Three-dimensional Superimposition of Optical Tomography Results and Subjacent Anatomic Structures

Christina Habermehl[1], Jan Mehnert[1,2], Susanne Holtze[1,2], Jens Steinbrink[1], Christoph Schmitz[1,3]

[1]Berlin NeuroImaging Center, Charité University Hospital Berlin, Germany, [2]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany, [3] NIRx Medizintechnik GmbH, Berlin, Germany

Introduction: Near Infrared Spectroscopy (NIRS) reveals cortical activation caused by focal hyperoxygenation in the activated area. Near infrared light is injected into the subject's brain by optical fibers, which are placed on the subject's head surface. Most commonly, planar optical to*p*ography is used which limits spatial resolution and offers no depth discrimination.
These shortcomings can be overcome by 3D optical to*m*ography (OT), which employs arrays of closely spaced fibers that allow the simultaneous measurement of light paths from different tissue depths (Zeff et al., 2007; Wylie et al., 2009). Because NIRS itself reveals no anatomical information, independent anatomical mapping is desirable, especially when studying regions prone to large inter-subject variability.
We show two ways to match OT data from high density fiber grids to anatomical structures without individual optical forward models:(1) Mapping onto the individual's anatomical MR-Scan, and (2) onto a generic brain model.

Methods: Healthy voluntary subjects performed a hand gripping task. Neural activity was measured with a rectangular grid of 30 optical fibers over the contralateral peri-central area. Each fiber served as source and detector facilitating the acquisition of 900 simultaneous optical data channels using the DYNOT 232 optical tomography imager (NIRx Medizintechnik GmbH, Berlin). From these we reconstructed volumetric image time series of oxy- and deoxy-hemoglobin concentration changes using the approach described in (Barbour et al., 2001)The algorithm achieves fast image reconstruction by inversion of a precalculated image operator, which is generated by solving the diffusion equation on a Finite Element Method (FEM) mesh which was obtained from a standard MRI image (Pei et al., 2001).
We compare two approaches of co-registration of volumetric OT results and anatomic scans. For the first method we indicated the corner positions of the imaging grid with fiducial marks and acquired anatomical MR scans. Using the SPM8 spatial preprocessing tool, we normalized the individual scans with the FEM model as a template. This resulted in a nonlinear transformation of the subject's head anatomy without losing structural information. The translocated positions of the fiducial marks were determined and assigned to the FEM model used for optical image reconstruction. We used a general linear model to reveal functional activation patterns and superimposed those on the individual MR scan.
The second method requires no structural scan of the subject. Coordinates of reference points and fiber positions on the subjects head surface were recorded using photogrammetric triangulation. These were transformed to the FEM model's head geometry using a least-square approach. We then translocated the fiber positions onto the FEM mesh, thereby ensuring the correct position of the reconstructed images. These were then mapped to the generic anatomy of the model scan.

Results: We show volumetric activation patterns for each subject. We superimposed these on both individual MR scans and a generic head model. We achieved a good overlap of the OT activation with the cortex structures known to represent motor control. While obtaining reasonable results for mapping the pattern with the generic brain we found better agreement when registering the OT results to individual MR scans.

Conclusion: 2D optical topography and volumetric optical tomography reveal cortical activation but cannot resolve anatomical structures. For optical topography a method of probabilistic mapping has been applied by (Singh et al., 2005). For optical tomography, first

the photon propagation in tissue is simulated, and then the inverse problem is solved to reconstruct internal absorption changes from optical surface measurements.
Recently, volumetric mapping of functional OT data has been demonstrated using forward models considering the individual's brain morphology (Custo et al., 2010). This approach is computationally burdensome for high-density grids and large numbers of channels. Instead, we use one generic, pre-calculated light propagation model in conjunction with individual anatomical superimposition. We demonstrate successful mapping onto individual brain scans or a generic atlas, which we deem most desirable for studying brain areas of great structural and functional individuality.

References

Barbour RL, Graber HL, Pei Y, Zhong S, Schmitz CH (2001) Optical tomographic imaging of dynamic features of dense-scattering media. J Opt Soc Am A Opt Image Sci Vis 18:3018-3036.

Custo A, Boas DA, Tsuzuki D, Dan I, Mesquita R, Fischl B, Grimson WE, Wells W, 3rd (2010) Anatomical atlas-guided diffuse optical tomography of brain activation. Neuroimage 49:561-567.

Pei Y, Graber HL, Barbour RL (2001) Influence of Systematic Errors in Reference States on Image Quality and on Stability of Derived Information for dc Optical Imaging. Appl Opt 40:5755-5769.

Singh AK, Okamoto M, Dan H, Jurcak V, Dan I (2005) Spatial registration of multichannel multi-subject fNIRS data to MNI space without MRI. Neuroimage 27:842-851.

Wylie GR, Graber HL, Voelbel GT, Kohl AD, DeLuca J, Pei Y, Xu Y, Barbour RL (2009) Using co-variations in the Hb signal to detect visual activation: a near infrared spectroscopic imaging study. Neuroimage 47:473-481.

Zeff BW, White BR, Dehghani H, Schlaggar BL, Culver JP (2007) Retinotopic mapping of adult human visual cortex with high-density diffuse optical tomography. Proc Natl Acad Sci U S A 104:12169-12174.