ROIs depicted in Fig3 are summarized in Table1. The averaged perfusion within the GM (95.1±4.6ml/100g/min) was higher than within the WM (39.7±3.2ml/100g/min). The perfusion within the GM was not homogeneous. It was within dGM (84.1±4.8ml/100g/min) lower than within vGM (100.0±5.6ml/100g/min). The highest perfusion values were noticed within the cGM (117.9±4.9ml/100g/min).

Discussion: The quality and the spatial resolution of the SCBF maps permitted an accurate identification of the high perfused GM and low perfused WM. The delineation GM/WM was confirmed by the DWI. A good SNR and a high in-plane spatial resolution (125x125μm^2) were obtained in about 25 min of ΔM averaging. None of the depicted images suffered from motion or aliasing artefacts which highlights the efficiency of both the respiratory gating and the adopted slice selection approach. The ratio $SCBF_{GM}/SCBF_{WM}$ is 2.4 which is in agreement with previous studies. dGM perfusion is slightly lower than vGM which is consistent with the literature. These multi-slice results are similar to those obtained on single slice studies (data not shown). The obtained values of the SCBF are significantly lower than the only published paper reporting quantitative measurements of mice SCBF at the lumbar level ($SCBF_{GM}$=285±27ml/100g/min and $SCBF_{WM}$=100±32 ml/100g/min) [2]. It was reported in this manuscript that the perfusion within the cervical SC GM is similar to the brain cortex and that the lumber perfusion is lower than the cervical one [2]. It was reported that the perfusion values within the rat brain cortex are 110-150 ml/100g/min [7,8]. Compared to these results, the averaged $SCBF_{GM}$ in our study is slightly lower but in the same range. However, the quantified perfusion within the cGM is in the same range.

Conclusion: Absolute quantification of SCBF of the rat SC at the lumbar level was obtained with high in-plane spatial resolution at 9.4 T. The images were acquired using multi-slice pre-saturation Q2TIPS FAIR ASL with a restricted extent of the selected slices and a reduced FOV. The developed technique will help in the understanding of the pathogenesis of certain pathologies where the perfusion is playing a key role like neurodegenerative diseases, SC injury and tumours. **References:** [1] Duhamel MRM2008; [2] Duhamel MRM09; [3]Tachrount ISMRM14; [4] Pell MRM99; [5] Luh MRM99 ; [6] Ordidge MRM96; [7] Zheng NMB10 ; [8] Pell MRM99.