

QUANTIFICATION OF SPINAL CORD BLOOD VOLUME IN HUMANS USING VASO MRI

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INTRODUCTION: Spinal cord hemodynamics is a key component in the pathophysiology of many related diseases such as spinal cord trauma, ischemia, infarction, and spinal arteriovenous malformation (1-2), but virtually no literature is reported to measure these parameters in humans. While several techniques are available to assess brain perfusion, they are not necessarily usable for spinal cord due to unique structural and functional characteristics of the spinal cord including small dimensions, complex vessel networks, tissue inhomogeneities and cord motions. We note spinal cord blood flow has been measured using ASL technique, but only on animal models (3). Recently, spinal cord blood volume (scBV) in human has been reported using Vascular-Space-Occupancy (VASO) MRI technique (4). VASO MRI provides a unique opportunity for measuring scBV because it has several advantages such as not requiring arterial input function (AIF) and not using single-shot EPI acquisition thus higher resolution without image distortion is feasible. However, the previous study did not have sufficient spatial resolution to separately assess gray and white matters in the spinal cord (4). Based on the knowledge in the brain, the gray and white matters in the cord should have different scBV values. In this work, we aim to confirm this hypothesis and to measure scBV in gray and white matters separately, the first report of this kind using any imaging modality. To achieve this goal, the resolution was further increased and multi-echo spin-echo schemes were used to improve signal-to-noise ratio. In addition, a spatial registration method was developed for motion correction of the cord tissue.

METHODS: A total of nine healthy subjects (age 25±4 yrs, 5 males) were studied after informed consent was obtained. All MR experiments were performed on a 3T Philips system using a body coil for transmission and a neck coil with 16 channel sensitivity for receiving. The VASO technique is a steady-state T1 method and uses a subtraction between pre and post-contrast images (5). For this study, in-plane spatial resolution was 0.5x0.5mm², which is sufficient for delineation of gray and white matters in the spinal cord. The slice thickness was 5mm or 8mm and the slices were positioned perpendicular to the cord to avoid partial voluming. We wanted to minimize FOV so that the imaging matrix (thus the scan duration) can be reduced. Our experience is that the fold-over direction (L-R) in cervical regions is smaller than 140mm for most people and the size of spinal cord is less than 20mm. Thus, a FOV=80mm would allow some fold-over in the muscle regions but spare the spinal cord (Fig. 1d). Other imaging parameters were: TR/TE=6000ms/16ms, EPI factor=5, number of slices=3, number of averages=3, duration=10 minutes. We tested two acquisition schemes: single gradient echo scheme (denoted by SGE) was used on six subjects and multiple spin echo (MSE) scheme (4 echoes with TE=16ms) was used on three subjects. In addition, a proton density (PD) image (Fig. 1a) at the same resolution of the VASO images was also acquired for anatomical reference and delineation of gray and white matters.

Post-processing: All VASO images and the PD image were spatially co-registered using an affine registration algorithm. Since our region-of-interest (i.e., cord region) only occupies the central region of the FOV, traditional algorithm based on cost-function minimization would not work because it will be weighted toward registering muscles and fold-over artifacts. Therefore, we developed an algorithm where the boundary line of the cord region (between white matter and CSF) were registered using a two-dimensional affine registration. The scBV was calculated from the difference of pre- and post-contrast VASO images with the M0 estimated from the CSF intensity (5).

RESULTS and DISCUSSION: Fig. 1 illustrates a complete data set of the experiment. Fig. 1a is a PD-weighted image showing clear contrast between gray and white matters. Figs. 1b and c are pre- and post-contrast VASO images, respectively. Note that even though the image quality and resolution are comparable to those of the PD image, the gray/white matter contrast is not apparent under this T1 contrast. Fig. 1e shows the magnified version of the PD image, on which the gray and white matter ROIs were manually drawn. These masks are applied to the VASO images (Fig. 1f) for gray and white matter scBV. Fig. 2 illustrates that the performance of the co-registration algorithm. The averaged image after co-registration clearly shows the cord boundary while the one without co-registration is blurred. The scBV values were 2.1±0.4 (mean±SEM) ml/100 ml tissue for gray matter and 1.3±0.3 for white matter using SGE (N=6). With MSE (N=3), they were 1.8±0.2 and 1.1±0.1 for gray and white matters, respectively. The scBV values obtained from the two acquisition schemes are similar, but the signal-to-noise-ratio (SNR) of spin-echo data (28.4±4.8) were higher than that of the gradient echo (17.9±5.6). Comparing the gray and white matter scBV values, the gray matter has significantly greater (p=0.01, N=9) value than white matter, consistent with the findings in the brain. We note that the scBV values measured from this study is quantitatively different from those previously reported (4). One of the possible reasons is that the current study has an increased value for the time between injection of contrast agent and post-contrast acquisition in order to remove water-exchange effect which would result in over-estimation (6). Another possibility is the error of estimating M0 from CSF due to the flow of CSF and the artifact from pulsation. In summary, we have measured scBV in humans with differentiation of gray and white matters. The results are in good agreement with spinal cord physiology but the blood volume values are lower than those in the brain.

REFERENCES: 1) Munnyao et al. *Neuroreport*, 9:321, 1998; 2) Ikeda et al. *Neurology*, 53:812, 1999; 3) Duhamel et al. *Magn Reson Med.*, 59:846, 2008; 4) Lu et al. *NMR Biomed.*, 21:226, 2008; 5) Lu et al. *Magn Reson Med.*, 54:1403, 2005; 6) Uh et al. *Magn Reson Med.*, 61:659, 2009.

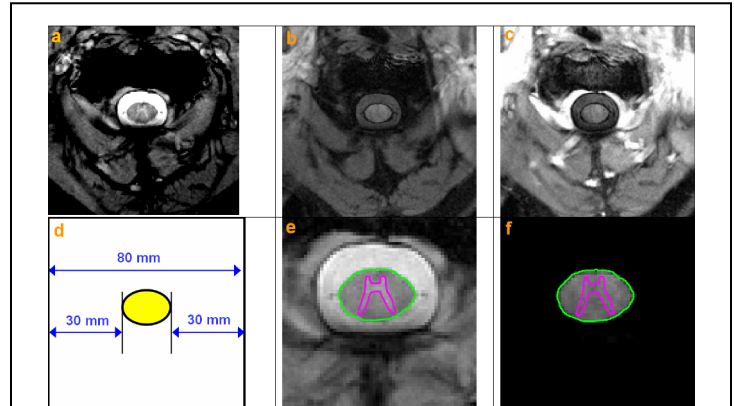


Fig. 1: Procedure for measuring scBV. (a) A PD image with clear delineations of gray and white matters. (b,c) Pre- and post-contrast VASO images with FOV=80mm showing fold-over. (d) Justification for the use of 80mm FOV. (e) Manually drawn gray/white matter masked on the (zoomed-in) PD image. (f) The masks applied on the pre-contrast VASO image.

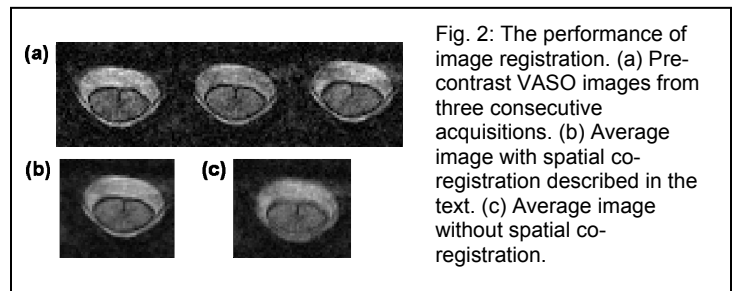


Fig. 2: The performance of image registration. (a) Pre-contrast VASO images from three consecutive acquisitions. (b) Average image with spatial co-registration described in the text. (c) Average image without spatial co-registration.