Use of an OVS-FAIR based ASL Technique for High Spatial Resolution Mouse Cervical Spinal Cord Blood Flow (SCBF) Mapping

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Introduction:

The assessment of Spinal Cord (SC) perfusion plays a key-role in the physio-pathological description and understanding of diseases such as SC injury, ischemia or spinal tumor. Previous work has demonstrated the feasibility of mouse SC blood flow (SCBF) measurement with arterial spin labeling techniques (ASL) using a presaturated flow-sensitive alternating inversion recovery (presat-FAIR) technique at the cervical level [1]. The achieved spatial resolution (~ 130x130 μm^2/pixel) permitted to accurately measure SCBF within the different cord structures. For visualization and validation of longitudinal pathological changes in lesioned rodent SC, higher resolutions would however be required. The purpose of this work was to develop a method that permits to obtain higher spatially resolved mouse SCBF maps within reasonable scan time. The combined use of a small volumic coil with an outer volume suppressed (OVS) presat-FAIR sequence was investigated.

Methods:

Imaging: Experiments were performed in mice (C57Bl/6J, age 14 weeks, 25 g. Anaesthesia: air+isoflurane (~1.4%)) on a 11.75T vertical MR system (Bruker, AV 500WB). Axial images were acquired at the C3 cervical level with an optimized 4-shot SE-EPI sequence [2] (TE=10.6ms, matrix 128x128, FOV=1.7x1.7cm^2, slice thickness 0.75 mm). Higher resolutions were achieved by decreasing the FOV and by applying OVS in the readout and phase encoding directions to avoid aliasing artifacts. Acquisitions were performed for 3 different FOVs (N=5 subjects each) leading to Standard Resolution (SR, FOV=1.7x1.7 cm^2, 130x130 μm^2/pixel), Intermediate Resolution (IR, FOV=1.7x0.9 cm^2, 130x70 μm^2/pixel) and High Resolution (HR, FOV=1.1x1.1 cm^2, 85x85 μm^2/pixel).

SCBF quantification: The sensitivity of the presat-FAIR signal detection was enhanced by the use of a small transmitter/receiver volumic coil (∅ 2cm, length 3cm), well adapted to the mouse SC imaging. However, since the coil did not provide a complete coverage of the subject, there was, in the global inversion scan of the presat-FAIR experiment, a coil inflow time (Δ) effect that had to be taken into account for the SCBF quantification. As described by *Pell et al* [3] and in order to estimate Δ, the variation of the presat-FAIR signal (ΔM) with the recovery time after the presaturation (τ) was examined for a fixed value of the inversion time (TI =1.3s). A Δ value of 2.7±0.2 s was found (figure 1). Therefore, with TI=1.3s and τ=3.5s, the presat-FAIR signal was simply related to blood flow by $\Delta M = 2M_0.\alpha_0.(SCBF/\lambda).[(e^{-TI.R1app} - e^{-TI.R1a}) / (R1^a - R1^{app})]$ (eq 1). λ is the water blood/tissue partition coefficient (0.9 ml/g) and $R1^a$ the longitudinal relaxation rate of arterial blood ($1/R1^a = 1/2.1\ s^{-1}$). M_0 (equilibrium magnetization), α_0 (inversion efficiency) and $R1^{app}$ (SC tissue apparent longitudinal relaxation rate) were determined with a slice selective inversion recovery prescan. The presat-FAIR signal ΔM was averaged over 20, 30 and 40 minutes for the SR, IR and HR experiments respectively. Absolute perfusion quantification was obtained by solving equation 1 and SCBF values were evaluated in the SC gray matter (GM) structures (Ventral Horn (VH), Dorsal Horn (DH)) as well as in the whole GM.

Results:

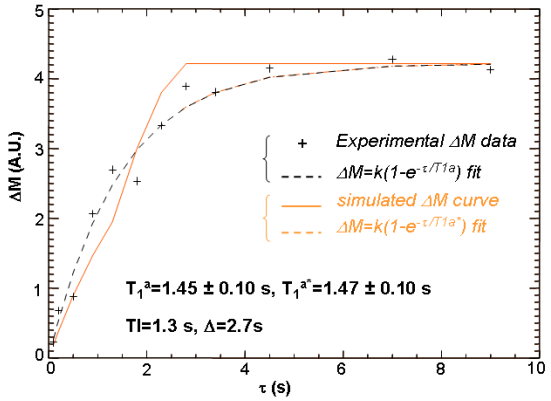
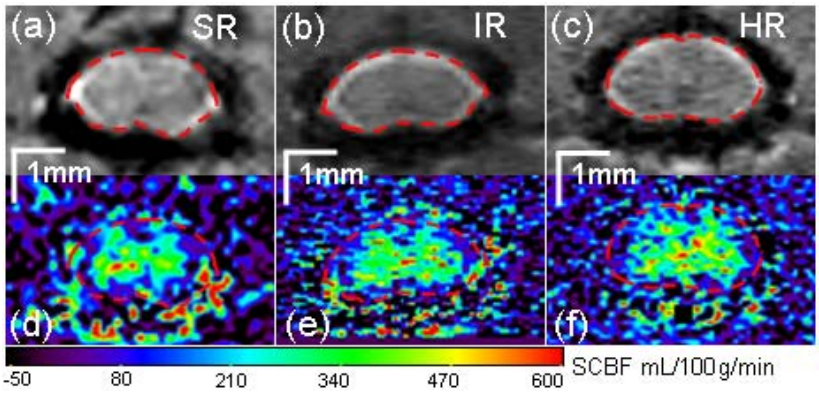


Fig 1: Coil inflow time determination [3]. The saturation recovery function $\Delta M(\tau)=k.(1-e^{-\tau/T1a})$ was fitted to the experimental ΔM data (T_1^a= 1.45±0.10s). Simulated theoretical $\Delta M(TI,\tau,\Delta)$ functions were constructed so as to obtain T_1^{a*} value similar to T_1^a by fitting the saturation recovery function $\Delta M(\tau)$ to $\Delta M(TI,\tau,\Delta)$. For Δ=2.7±0.2s, T_1^{a*} of1.47±0.10s was obtained.

Table 1 - SCBF values (mL/100g/min) – HR experiment

Subject	VH	DH	Whole GM
1	315±103	347±84	360±100
2	290±72	322±68	300±100
3	320±70	316±78	290±100
4	309±70	319±78	328±101
5	328±84	311±66	322±100
Mean±std	**312 ± 14**	**323 ±14**	**320 ±27**



The figure to the left shows anatomic SC (C3) EPI images (top) along with the corresponding SCBF maps (bottom) for standard (a, d), intermediate (b, e) and high (c, f) spatial resolutions. The red dotted lines, surrounding the SC boundaries on the anatomic images, were reported to the SCBF maps. The SC structures, highly-perfused GM and low-perfused WM, can clearly be seen, with a more precise and sharp delineation obtained for the IR and HR conditions (e, f). Similar perfusion values were obtained for the 3 resolutions conditions. Individual (mean + Std_{ROI}) and group (mean + Std_{group}) SCBF values measured in the gray matter structures for the HR experiment are reported in the table 1. Mean ROI standard deviations of ~ 25% and group standard deviations of ~ 5% were obtained.

Discussion:

The absolute SCBF values measured in this study are similar to those obtained in our previous work performed with a large coil and for which there was no coil inflow time effect (327+33 mL/100g/min for VH and 346+38 mL/100g/min for DH) [1]. Better ROI and group standard deviations are however obtained in this study due to the increased sensitivity provided by the small coil well suited to SC imaging. The OVS, preventing from aliasing artefacts when decreasing the FOV, permitted to achieve high spatial resolution without alteration of the image quality. Therefore, by combining the use of a small coil with an OVS-presat-FAIR experiment we were able to obtain quantitative SCBF maps of less than 100x100 μm^2/pixel of spatial resolution in 30 minutes. Such a method, combining short scan times and high spatial resolutions, is appropriated for repeated measurements and longitudinal pathological studies involving SC blood supply alteration. This work has focused on cervical SC only. One next step would be to assess perfusion at lower levels of the cord (thoracic, lumbar), which are of interest for different and numerous disease models (contusion…) but challenging due to more amplified bulk motion.

References :*[1] Duhamel et al., MRM (2007) in revision, [2] Callot et al., Magn. Reson. Mater. Phy., MAGMA (2007) [3] Pell et al, MRM (1999)*