Clinical near-infrared spectroscopy and imaging of the brain

Marco Ferrari
Joseph P. Culver
Yoko Hoshi
Heidrun Wabnitz
Clinical near-infrared spectroscopy and imaging of the brain

Marco Ferrari
University of L’Aquila
Department of Physical and Chemical Sciences
Via Vetoio, 67100, L’Aquila, Italy

Joseph P. Culver
Washington University School of Medicine
Department of Radiology
4525 Scott Avenue, Campus Box 8225
St. Louis, Missouri 63110, United States

Yoko Hoshi
Hamamatsu University School of Medicine
Institute for Medical Photonics Research
Department of Biomedical Optics
1-20-1 Handayama, Higashi-ku, Hamamatsu
Shizuoka 431-3192, Japan

Heidrun Wabnitz
Physikalisch-Technische Bundesanstalt (PTB),
Department of Biomedical Optics
Abbestr. 2-12
10587 Berlin, Germany

The Journal of Biomedical Optics (JBO) was founded in 1996. In the fourth issue of 1996 and in the subsequent first issue of 1997, JBO published a Special Section on Near Infrared Spectroscopy and Imaging of Tissues, guest edited by Marco Ferrari, David T. Delpy, and David A. Benaron. The special section included 12 articles on fetal- and infant-brain oximetry, muscle oximetry, and breast spectroscopy. In 2016, JBO celebrates its 20th anniversary. Throughout these two decades, JBO papers reported the tremendous progress in this field. A new Special Section on Clinical Near Infrared Spectroscopy and Imaging in JBO (including 7 reviews and 8 original articles) and this parallel Special Section on Clinical Near-Infrared Spectroscopy and Imaging of the Brain in Neurophotonics highlight these achievements.

The discovery of the medical near infrared spectroscopy (NIRS) goes back to 1977 when Frans Jöbsis reported that the relatively high degree of transparency of brain tissue in the near infrared range enables real-time noninvasive detection of hemoglobin (Hb) oxygenation using transillumination spectroscopy. Brain and muscle oximetry and functional NIRSD (fNIRS) represent the most established clinical and/or basic research areas, but additional applications to other tissues and organs are emerging.

This Neurophotonics special section includes 6 reviews and 8 original articles. In the last 20 years the clinical applications of brain oximetry have consistently increased. Goodwin et al. investi...
The lack of a diagnostic index is a problem that needs to be overcome in the diagnostics of autism spectrum disorder. Yanagisawa et al. propose an auxiliary diagnosis index for autism spectrum disorder based on NIIRS during working memory and nonworking memory tasks.

Mihara and Miyata review the research on fNIRS application in neurorehabilitation. Topics include potential advantages and shortcomings of fNIRS for investigating the neural mechanism of functional recovery after brain damage and as therapeutic tool for rehabilitation including brain-computer interface and neurofeedback. Peng et al. first review the recent use of multichannel continuous electroencephalography (EEG) combined with fNIRS in epilepsy research and then describe applications to study focal seizures and interictal epileptiform discharges. Chalia et al. use simultaneous EEG and diffuse optical tomography (DOT) to investigate whether bursts of EEG activity in infants with hypoxic ischemic encephalopathy are associated with an observable cerebral hemodynamic response. DOT reveals patient-specific spatial distributions of the hemodynamic response that may be indicative of a complex pattern of cortical activation underlying discontinuous EEG activity that is not readily apparent in scalp EEG.

Cainini et al. provide a comprehensive description of principles, methods, and clinical requirements of cerebral blood flow and cerebral autoregulation measurements and highlight the potentially important role that noninvasive optical methods can play in the assessment of neurovascular health.

Diffuse correlation spectroscopy (DCS) measurements of blood flow rely on the sensitivity of the temporal autocorrelation function of diffusively scattered light to red blood cell mean square displacement. Soas et al. offer, for the first time, theoretical support for the empirically accepted ability of the DCS blood flow index to quantify tissue perfusion.

Casseano et al. review the use of near-infrared and red radiation (photobiomodulation, PBM) for treating major depressive disorder. PBM appears to be a promising treatment for depression that is safe and well-tolerated. However, large randomized controlled trials are still needed to establish the safety and effectiveness of this new treatment.

The guest editors believe that this special section and the parallel special section in JBO are valuable reading for scientists both inside and outside the biomedical optics community. Readers will get a glimpse of how NIRS technologies impact medicine today and what can be expected from developments of tomorrow’s technologies. In the coming years, current generations of NIRS instruments will migrate along the translational path toward clinical adoption as both the product engineering and use protocols are refined. However, while many aspects of NIRS technology have been tested for limits such as resolution, quantitative accuracy, field-of-view, depth sensitivity, wearability, portability and integration with other modalities, many of these individual demands are at odds with other performance measures. For example, the solutions to several performance specifications positively correlate with instrument weight and thus work against wearability. Thus the phase-space for optimizing and engineering real world NIRS instruments remains immense. In summary, NIRS has already provided many valuable insights in clinical research. While NIRS is on the verge of entering everyday clinical routine, the innovation yet to come is still brighter.

The guest editors would like to thank all of the authors who contributed to this special section, as well as the reviewers whose hard work ensured its high quality. Finally, the guest editors express their gratitude to Lihong Wang, editor-in-chief of JBO, and David Boas, editor-in-chief of Neurophotonics, for giving us this opportunity, as well as JBO staff, for their support.

References

Marco Ferrari is a biochemistry professor at the Department of Physical and Chemical Sciences, L’Aquila University, Italy. He has pioneered clinical applications of NIRS of the adult and infant muscle and brain, and has given substantial contributions to the wider NIRS scientific community. His recent research activity is focused on the study of the cerebral cortex hemodynamic changes upon cognitive and motor tasks of different complexity by using functional near-infrared spectroscopy (fNIRS). He has been a member of the editorial board of Journal Biomedical Optics since 1996.

Joseph P. Culver is a professor of radiology at Washington University. He obtained a PhD in physics at the University of Pennsylvania for work in ultrafast infrared laser spectroscopy. As a postdoc he developed diffuse optical tomography systems for imaging breast cancer and imaging cerebral hemodynamics in animals. His lab explores ways of leveraging optical measurements for neuroimaging, with a focus on development of diffuse optical tomography techniques for mapping human brain function.

Yoko Hoshi is a professor in the Department of Biomedical Optics at Hamamatsu University School of Medicine. She graduated from Akiha University School of Medicine and got her medical license in 1981, and received a PhD at Hokkaido University in 1990. She is a pediatrician (a child neurologist), while she has also been participating in developing NIRS and research in cognitive neuroscience, mainly neural mechanisms of emotion generation and emotion regulation. Her recent research interest is developing time-domain diffuse optical tomography.

Heidrun Wabnitz is a senior scientist in the Department of Biomedical Optics at Physikalisch-Technische Bundesanstalt (PTB) in Berlin. She received her Dr. rer. nat. degree from Friedrich Schiller University in Jena. Her fields of work included picosecond spectroscopy of molecules and time-resolved laser scanning microscopy. She joined PTB in 1991, where she focused on medical optical imaging, in particular optical mammography and optical brain imaging. She is active in the development of time-domain instrumentation, modeling and data analysis, performance characterization of instruments, and clinical applications.