Measurement of brain oxygen saturation using near infrared spectroscopy and susceptibility maps

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Introduction: Brain oxygen saturation is a key parameter for assessing oxygen supply, metabolism and tissue viability. Measurement of oxygen saturation in small veins may reflect the level of local brain metabolism. In contrast, oxygen saturation in the large veins may be influenced by the blood drained from different brain areas. Thus, development of new technology to measure oxygen saturation in the small veins is important for assessment of regional brain metabolism or tissue viability because of anatomic, functional and hemodynamic heterogeneity. Near infrared spectroscopy (NIRS) is a widely used technique to measure brain tissue oxygen saturation. However, this technique cannot be used to measures brain tissue oxygenation in deep brain structures and could be contaminated by changes in extracranial tissue oxygenation. Susceptibility weighted image mapping (SWIM) generates susceptibility maps (SM) which can be used to measure oxygen saturation in local venous structures in the brain (1). This study compared measurements of brain oxygen saturation using SM and spatially resolved spectroscopy NRIS in normal healthy subjects.

Method: High resolution (0.5x0.5x1) SW images were collected from 28 healthy volunteers (male=12, female =16, mean age ± SD = 49 ± 16) using an Achieva 3.0T system (Philips Medical Systems) with 8 channel head coil. An SWI sequence was run with following parameters: GRE; axial images with FOV 256x256mm, matrix size 512x512, slice thickness 1mm. T_R=30 ms and 20 ms, FA 15^0, and a SENSE factor 2. Spatially resolved NIRS (NIRO-200NX, Hamamatsu Photonics) was used to measure brain tissue oxygenation (i.e., the ratio of intravascular oxygenated to total hemoglobin concentration) expressed as a tissue oxygenation index (TOI). NIRS probes were placed laterally on the forehead and high from the eyebrow line according to the recommended procedures to avoid the influences of the superior sagittal sinus and temporalis muscles on data acquisition.

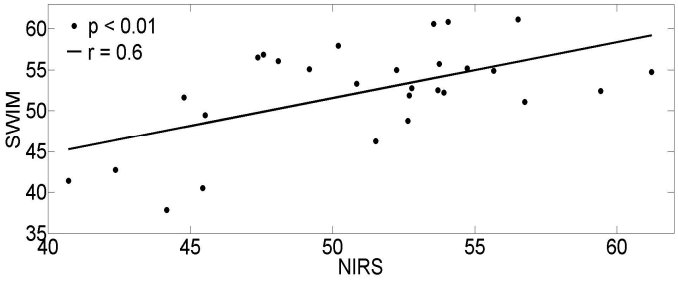

Figure 1: Percent of oxygenation uisng SWIM and NIRS

*Image processing:*SWI data were processed using a SMART SWIM from Dr. Haacke's lab and involves: 1) skull removal; 2) phase unwrapping; 3) background field removal using harmonic artifact reduction; and 4) generating quantitative SMs by solving the ill-posed inverse problem, using a truncated k-space division method with a threshold of 0.1 (1). The SMs were used to draw ROIs of interest to measure susceptibility values inside the veins. Oxygen saturation was calculated using: $\Delta\chi = \chi_{do}$ Hct (1-Y); where $\Delta\chi$ is the magnetic susceptibility of the vein, Y is the fractional oxygenation of hemoglobin in the venous blood and χ_{do} is the susceptibility difference between the fully oxygenated and deoxygenated blood per unit hematocrit (Hct). The value of χ_{d0} is taken to be 0.18 ppm in cgs units (2). Assuming a Hct of 44% for males and 40% for females, blood oxygenation (Y) was estimated from susceptibility mapping using the above equation in (a) the superior sagittal sinus and (b) two to four small veins in the frontal lobe approximately at the same level of NIRS. The values measured from the small veins were averaged for correlation analysis. Correlations between SM and NIRS measurements of brain oxygen saturation were assessed using the Pearson product-moment correlation coefficients.

Results: A significant correlation between the NIRS and SM measurements in the sagittal sinus was observed ($r=0.6$, $p<0.01$), as shown in Figure 1. Measurements of oxygen saturation (mean ± SD) using the two methods were 51 ± 5, 52 ± 6 (%), respectively. There was no significant correlation between the local oxygenation measured from NIRS versus small veins in SM. Averaged oxygen saturation from the small veins across all subjects was 74 ± 5 (%).

Discussion: This is the first study of simultaneous measurements of regional brain oxygen saturation using SWIM and NIRS. The results suggest that brain oxygen saturation measured using NIRS correlate reasonably well with the SWIM measures in the sagittal sinus, but not in small veins. Further studies are warranted to confirm these findings and to understand the underlying mechanisms.

References: 1). Haacke EM, Tang J, Neelavalli J, Cheng YC. Susceptibility mapping as a means to visualize veins and quantify oxygen saturation. J Magn Reson Imaging. Sep; 32(3):663-76, 2010. 2).Weisskoff RM et al. Kiihne S. MRI susceptometry: Image-based measurement of absolute susceptibility of MR contrast agents and human blood. Magn Reson Med Apr; 24(2):375–383, 1992.