Mouse Lumbar Spinal Cord Blood Flow Imaging using 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 spinal cord blood flow (SCBF).

Introduction: Spinal cord ASL perfusion imaging, performed at the cervical level with a presat-FAIR EPI technique has shown to provide valuable information relative to tissue alteration and recovery in a mouse model of spinal cord injury (SCI). Numerous rodent models of SCI are however developed at the thoracic or lumbal levels and, although FAIR EPI also appeared to be feasible at these levels, the technique suffered from several drawbacks. First, in order to enhance the sensitivity of the FAIR signal and to limit the inflowing fresh blood effects, a large blood volume was required to be submitted to the global inversion FAIR labeling pulse. This consequently implies constraints on the animal positioning in the RF coil. Moreover, when used in combination with respiratory gated acquisition, the FAIR strategy required full relaxation conditions, limiting then the sensitivity per unit of time. Additionally, in order to minimize distortion artifacts which are likely to occur at this level of the cord and at very high field, segmentation of the EPI readout module was required. This imaging strategy was thus very sensitive to motion. As an alternative to FAIR-EPI for lumbar spinal cord blood flow imaging, we investigated the feasibility of pseudo-continuous ASL (pCASL) combined with single-shot RARE imaging, with the objective of benefiting from higher sensitivity, more flexibility and more robustness to motion.

Methods: Experiments were performed at 11.75T on a vertical MR system (Bruker, AV 500WB, transmitter/receiver volume coil: 2 cm, length 3 cm) on anaesthetized mice (C57BL/6j, 10 weeks, weight 25±1g, N=4). pCASL experiments were performed with the unbalanced (ubpCASL) scheme (bubpCASL=4.7 μT.m, Gpu=0/10 mmT/m, Hanning pulse duration Δt=200μs and repetition rate Δt=450μs, labeling duration τl=3s, post-labeling delay w=0.3s, recovery time 3s). The transverse labeling plane was located perpendicularly to the descending aorta, ~6 mm above the axial imaging slab placed at the lumbar level of the spinal cord (Fig1.). Single-shot RARE readout (TE=2.37ms, TEp=28.5ms, fat sat) was used with an in-plane resolution of 200x200μm²

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Results: Typical $M_0^e$, DW, and $ΔM_0^{CASL}$ images are shown on Fig 2. The long echo train length of the single-shot RARE sequence led to slight blurring visible on the $M_0^e$ image. The contrast of the DW image highlights the spinal cord gray matter (GM) structure relative to the white matter (WM). The ASL image ($ΔM_0^{CASL}$) shows very clean subtraction signal, highlighting good robustness to motion. Hypersignal can be seen in the highly perfused SC GM area (ventral and dorsal horns) whereas less-perfused WM showed low signal (see enlarged images, Fig2.). Motion evaluation and a typical quantitative SCBF map obtained in less than 5 minutes are reported on Fig3. Quantitative measurements performed on the gray matter tract (ventral and dorsal horns) gave a mean percentage of signal change ($ΔM_0^{CASL}/M_0$) of 6% (n=4, SNR>6.5), which corresponded to SCBF of 240±50 mL/100g/min (fig3).

Discussion: pCASL combined with single-shot RARE imaging was used to obtain quantitative lumbar SCBF images. The pCASL labeling, performed in the descending aorta, allowed efficient upstream tagging of the blood nourishing the lumbar spinal cord. Unlike for the FAIR technique, the positioning of the animal inside the RF coil had no effect on the pCASL sensitivity and perfusion quantification. Absolute SCBF values obtained in this study were however slightly lower than those previously obtained with the FAIR technique (240±50 vs 285±27 mL/100g/min), which is more likely due to a slight loss of the pCASL inversion efficiency (true-β<0.6). A careful study of β, which takes into account $B_1$ and $B_0$ inhomogeneities, should help in increasing the pCASL sensitivity.

Moreover, the single-shot RARE sequence combined with respiratory synchronization appeared very robust despite the high motional area, and, compared to segmented-EPI imaging, very few images were altered by motion artifacts in the spinal cord area. Five minutes only were required to obtain 200x200 μm² spatial resolution quantitative SCBF maps. Further studies will investigate higher spatial resolution. Finally, since multislice imaging can be straightforwardly performed with pCASL, the proposed technique might be a method of choice for investigating perfusion alteration in mouse models of SC injuries.

References: