A combination NIR/MRI imaging modality for neurological studies

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INTRODUCTION

Near infrared (NIR) light is absorbed by oxy- and deoxyhemoglobin, and so can be used to study the saturation of blood and total blood volume. It can also be used to monitor water, lipids and cytochrome-c-oxidase, making it a powerful tool for studying pathophysiology. MRI is synergistic, in that it can be used to study structure, blood flow, blood volume, and cellular integrity. NIR data are difficult to reconstruct into an image, as the light is scattered and diffused through the tissue. MRI has the advantage of having excellent spatial resolution. A NIR/MRI imaging system have been developed which combines the strengths of both modalities and first ever provides NIR cross-sectional images with MRI data. The system can collect simultaneous NIR and MRI data, for physiological studies, but also uses the structural information from NMR as a-priori knowledge to improve the image reconstruction of the NIR data. In this study, the system is described and proof of principle is shown by undertaking simultaneous BOLD MRI and NIR data collection during graded hypoxia in a rat brain

METHODS

NIR diffuse optical tomography: A broadband-spectral MRI-coupled NIR tomography system (Fig 1) [1] for rat brain study was built. The complete attenuation spectra over the wavelength range 700-900nm were taken from 8 transmit fibers and 8 receive fibers placed interlacedly around the rat head within the transverse plane. A birdcage coil was made to hold the optical fibers in the magnet for simultaneous collection of MRI and NIR data. Optical pathlength was estimated from the water feature in the broadband NIR spectrum using the second-derivative spectral analysis [2]. Both absorption and reduced scattering tomography images were reconstructed at 740nm and 840nm based on the diffusion approximation equation using finite element method (FEM) [1]. Oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) concentrations were calculated from the absorption images.
MRI Protocol: T_2-weighted images were obtained (TR = 2000ms, TE = 40ms, FOV = 3.5cm x 3.5cm, matrix size = 256 x 128, 9 slices thickness of 1mm) in a 7T horizontal magnet (Magnex, UK) using a Unity INOVA console (Varian, CA) to guide the optical fiber placement and provide a-priori structural information for diffuse optical tomography image reconstruction. To measure the BOLD effect, T_2*-weighted gradient echo images were acquired (TR = 700ms, TE = 15ms, FOV = 3.5cm x 3.5cm, matrix size = 256 x 64, slice thickness = 1mm and 4 averages).
Animal Protocol: An adult male Sprague-Dawley rat (325g) was anesthetized (isoflurane 1-1.5%, N2O 70%, O2 30%), tracheotomized, mechanically ventilated and fixed in the NIR-MRI coil placed in the magnetic. The oxygen fraction (FiO_2) in the inspired gas was varied in a sequence of 30%, 15%, 12%, 10%, 100%, 30%, 0% and 0% with a 10 minutes interval, while both NIR spectral data and BOLD MRI data were acquired.

RESULTS

Fig 2a shows the T_2-weighted MRI slice overlapping with the optical plane. It was processed to define the tissue boundary and fiber positions and create triangular FEM meshes with highlighted brain region (Fig 2b). An example of NIR absorption images is shown in Fig 2c and brighter area indicates the high absorption due to the high blood content. An example of reduced scattering images is shown in Figure 2d. Hemoglobin dynamics and BOLD R_2* changes during the FiO_2 sequence are plotted in Fig 3. The correlation of ΔHbR and ΔR2* (Fig 4) is $\Delta R_2^* = 0.48^* [\Delta HbR] - 2.8$.

DISCUSSION/ CONCLUSIONS

Reconstructed optical images clearly showed changes in saturation and regional oxygenation in brain, indicating that functional changes in the rat can be monitored. The trends of HbR and HbO_2 followed predictable trends during hypoxia but the expected increases of CBV and HbT were not observed. Further experiments are needed to investigate this issue. A strong correlation (r = 0.97) between deoxyhemoglobin and R_2* was observed and the ratio (0.48) was similar to 0.47 observed by [4] using NIRS without image reconstruction. NIR image resolution is about 5mm and can be improved by increasing SNR and optimizing the reconstruction algorithm. This dual-modality imaging tool is the first NIR system which provides cross-sectional spatial information in combination with MRI data and will be a powerful tool for studying animal models of neuro-pathophysiology

REFERENCES

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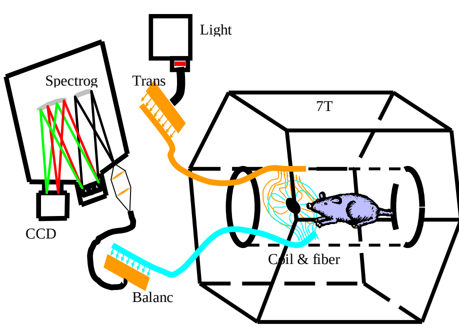

Fig 1. System configuration

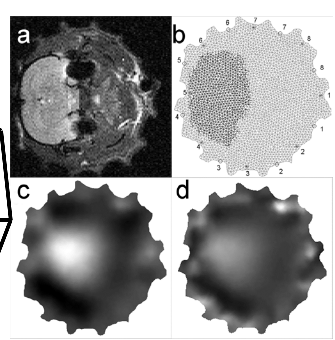

Fig 2. MRI image and absorption image

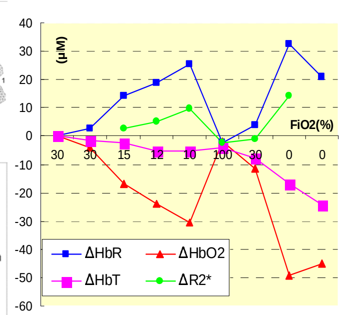

Fig 3. Trends of [Hb] and R2*

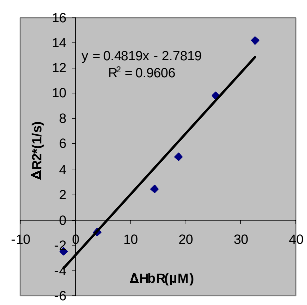

Fig 4. Correlation of [HbR] and R2*