
SPECIAL SECTION EDITORIAL

NEAR INFRARED SPECTROSCOPY AND IMAGING OF TISSUES

Considerable progress has been made since 1977 when Frans Jobsis first described the use of near infrared spectroscopy (NIRS) for tissue oxygenation monitoring. The early work in this area was focused on the spectroscopic aspects of the technique and how to obtain from the spectral data signals reflecting changes in the oxygenation of the hemoglobin in the tissue (and hence intravascular oxygenation), and the redox state of cytochrome oxidase (and hence intracellular oxygenation). Early animal studies applied the technique to the monitoring of the peripheral muscle or the intact brain, but most of the initial clinical studies were concentrated on the latter area since there are virtually no other clinically acceptable techniques that can provide this type of information. Although NIRS has been applied to both the adult and the newborn infant head, it is in the newborn that it has had the most success to date, largely because the small size of the infant head and the lower scattering coefficient of the infant brain has enabled large volumes of the brain to be interrogated. The thin overlying surface tissues and skull have also meant that contamination of the signal by these tissues is small. Studies on the adult head are now being increasingly reported, and the outstanding questions about the extent of the surface tissue contamination and the depth of penetration of the optical signal in the brain are slowly being resolved.

Together with the experiments aimed at answering the "physiological" questions raised by NIRS, instrumental developments have proceeded at an increasing pace. Early NIRS instruments only made measurements of attenuation changes at a few discrete wavelengths from which the corresponding changes in chromophore concentration could be calculated. With the development of the cooled CCD spectrometer, full spectral data is now measurable across many centimeters of tissue. In the early days of the field, a major problem was the nonquantitative nature of the data, since the optical pathlength of the light in the tissue was unknown. Again, the development of picosecond lasers and the streak camera made "time of flight" measurement of the pathlength possible, and equivalent data measured in the frequency domain from the phase delay of intensity modulated light is now available at the bedside.

The idea of attempting to image through tissues with light go back before the turn of the century, although the first systematic studies were probably those of Cutler who in 1929 attempted to image breast abnormalities by viewing the transilluminated breast by eye in a darkened room. Since that time, many further studies have been reported using a variety of increasingly sophisticated detectors, until in the late 1970s instruments capable of full spectral imaging using NIR-sensitive cameras were available. However, the clinical results with such instruments were disappointing, the image blurring due to the high scattering coefficient

of tissue, limiting resolution to >2 cm in the middle of the compressed breast. Again, technological improvements have led the way in the development of new instruments which can improve upon this performance. The most hopeful of these involve the same "time of flight" or "phase resolved" techniques being so successfully employed in NIR spectroscopy, and over the past decade several groups around the world have been working on the development of NIR imaging systems, especially for the breast and brain. In the 1990s two companies (Carl Zeiss and Siemens) installed prototype breast imaging systems employing the "phase resolved" measurement technique in hospital mammography units. A photograph of one of these prototypes is on the cover of this issue of the journal.

In the last few years, interest in this research area has grown enormously. Since 1990, several national agencies, among them the European Union in Europe, the National Institutes of Health in the USA, and the Ministry of International Trade and Industry in Japan, have consistently supported this research area. Three SPIE-BIOS and two OSA conferences have now been devoted purely to this topic, and in the past year about 100 clinical NIRS papers were published in technical and clinical journals. This reflects the presence of more than 500 commercial clinical instruments and several prototypes worldwide. Although most of these studies identify promising clinical applications, new quantitative instruments and large scale clinical studies will be necessary before NIRS technologies enter into widespread and routine clinical use.

This first part of the special section of the *Journal of Biomedical Optics* includes review articles as well as original research papers on NIRS. The second part will appear in January 1997. In soliciting articles for this special section, we have tried to include specifically original papers and review articles covering the clinical as well as the technical aspects of the field, since it is only by understanding the requirements of the clinical end users and the practical problems involved in applying the technique that clinically usable instruments will evolve.

Marco Ferrari, M.D.
David T. Delpy, Ph.D.
David A. Benaron, M.D.
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