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Simultaneous Functional Magnetic Resonance and Near-Infrared Imaging of Adult Human Brain

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ABSTRACT

The aim of this study was to compare functional cerebral hemodynamic signals obtained simultaneously by near infrared spectroscopy (NIRS) and by functional magnetic resonance imaging (fMRI). The contribution of superficial layers (skin and skull) to the NIRS signal was also assessed.

Keywords: brain, near-infrared spectroscopy, fMRI

1. INTRODUCTION

Functional magnetic resonance imaging (fMRI)[1] is a key method for studying brain function. It has no penetration limits and provides high spatial resolution. However, fMRI gives little independent information about event-related changes in oxy- and deoxy-hemoglobin concentrations. In cortical brain areas such information can be obtained using near-infrared (NIR) spectroscopy and imaging. Although the spatial resolution of near-infrared imaging is limited by the nature of light propagation in tissue, potentially it can reach a level acceptable for practical applications. In this study we compare NIR and fMRI signals acquired simultaneously on the adult head during motor activity.

2. MATERIALS AND METHODS

For NIRS measurements we use a two-wavelength (758 and 830 nm) frequency-domain (110 MHz modulation frequency) Oximeter (ISS, Champaign, IL), which has sixteen laser diodes (eight per each wavelength) and two photomultiplier tube detectors. At a wavelength of 758 nm light absorption by the deoxy-hemoglobin (HHb) substantially exceeds absorption by the oxy-hemoglobin (O_2Hb), while at 830 nm the O_2Hb absorption prevails over the HHb absorption. The laser diodes operate in a sequential multiplexing mode with 10 ms "on" time per each diode. Light emitted by these laser diodes is guided to the tissue through 10-meter long multi-mode silica optical fibers. Two 10-m long glass fiber bundles collect the scattered light and bring it to the detectors. The paired (758 and 830 nm wavelength) source fibers are attached to the probe at 8 positions. Together with two detectors, they provide ten bi-wavelength source-detector channels with a source-detector distance of 3 cm. The probe covers an area 9 x 6 cm^2. The probe is centered at the measured C3 position according to the International 10-20 System. Three multi-modality radiological markers (IZI Medical Products Corp, Baltimore, MD) are embedded into the optical probe to facilitate correct orientation of the MRI slices with respect to the probe and to enable recovery of the probe orientation for data analysis.

Magnetic resonance imaging was performed using a 1.5 Tesla whole body MR scanner (Signa, General Electric Medical Systems, Milwaukee, WI) equipped with echospeed gradients and a standard circularly polarized birdcage head-coil. Sagittal T1-weighted localizer scans were used to determine the correct plane for the functional scans. Gradient-echo echo-planar images were acquired using a data matrix of 64 x 64 complex points, TR=640 ms, TE = 40 ms, FOV = 240 mm, slice thickness = 7 mm, no inter-slice gap, receiver bandwidth 62.5 kHz, and tip angle 90 degrees. The slices are parallel to the plane of three radiological markers on the optical probe. The middle slice (see Fig.1) was set between the skull and the brain surface at C3 position. This slice was mostly filled with the cerebrospinal fluid (CSF), dura mater, arachnoidal tissue, and pia mater, but also could touch the cortical tissue depending on the subject's anatomy. Two deeper slices mostly contained the brain tissue, while two outer slices included the skull, the skin and the markers.

Optical Tomography and Spectroscopy of Tissue IV, Britton Chance, Robert R. Alfano, Bruce J. Tromberg, Mamoru Tamura, Eva M. Sevick-Muraca, Editors, Proceedings of SPIE Vol. 4250 (2001)

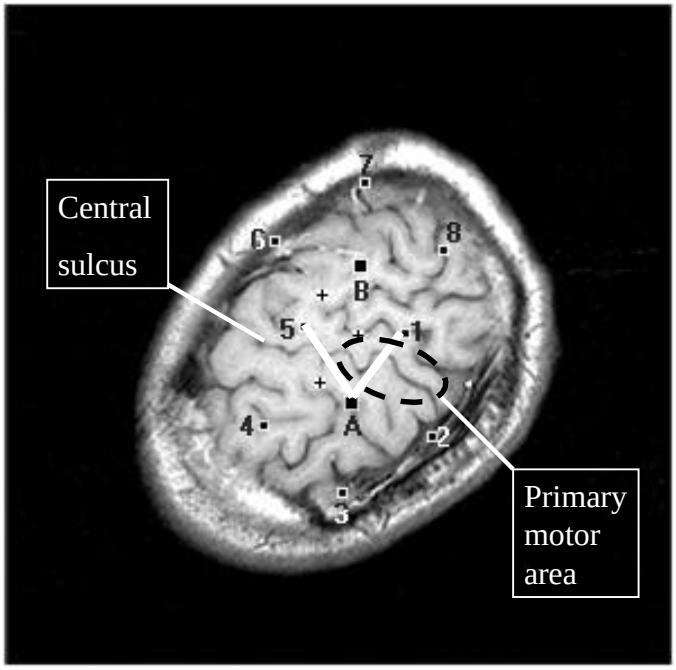

Fig.1. Orientation of the optical probe relative to the middle MRI slice. Numbers indicate source locations, letters – detectors. Light channels A5 and A1 cross the central sulcus in the primary motor area

The studies were performed in six healthy right-handed male volunteers, 18 to 37 years old. Informed consent was obtained from all subjects. Each exercise run consisted of a 30-s pre-exercise epoch, ten 20-s stimulation epochs separated by ten 20-s control epochs, and a 50-s after-exercise epoch. During stimulation epochs subjects performed light palm squeezing with the right hand. The synchronization of the exercise sequence with the MRI and NIRS recording was provided by a computer program generating the commands for the subject and the scanner operator based on the preset command timing. To convert optical intensity data into hemodynamic concentration changes, we used a model of light transport in strongly scattering medium based on the modified Lambert-Beer law[2].

3. RESULTS

In all subjects the analysis of the fMRI BOLD signal[1] revealed an area under the optical probe where the signal was highly correlated with the paradigm boxcar function. It was an area in the primary motor cortex with the center close to the central sulcus. In all subjects the folding average analysis revealed the same type of [O_2Hb] and [HHb] changes for light channels situated above the major activated area, namely a significant decrease of [HHb] during the stimulation, which was concurrent with a significant increase of the oxy-hemoglobin concentration (see Fig.2). A rapid recovery toward the baseline level begins 4-6 s after the onset of the rest epoch in both [HHb] and [O_2Hb]. No significant decrease in the folding average [HHb] traces concurrent with the significant [O_2Hb] increase were observed during stimulations in the light channels outside the activated area.

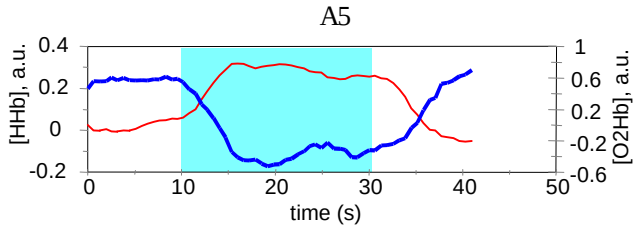

Fig.2. [O_2Hb] (thin line) and [HHb] (thick line) changes in activated area as measured by NIR spectroscopy. Shaded rectangle between 10 and 30 s indicates stimulation epoch.

To determine the location of the tissue contributing task-related NIR signals we performed a correlation analysis of the BOLD signals using the inverse NIRS [HHb] signals as the reference function. ([HHb] signal was taken with the opposite sign because an increase in BOLD signal should correspond to a decrease in [HHb].) High temporal correlation between optical and BOLD signals in cerebral and near-cerebral tissues was detected in three subjects. In these subjects the voxels of fMRI images demonstrating high temporal correlation with optically measured [HHb] changes were collocated with the corresponding light channels (see Fig.3).

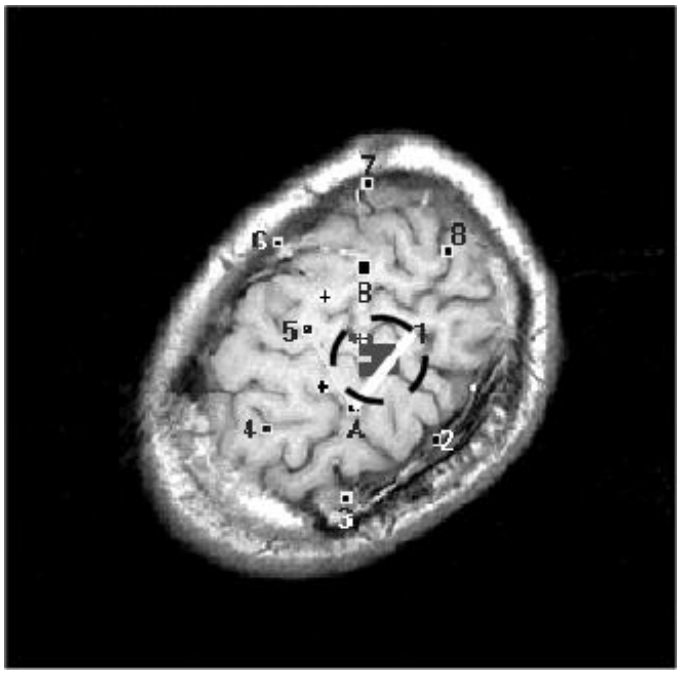

Fig.3. NIRS-fMRI correlation map. The blackened encircled area on the central sulcus is formed by voxels of fMRI images exhibiting high temporal anti-correlation of intensity changes with [HHb] changes measured by NIRS in channel A1.

In three other subjects the task-related changes were superimposed with the significant hemodynamic fluctuations in the upper tissue layers. In these subjects the no significant temporal correlation between the intracranial BOLD signal and optically measured hemodynamic signals was detected. However, if all subjects folding average analysis indicated task-related changes similar to ones shown in Fig.2.

4. CONCLUSION

Analyzing near-infrared and BOLD signals acquired simultaneously under the motor stimulation conditions, we found a good collocation between the light channels with significant task-related folding average hemodynamic changes and the functionally activated area in the motor cortex in six human subjects. A direct temporal correlation between NIRS and the intracranial BOLD signals was demonstrated in 50% of subjects. These results show the intracranial origin of the NIRS signals obtained under the periodical stimulation conditions. The lack of temporal correlation between the optical and fMRI signals in three subjects was due to the contamination of the optical signal by hemodynamic fluctuations in the superficial tissue layers.

5. REFERENCES

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