Biomedical optics

Peter E. Andersen, editor
Optics and Fluid Dynamics Department
Risø National Laboratory
P.O. Box 49, DK-4000 Roskilde, Denmark
Tel. +45 4677 4555, fax +45 4677 4565,
peter.andersen@risoe.dk

Introduction

Many up-to-date medical modalities have been developed based on recent progress in physics including optics, such as ultrasound, X-ray, magnetic resonance, and positron-emission imaging techniques. However, drawbacks of these modalities, such as size, cost, resolution, safety, and use of ionizing radiation, make use of visible and near-infrared light and optical measurement and imaging techniques highly attractive alternatives for *in vivo* medical diagnostics and, furthermore, therapeutic modalities.

For *in vivo* optical diagnostics, spectroscopy, fluorescence spectroscopy and therapeutic applications, light is delivered to, interacting with, and then re-emitted from the tissue being investigated before being detected for subsequent analysis. Some interactions may cause the on-set of other processes, e.g., photochemical reactions as seen in therapeutic applications, or cause fluorescence. Therefore, it is important to have a firm understanding of the light-tissue interaction including light scattering, absorption and fluorescence properties.

From the viewpoint of optics, biological tissues and fluids can be divided into two categories. The first category includes strongly scattering biological tissues and fluids including skin, brain, eye sclera, and blood. Light propagation in these tissues may be described by using models capable of handling multiple scattering effects, e.g., radiative transport theory, or numerical methods, such as Monte Carlo simulations. The second category consists of weakly scattering tissues and fluids, such as crystalline lens, and aqueous humor of the front chamber of eye. Single scattering models, such as Lambert-Beer's law, may be applied to model light scattering in these cases.

The transparency of tissues reaches its maximum in the near-infrared (NIR), i.e., around 800 nm, since living tissues do not contain strong intrinsic chromophores absorbing in this spectral range, and it is often referred to as the 'biological window'. In this range, light penetrates into a tissue over several centimeters, which, for example, is important for the transillumination of solid human organs. However, tissues are characterized by strong scattering of NIR radiation, which prevents one from obtaining clear images of localized inhomogeneities due to various pathologies, e.g., tumor formation.

The coherence of light is of fundamental importance for the selection of photons that have experienced no or a small number of scattering events, and therefore essential in medical applications based on coherent tomography, photon-correlation spectroscopy, laser Doppler anemometry, and speckle-interferometry. The use of optical sources with a short coherence length opens up new opportunities in coherent interferometry and tomography of tissues, organs, and blood flows, most importantly optical low-coherence tomography.

In summary, the majority of *in vivo* diagnostics methods and therapeutic procedures employ the results of fundamental studies devoted to the propagation of laser beams in scattering and absorbing media. A multitude of light sources including low-power and high-power lasers, pulsed lasers, and broad bandwidth sources are employed in biomedical optics. Therefore, enhanced research efforts within new laser systems, laser accessories and also related optical measurement technologies are still required in order to successfully develop applications in bio-optics.

The above introduction has focused on the optics part of biomedical optics. However, the field is inherently multidisciplinary, since applications rely on fundamental research and development in optics, physics, biology and biochemistry, and medicine. Combining these results and bringing together experts from different fields, who challenge each other's knowledge, provide an inspiring research environment that leads to new, exciting applications.

Biomedical optics focus section

Biomedical optics is experiencing remarkable worldwide growth in terms of research activities, applications and formation of companies. In Denmark, the field is experiencing an expansion similar to that seen in other European countries and the United States. Therefore, with this special section, DOPS-NYT has chosen to put the spotlight on this topic.

The papers of the special section may be grouped in three categories: optical diagnostics, therapeutic procedures, and image processing. The first four papers are concerned with various optical diagnostic methods. The promising imaging modality optical coherence tomography for medical applications is reviewed by Thrane *et al.* (see also front cover image). Detection of breast cancer by optical mammography using ultra-short laser pulses may be a viable alternative to conventional methods, and the development of such modality in a European joint project is described by Swartling and Andersson-Engels. In ophthalmology, detection of lens autofluorescence may be a new method for screening for tissue-damage associated with cardio-vascular diseases as described by Kessel. Blood gases, pH and oximetry are important clinical assessments covered by Boalth, who describes a commercially available device.

Applying lasers in therapeutic procedures is now commonly accepted. There are two papers concerned with this topic. The first paper is by Black and Barton, who describe a novel two-photon scheme for use in laser therapy of vascular diseases. Moreover, their novel scheme may also be used for *in vivo* diagnostic applications. Samsø *et al.* describe the development of a novel diode laser system for application in photodynamic therapy, which is a method for treatment of certain cancerous lesions.

An important aspect in biomedical optics is signal and image processing. This topic is introduced by Ersbøll on page 38. Three papers cover various aspects in image analysis and image classification algorithms, thus, representing general methods.

To end the special section, I have invited two contributions, one from the BIOP center in Denmark, and one from Lund Medical Laser Centre in Sweden. The activities encompassed by these two research centers show that the field biomedical optics has strong research environments in both countries, which form the foundation of educating highly specialized candidates. Moreover, both centers are excellent starting points for interactions between academia and industry for developing applications.

Finally, it has been a privilege to compile the papers for this section, and I hope you find the topics covered interesting and stimulating reading.