MR Susceptometry for Measuring Global Brain Oxygen Extraction

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Introduction

Jugular venous oxygenation monitoring based on blood sampling from a catheter extending into the jugular bulb is used clinically to monitor changes in cerebral oxygenation in neurointensive care settings. Here we present a non-invasive approach to measure oxygen saturation in the jugular vein using MR susceptometry by exploiting the characteristic susceptibility of deoxyhemoglobin and demonstrate the feasibility of performing such measurements in a group of subjects.

Theory

The principle of the proposed technique is based on the measurement of the susceptibility difference between the blood in the jugular vein and its surroundings using phase mapping. The common jugular vein and the internal carotid artery can be modelled as infinitely long cylinders oriented parallel to the static magnetic field, as the subject lies in the scanner. The difference in effective field between the blood vessel and the surrounding tissue can be measured from a phase image. The phase difference $\Delta\varphi$ is given by $\Delta\varphi = \gamma(B_v - B_s)TE$, where B_v is the field in the vein, B_s is the field in the surrounding tissue and *TE* is the echo time. The field difference is related to the fractional oxygen saturation *Y* and the hematocrit *Hct* by $|B_v - B_s| = 4\pi\Delta\chi Hct \cdot (1 - Y_v)$. Once the hematocrit is known (determined from a blood sample), the only unknown therefore is the oxygen saturation.

Materials and Methods

Experiments were performed using a Siemens Trio scanner operating at 3T. Axial phase images of the neck of 5 volunteers were acquired with a 2D GRE sequence, with flow compensation in slice and read directions to eliminate confounding flow-motion-induced phase shifts. Two gradient-echo images were acquired at TE(1) = 4.92 msec, TE(2)=7.38 msec, so that water and fat were in-phase at both echo times. Signal was collected using a head coil (USA instruments). Other imaging parameters were: voxel size = 1 x 1 x 5 mm, FOV =128 mm^2, 30 slices, matrix size = 128 x 128, BW = 520 Hz/pixel. TR = 1sec, flip angle=90°, 2 acquisitions, total-scan time = 4.26 min. The k-space data was saved and reconstructed off-line. A 2D high-pass filtering algorithm was applied to the k-space data to achieve a homogeneous phase image and remove the effect of background gradients caused by the air-tissue interface around the trachea, similar to the approach described in (1). Briefly, a low-pass Hanning filter was applied to the raw data to obtain a filtered phase image which was then subtracted from the original image by complex division to remove the low frequency components. The size of the filter was 8x8 pixels. Phase difference maps were obtained by subtraction of the phase images computed at the two echo times. Phase measurements were done in a region of interest encompassing the cross-sectional area of the jugular vein and in a second region of interest placed in the surrounding tissue (see Figure 1). The phase difference was used to compute venous oxygen saturation, assuming a hematocrit value of 0.4. Reproducibility of the measurement was assessed by scanning one subject three times on different days. The measurements of phase difference were performed in the same location as determined from the anatomic images.

Results and Discussion

Venous oxygen saturation values measured for each individual subject are given in Table 1. The average value for the group is 82.1 ± 3. 2 %. The reproducibility test performed in one of the subjects gives a coefficient of variation in the phase measurement of 3.5%, which translates into a coefficient of variation for the oxygen saturation of 0.65%. The values measured in this work are higher than those reported in the literature for oxygen saturation in the jugular bulb that range from 55 to 75% (2). However, the measurements presented here were done a few cm below the jugular vein bulb and include contributions from facial and neck veins that may be less deoxygenated. A lower location was chosen to ensure that our assumptions are valid (i.e. that the approximation of the vein as an infinitely long cylinder is reasonable). In fact, Oh et al. (3) measured oxygen saturation in a group of subjects by placing catheters in the bulb of the left jugular vein and in the right jugular vein at a lower location. They reported a value of 67.3 ±5.9 % oxygen saturation in the left jugular vein bulb and a value of 82.3 ± 4.4 % in the right jugular vein. Potential sources of error in our measurements are residual background gradient effects not eliminated by the filter and deviations of the vessel shape from the infinite cylindrical model, such as finite length, non-circular cross-section and tilt with respect to the magnetic field. Errors of this nature can be addressed in future work by numerically modelling the jugular vein, using the information obtained from high resolution anatomic images. Other approaches to measure oxygen saturation of blood in vivo by MR have previously been reported (4), but these require longer scan times and in vitro calibration which make the procedure cumbersome and potentially less accurate.

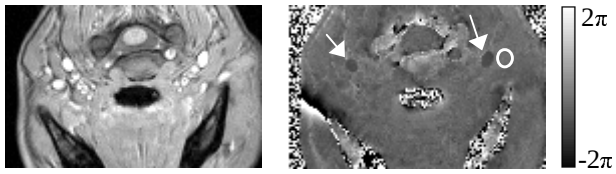

Figure 1: (a) Magnitude image. (b) Phase difference image (in radians). The jugular veins appear dark (white arrows). The white circle in (b) represents the region of interest where the phase was measured in the adjacent tissue.

Table 1: Jugular vein oxygen saturation (SvO_2) in %

Subject	S1	S2	S3	S4	S5
SvO_2	81.98	77.06	83.94	85.50	82.09

Conclusions

We have presented an approach to measure oxygen saturation in the jugular vein using MRI and demonstrated the feasibility of performing this measurement in a group of subjects. The approach may have potential for assessing oxidative metabolism in human brain in a variety of clinical scenarios. The method can possibly be extended to other major blood vessels in the brain such as the sagittal sinus to provide better localization. By combining jugular venous oxygenation measurements with global CBF measurements, oxygen metabolic rates in the brain could be quantified.

Bibliography

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