

THEO MURPHY INTERNATIONAL
SCIENTIFIC MEETING ON

**Making light work: illuminating the
future of biomedical optics**

Monday 8 November – Wednesday 10 November 2010
**The Kavli Royal Society International Centre, Chicheley Hall,
Buckinghamshire**

Organised by Professor Clare Elwell, Professor Jeremy Hebden,
Professor Paul Beard, Professor Elizabeth Hillman and Professor Chris Cooper

- **Programme and abstracts**
- **Speaker biographies**
- **Notes**
- **Participant list**
- **Publication order form**

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Making light work: illuminating the future of biomedical optics

Monday 8 – Wednesday 10 November 2010

Organised by Professor Clare Elwell, Professor Jeremy Hebden, Professor Paul Beard, Professor Elizabeth Hillman and Professor Chris Cooper

Day 1 – Monday 8 November 2010

12.00 Registration and lunch*

13.00 Welcome by Professor Clare Elwell, Organiser

Welcome by Professor Sir Peter Knight FRS, Principal, The Kavli Royal Society International Centre

SESSION 1 – CURRENT STATUS AND INNOVATIONS IN OPTICAL TECHNOLOGIES

Chairs – Professor Joseph Culver, Washington University in St Louis, USA

Professor Matthias Kohl-Bareis, University of Applied Sciences Koblenz, Germany

13.15 'Near-infrared spectroscopy and imaging of living systems': from 1996 to 2010 and beyond

Professor Clare Elwell, University College London, UK

13.40 Discussion

14.00 Blood flow monitors & other recent developments in diffuse optics

Professor Arjun Yodh, University of Pennsylvania, USA

14.25 Discussion

14.45 Tea

15.15 Hemoglobin oxygen saturation as a biomarker: the problem and a solution

Professor David Boas, Harvard Medical School, USA

15.40 Discussion

16.00 Toward the next generation of near-infrared spectroscopy

Professor Yoko Hoshi, Tokyo Institute of Psychiatry, Japan

16.25 Discussion

16.45 End of session

17.00 FACILITATED PANEL DISCUSSION - HARDWARE INNOVATIONS AND PROSPECTS

Chair – Professor Jeremy Hebden, University College London, UK

Panel Members:

Dr Willy Colier, Artinis Medical Systems BV, The Netherlands

Professor Rinaldo Cubeddu, Politecnico di Milano, Italy

Dr Atsushi Maki, Hitachi, Japan

Dr Wolfgang Becker, Becker & Hickl GmbH, Germany

Professor Randall Barbour, SUNY Downstate Medical Center, USA

18.00 End of day 1

18.30 Dinner*

Day 2 – Tuesday 9 November 2010

SESSION 2 – KEY ORGANS: BRAIN

Chairs – Professor Martin Wolf, University Hospital Zurich, Switzerland
Professor Gunnar Naulaers, University Hospitals Leuven, Belgium

09.00 NIRS in newborn under intensive care - is it time to move?

Professor Gorm Greisen, Neonatology, Rigshospitalet and University of Copenhagen, Denmark

09.25 Discussion

09.45 Shedding light on the injured brain

Dr Martin Smith, National Hospital for Neurology and Neurosurgery, University College London Hospitals, UK

10.10 Discussion

10.30 Coffee

11.00 Non-invasive optical imaging of stroke

Professor Hellmuth Obrig, Max Planck Institute for Human Cognitive & Brain Sciences and Bernstein Centre for Computational Neuroscience, Germany

11.25 Discussion

11.45 Near infrared spectroscopy to study the developing brain

Professor Gentaro Taga, The University of Tokyo, Japan

12.10 Discussion

12.30 Lunch*

13.30 DISCUSSION: FUTURE MEETINGS FOR DEVELOPERS AND USERS OF BIOMEDICAL OPTICS TECHNOLOGIES

Professor David Boas, Harvard Medical School, USA

SESSION 3 – KEY ORGANS: BREAST AND MUSCLE

Chairs – Professor Robert Boushel, University of Copenhagen, Denmark
Dr Adam Gibson, University College London, UK

14.30 Diffuse optical spectroscopic imaging in breast cancer detection and treatment

Professor Bruce Tromberg, University of California, USA

14.55 Discussion

15.15 Extracting accurate estimates of biochemical data *in vivo* using NIR spectral imaging and prior informatio

Professor Brian Pogue, Dartmouth College, USA

15.40 Discussion

16.00 Tea

16.30 The use of near-infrared spectroscopy (NIRS) in understanding skeletal muscle physiology: recent developments

Professor Marco Ferrari, University of L'Aquila, Italy

16.55 Discussion

17.15 The use of muscle near-infrared spectroscopy in sport, health, and medical sciences: recent developments

Professor Takafumi Hamaoka, Ritsumeikan University, Japan

17.40 Discussion

18.00 End of session

18.15 FACILITATED PANEL DISCUSSION - HOW DOES NIRS INFORM BIOLOGY AND MEDICINE?

Chair – Professor Chris Cooper, University of Essex, UK

Panel Members:

Dr Ilias Tachtsidis, University College London, UK;

Professor Kenneth Schenkman, University of Washington, USA;

Dr Topin Austin, University of Cambridge, UK;

Professor Babs Soller, University of Massachusetts, USA;

Dr Aparna Hoskote, Great Ormond Street Hospital for Children, UK

19.15 End of day 2

19.15 Dinner*

Day 3 – Wednesday 10 November 2010

KEYNOTE LECTURE

Chair – Professor Paul Beard, University College London, UK

08.00 In vivo molecular imaging: trends, opportunities and challenges

Professor Simon Cherry, University of California, USA

SESSION 4 – NEW DEVELOPMENTS IN PRE CLINICAL OPTICAL IMAGING METHODOLOGIES

Chairs – Dr Turgut Durduran, The Institute of Photonic Sciences, Spain

Professor Bruce Tromberg, University of California, USA;

08.45 Real-time in-vivo optical imaging for biomedical research

Professor Elizabeth Hillman, Columbia University, USA

09.10 Discussion

09.30 Photoacoustic tomography: ultrasonically breaking through the optical diffusion limit

Professor Lihong Wang, University of Washington, USA

09.55 Discussion

10.15 Coffee

10.45 Spelling optical imaging for the new grammar of drug discovery

Professor Thomas Krucker, Novartis Institutes for BioMedical Research Inc. and the Scripps Research Institute, USA

11.10 Discussion

11.30 Advancing biology and medicine with optical and optoacoustic imaging

Professor Vasilis Ntziachristos, Technische Universität München and Helmholtz Zentrum München, National Research Centre for Environment and Health, Germany

11.55 Discussion

12.15 FACILITATED PANEL DISCUSSION - INTRINSIC AND EXTRINSIC PROBES IN OPTICAL IMAGING

Chair – Professor Paul French, Imperial College London, UK

Panel Members:

Dr Heidrun Wabnitz, Physikalisch-Technische Bundesanstalt, Germany

Professor Adam Liebert, Institute of Biocybernetics and Biomedical Engineering, Poland

Dr Daniel Elson, Imperial College London, UK

Dr Adrien Desjardins, University College London, UK

13.30 Final remarks

13.45 End of meeting

13.45 Lunch*

Making light work: illuminating the future of biomedical optics

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Synopsis

The purpose of this meeting is to exploit the recent surge of interest in the development of new diagnostic optical technologies to explore their future transition from benchtop prototypes to routine use in the clinical and life sciences. It will bring together a highly interdisciplinary group of scientists working towards a new generation of monitoring and imaging techniques.

Day 1 – Monday 8 November 2010

12.00 Registration and lunch

13.00 Welcome by Professor Clare Elwell, Organiser

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SESSION 1 – CURRENT STATUS AND INNOVATIONS IN OPTICAL TECHNOLOGIES

Chairs – Professor Joseph Culver, Washington University in St Louis, USA

Professor Matthias Kohl-Bareis, University of Applied Sciences Koblenz, Germany

13.15 'Near-infrared spectroscopy and imaging of living systems': from 1996 to 2010 and beyond

Professor Clare Elwell, University College London, UK

In 1996 a Royal Society Scientific Discussion meeting brought together a highly interdisciplinary audience to discuss the current capabilities, outstanding issues and possible future directions of *in vivo* optical spectroscopy technologies, the proceedings of which were published as "*Discussion on Near-infrared Spectroscopy and Imaging of Living Systems*" Phil Trans R. Soc Lond. B (352, 645-761). These proceedings provide a snapshot of the state of our research area as defined by leading experts in the field at that time. At this meeting in 2010 we have an opportunity to reflect on which areas of promise have been fulfilled and which questions remain unanswered over a decade later. This talk will provide an overview of how the research landscape has shifted since 1996 and where the key innovations for instrumentation development and targeted application in the clinical and life sciences lie for the future of our technology.

13.40 Discussion

14.00 Blood flow monitors & other recent developments in diffuse optics

Professor Arjun Yodh, University of Pennsylvania, USA

Diffuse optics has proven to be quite useful for quantitative assessment of tissue oxy- and deoxy-hemoglobin concentrations and, more recently, tissue blood flow. In this talk I will describe representative clinical studies from my lab wherein blood flow plays a key role, and I will outline basic concepts and methods which permit these clinical investigations. Examples will illustrate the strengths and weaknesses of the diffuse optical blood flow correlation measurement.

14.25 Discussion

14.45 Tea

15.15 Hemoglobin oxygen saturation as a biomarker: the problem and a solution

Professor David Boas, Harvard Medical School, USA

Hemoglobin oxygen saturation is often used as an indicator of sufficient oxygen delivery to assess injury susceptibility and tissue damage, and has also often been used as a surrogate measure of oxygen metabolism. Unfortunately, these measures have generally failed to be robust indicators of injury and metabolism. We first review when hemoglobin oxygen saturation does work as a robust indicator, and then detail when and why it fails for assessing brain injury and breast cancer. Finally, we discuss the solution to obtain more robust measures of tissue injury and cancer by combining oxygen saturation measurements with measures of blood flow and volume to more accurately estimate oxygen metabolism.

15.40 Discussion

16.00 Toward the next generation of near-infrared spectroscopy

Professor Yoko Hoshi, Tokyo Institute of Psychiatry, Japan

In 1977, Jöbsis first described the in vivo application of near-infrared spectroscopy (NIRS); this technique was originally designed for clinical monitoring of tissue oxygenation. Since the early 1990s, it has also been developing as a useful tool for neuroimaging studies (fNIRS). For about 35 years, the technology has advanced and a wide range of NIRS instruments have been developed. The recent advent of multichannel CW-type instruments has greatly increased the use of NIRS in a variety of fields.

At the same time, however, the accuracy and reliability of NIRS have not yet been widely accepted. This is mainly attributable to difficulty in selective quantitative detection of NIRS signals arising from the cerebral tissue. The use of NIRS is under several restrictions due to these problems, which is not well understood by many NIRS users. To overcome limitations of NIRS, we have been developing time-domain near-infrared optical tomography (TNOT). This technique will facilitate the development of molecular imaging in living subjects and the establishment of diagnostic optical imaging. In this meeting, firstly I will summarize the problems of CW measurements, and then talk about the current status and future prospects of TNOT.

16.25 Discussion

16.45 End of session

17.00 FACILITATED PANEL DISCUSSION - HARDWARE INNOVATIONS AND PROSPECTS

Chair – Professor Jeremy Hebden, University College London, UK

Panel Members:

Dr Willy Colier, Artinis Medical Systems BV, The Netherlands

Professor Rinaldo Cubeddu, Politecnico di Milano, Italy

Dr Atsushi Maki, Hitachi, Japan

Dr Wolfgang Becker, Becker & Hickl GmbH, Germany

Professor Randall Barbour, SUNY Downstate Medical Center, USA

18.00 End of day 1

18.30 Dinner

Day 2 – Tuesday 9 November 2010

SESSION 2 – KEY ORGANS: BRAIN

Chairs – Professor Martin Wolf, University Hospital Zurich, Switzerland

Professor Gunnar Naulaers, University Hospitals Leuven, Belgium

09.00 NIRS in newborn under intensive care - is it time to move?

Professor Gorm Greisen, Neonatology, Rigshospitalet and University of Copenhagen, Denmark

Several instruments implementing spatially resolved near-infrared spectroscopy to monitor tissue oxygenation are now approved for clinical use.

The neonatal brain is readily assessable by NIRS. Neurodevelopmental handicap is common in children who were in need of intensive care during the neonatal period. It is likely that an important part of the burden of this handicap is due to brain injury induced by hypoxia-ischaemia during intensive care. In particular, this is true for infants born extremely preterm. Thus monitoring of cerebral oxygenation has considerable potential benefit in this group.

The benefit, however, should be weighted against the disturbance to the very small and fragile infant, the limitations that this monitoring imposes on the already complex clinical care, and against costs in terms of equipment and staff time. Most importantly, the clinical benefit of cerebral oximetry should be evaluated as 'added value', i.e. information that is supplementary to the information available to the clinician already. Furthermore the information should be useful, i.e. allow the clinician to modify treatment to the final benefit of the infant. Among other things, this means that an effective treatment should be available and that the situation where this treatment is needed should be reasonably frequent. The ultimate way of demonstrating the 'added value' is by a randomised controlled trial, where infants are randomised to monitoring by cerebral oximetry. Cerebral oximetry must reduce the occurrence of a clinically relevant endpoint, such as death-or-neurodevelopmental handicap. We estimate that such a trial should recruit about 1000 infants to have the power to detect a reduction in brain injury by one third. This is an illustration of the formidable task to provide 1st grade evidence for the clinical value of diagnostic methods.

So is it time to move? Or is it a time-window to establish a rational basis before another technology invades neonatal intensive care?

09.25 Discussion

09.45 Shedding light on the injured brain

Dr Martin Smith, National Hospital for Neurology and Neurosurgery, University College London Hospitals, UK

Earlier NIRS methodology using differential spectroscopy methods provides trend monitoring with variables that are generally unfamiliar to clinicians. Technical developments allowed the introduction of clinical monitors that incorporate an absolute measure of cerebral tissue oxygen saturation (ScO_2). Many clinicians use such devices as 'black box' technology to provide an assessment of the balance between cerebral oxygen delivery and utilization without being mindful that ScO_2 is a complex variable affected by multiple systemic and cerebral physiological changes.

Cerebral hypoxia/ischemia (H-I) is a major contributor to poor neurological outcome in a variety of clinical situations. Although time critical windows to prevent or minimize permanent ischemic neurological injury exist, these often pass silently because detection of cerebral H-I in real-time remains problematic. The logical application for a non-invasive cerebral monitor, such as NIRS, is in acute brain injury where secondary ischemic injury is common. However, its clinical application is hampered by the inability to define 'thresholds' for H-I using ScO_2 . There has been recent focus on the importance of cellular energy failure as a key component of the pathophysiology of acute brain injury. The oxidation status of cytochrome c oxidase (CCO) has been validated in animal studies as a measure of cellular energy status but there are enormous challenges in monitoring CCO. Our group has developed a multimodal monitoring strategy incorporating a novel NIRS system optimized for CCO measurement in adults in association with mathematical model informed data interpretation. This lecture will discuss the translation of NIRS systems and methods into adult neurocritical care.

10.10 Discussion

10.30 Coffee

11.00 Non-invasive optical imaging of stroke

Professor Hellmuth Obrig, Max Planck Institute for Human Cognitive and Brain Sciences and Bernstein Centre for Computational Neuroscience, German

The acute onset of a neurological deficit is the key clinical feature of stroke. In most cases, though, pathophysiological changes in the cerebral vasculature precede the event, often for many years. Also persisting neurological deficits may require long-term rehabilitation. Hence stroke may be considered a chronic disease and diagnostic and therapeutic efforts must include (i) identification of specific risk factors (ii) the monitoring and interventions in the acute and subacute stage and (iii) should aim at a pathophysiologically based approach to optimize the rehabilitative effort. Non-invasive optical techniques have been experimentally used in all three stages of the disease and may complement the established diagnostic and monitoring tools. Here we give an overview over studies using the methodology in the context of stroke and sketch perspectives of how they may be integrated in the assessment of the highly dynamic pathophysiological processes during the acute and subacute stage of the disease but also during rehabilitation and (secondary) prevention of stroke.

11.25 Discussion

11.45 Near infrared spectroscopy to study the developing brain

Professor Gentaro Taga, The University of Tokyo, Japan

Multi-channel near infrared spectroscopy (NIRS) has been used to investigate spatio-temporal dynamics of activation of the developing brain. Observation of spontaneous changes in hemoglobin oxygenation during sleeping state has revealed developmental changes in global cortical network of the functional connectivity during the first six months of life. Studies on stimulus-induced cortical activation in relation to perceptual-cognitive ability have demonstrated the early functioning not only in sensory regions but also in the association and higher association regions as early as 3 months of age. These studies suggest that the functional hierarchy of the cortical regions may concurrently emerge from the dynamic interaction of diverse regions of the cortex in early infancy. An important challenge is to clarify the relationship between the spontaneous and stimulus-induced activity in the developing brain, where the structure and function dynamically change over time.

12.10 Discussion

12.30 Lunch

13.30 DISCUSSION: FUTURE MEETINGS FOR DEVELOPERS AND USERS OF BIOMEDICAL OPTICS TECHNOLOGIES

Professor David Boas, Harvard Medical School, USA

SESSION 3 – KEY ORGANS: BREAST AND MUSCLE

Chairs – Professor Robert Boushel, University of Copenhagen, Denmark

Dr Adam Gibson, University College London, UK

14.30 Diffuse optical spectroscopic imaging in breast cancer detection and treatment

Professor Bruce Tromberg, University of California, USA

We describe the development of a Diffuse Optical Spectroscopic Imaging (DOSI) method that combines broadband frequency-domain photon migration with time-independent spectroscopy in order to acquire high-resolution NIR absorption and scattering spectra (650 - 1000 nm) from thick tissues. Spectral maps are obtained using a scanning handpiece and transformed into quantitative DOSI images of tissue structure and biochemical composition. Intrinsic breast tissue contrast is derived from hemoglobin (oxy- and deoxy-), water, and lipid content, as well as from spectral shifts that reveal differences in tumor water binding state. The sensitivity of broadband DOSI to metabolic changes in breast cancer is assessed in patients undergoing pre-surgical neoadjuvant chemotherapy (NAC). The relationship between intrinsic optical signatures and tumor aerobic glycolysis, i.e. the Warburg effect, is examined by correlating histopathology biomarkers of proliferation and glucose metabolism with non-invasive DOSI measurements. This approach is used to understand the importance of processes such as tumor perfusion and cellular proliferation on individual NAC response. Particular emphasis is placed on identifying dynamic metabolic changes in the first week of chemotherapy and predicting final pathologic response as early as possible in the course of treatment.

14.55 Discussion

15.15 Extracting accurate estimates of biochemical data *in vivo* using NIR spectral imaging and prior information

Professor Brian Pogue, Dartmouth College, USA

Near-infrared spectroscopy of tissue provides a way to quantify absorbers, scattering features and luminescent agents in bulk tissue, through the use of measurement data and assumptions (or prior knowledge) about the interior. A conceptual description of NIRS imaging with prior information is presented as a matrix convolution problem, where individual prior information sets are used in the NIRS estimation sequence. Most of the development in NIRS has used ad hoc or empirical implementation of prior information such as pre-measured absorber or fluorophore spectra, or tissue shapes as estimated by additional imaging tools. Ideally a comprehensive analysis should include what prior information maximizes the accuracy in recovery and value for medical diagnosis, when implemented at separate stages of the NIRS sequence. Individual applications of prior information are shown to increase the accuracy or improve the ability to estimate biochemical features of tissue, while other approaches do not necessarily lead to improvements. More accurate estimation of hemoglobin and oxygen saturation are shown in tumors, and increased ability to estimate injected agent binding is illustrated with prior model information.

15.40 Discussion

16.00 Tea

16.30 The use of near-infrared spectroscopy (NIRS) in understanding skeletal muscle physiology: recent developments

Professor Marco Ferrari, University of L'Aquila, Italy

This talk is aimed at summarising the current status and the future scenario of the use of near-infrared spectroscopy (NIRS) in understanding skeletal muscle physiology. Presently, different NIRS instruments/methods (e.g., spatially-, time- and frequency-resolved spectroscopy) have been utilised for measuring muscle oxidative metabolism during voluntary and involuntary (electrically evoked) muscle contractions. In the last 4 years, approximately 160 muscle NIRS articles (excluding the clinical studies) have been published on different physiological aspects (primarily muscle oxygenation and haemodynamics) of several upper and lower limb muscle groups investigated by using mainly 1-2-channel spatially-resolved spectroscopy commercial instruments. Unfortunately, in only 15 of these studies the advantages of using multi-channel systems were exploited. The main NIRS parameters measurable at rest and during exercise will be presented; the most important findings linked to the physiological aspects of peripheral/central fatigue, training, hypoxia, ergonomics, cognition, etc. will be discussed. Guidelines/standardisation for muscle NIRS studies and technical needs (i.e. new algorithms and modelling techniques, multi-channel wearable wireless systems, integration of muscle/brain NIRS with other methods, most advanced NIRS technologies, such as diffuse correlation spectroscopy) will be mentioned.

16.55 Discussion

17.15 The use of muscle near-infrared spectroscopy in sport, health, and medical sciences: recent developments

Professor Takafumi Hamaoka, Ritsumeikan University, Japan

There is an increasing need to develop noninvasive and real-time methods in a portable manner for evaluating skeletal muscle oxidative metabolism in humans. Near-infrared spectroscopy (NIRS) has been developed to fulfill this need for measuring oxygenation in muscle and other tissues in vivo. This review paper highlights the progress, specifically in this decade, which has been made for evaluating skeletal muscle oxygenation and oxidative energy metabolism in sport, health, and clinical sciences. Development of NIRS technologies has included novel approaches to quantification of the signal with a multiple measurement modality, as well as the improvement of accessibility and portability for a practical use. NIRS measurements have been extended to training-induced adaptations in oxidative metabolism in various athletes during resting, ischemic, localized exercise, and whole body exercise. Furthermore, NIRS technology has been utilized in the study of a number of chronic health conditions, including patients with heart failure, peripheral vascular disease, chronic obstructive pulmonary disease, various muscle diseases, spinal cord injury, and renal failure. As NIRS technology continues to progress, the future of muscle NIRS study first illuminated by Jobsis continues to be bright.

17.40 Discussion

18.00 End of session

18.15 FACILITATED PANEL DISCUSSION - HOW DOES NIRS INFORM BIOLOGY AND MEDICINE?

Chair – Professor Chris Cooper, University of Essex, UK

Panel Members:

Dr Ilias Tachtsidis, University College London, UK

Professor Kenneth Schenkman, University of Washington, USA

Dr Topin Austin, University of Cambridge, UK

Professor Babs Soller, University of Massachusetts, USA

Dr Aparna Hoskote, Great Ormond Street Hospital for Children, UK

19.15 End of day 2

19.15 Dinner

Day 3 – Wednesday 10 November 2010

KEYNOTE LECTURE

Chair – Professor Paul Beard, University College London, UK

08.00 In vivo molecular imaging: trends, opportunities and challenges

Professor Simon Cherry, University of California, USA

In vivo molecular imaging technologies have become a powerful and widely utilized tool for studying animal models of human disease and in preclinical evaluation of novel therapeutic strategies. A variety of imaging modalities are used, however, optical imaging using bioluminescence or fluorescence signals are the most widely adopted approach. Significant efforts also underway to translate molecular imaging methodologies into the clinical setting, however this is a slow and expensive undertaking due to the regulatory environment, specifically when exogenous targeted imaging agents are involved.

This presentation will review current state-of-the-art approaches for in vivo molecular imaging, with a focus on optical technologies. Recent trends will be explored, including the deployment of systems with capability of reconstructing three-dimensional optical images, the rapid development of photoacoustic approaches and the integration of optical tomography with other imaging modalities such as CT and PET to create hybrid systems. Some novel approaches to molecular optical imaging using Cerenkov radiation or x-ray activatable nanophosphors, which are being explored in our own laboratory, also will be discussed.

Finally, challenges such as the difficulty in routinely obtaining quantitative 3-D optical images across a wide range of possible imaging conditions, and the hurdles in translating these promising molecular imaging approaches to the patient setting, will be outlined to serve as a platform for audience discussion.

SESSION 4 – NEW DEVELOPMENTS IN PRE CLINICAL OPTICAL IMAGING METHODOLOGIES

Chairs – Dr Turgut Durduran, The Institute of Photonic Sciences, Spain
Professor Bruce Tromberg, University of California, USA

08.45 Real-time in-vivo optical imaging for biomedical research

Professor Elizabeth Hillman, Columbia University, USA

Optical imaging can exploit a wide range of contrast mechanisms in living tissue; from the absorption of oxy- and deoxy-hemoglobin, to the fluorescence of metabolites NADH and FAD, targeted dyes and genetically encoded fluorescent proteins. While light scattering makes deep tissue imaging highly challenging, high-resolution imaging of superficial tissues or small animals is more readily achievable. A wide range of in-vivo optical techniques have therefore been adopted for biomedical research, including confocal and two-photon microscopy, wide-field spectroscopy, and multispectral and dynamic molecular imaging for studies of brain function, the pathogenesis of cancer and other diseases, and drug and contrast agent development. This talk will provide an overview of current optical imaging techniques that are being increasingly adopted for state of the art biomedical research.

09.10 Discussion

09.30 Photoacoustic tomography: ultrasonically breaking through the optical diffusion limit

Professor Lihong Wang, University of Washington, USA

We develop photoacoustic tomography (PAT) for functional and molecular imaging by physically combining optical and ultrasonic waves via energy transduction. Key applications include early-cancer and functional imaging. Light provides rich tissue contrast but does not penetrate biological tissue in straight paths as x-rays do. Consequently, high-resolution pure optical imaging (e.g., confocal microscopy, two-photon microscopy, and optical coherence tomography) is limited to depths within one optical transport mean free path (~1 mm in the skin). Ultrasonic imaging, on the contrary, provides good image resolution but suffers from poor contrast in early-stage tumors as well as strong speckle artifacts. PAT—embodied in the forms of computed tomography and focused scanning—overcomes the above problems because ultrasonic scattering is ~1000 times weaker than optical scattering. In PAT, a pulsed laser beam illuminates the tissue and generates a small but rapid temperature rise, which induces emission of ultrasonic waves due to thermoelastic expansion. The short-wavelength ultrasonic waves are then detected to form high-resolution tomographic images. PAT broke through the diffusion limit for penetration and achieved high-resolution images at depths up to 7 cm in tissue. Further depths can be reached by thermoacoustic tomography (TAT) using microwaves or RF waves instead of light for excitation.

09.55 Discussion

10.15 Coffee

10.45 Spelling optical imaging for the new grammar of drug discovery

Professor Thomas Krucker, Novartis Institutes for BioMedical Research Inc. and the Scripps Research Institute, USA

Optical technologies used in biomedical research have undergone tremendous development in the last decade and enabled important insight into biochemical, cellular, and physiological phenomena at the microscopic and macroscopic level. Historically in drug discovery, to increase throughput in screening, or increase efficiency through automation of image acquisition and analysis in pathology, efforts in imaging were focused on the reengineering of established microscopy. However, with the emergence of the new grammar for drug discovery [1], other requirements and expectations have created unique opportunities for optical imaging. The new grammar of drug discovery provides rules for translating the wealth of genomic and proteomic information into targeted medicines with a focus on complex interactions of proteins. This paradigm shift requires highly specific and quantitative imaging at the molecular level with tools that can be utilized in cellular assays, animals, and finally translated into patients. The development of fluorescent targeted and activatable “smart” probes, fluorescent proteins, and new reporter gene systems, as functional and dynamic markers of molecular events in vitro and in vivo is therefore playing a pivotal role. An enabling optical imaging platform will combine optical hardware refinement with a strong emphasis on creating and validating highly specific chemical and biological tools.

[1] Fishman and Porter, Nature, 2005

11.10 Discussion

11.30 Advancing biology and medicine with optical and optoacoustic imaging

Professor Vasilis Ntziachristos, Technische Universität München and Helmholtz Zentrum München, National Research Centre for Environment and Health, Germany

Optical imaging is unequivocally the most versatile and widely used visualization modality in clinical practice and life sciences research either through microscopy and optical assays or endoscopic methods. In recent years, advances in photonic technologies and image formation methods have

received particular attention in biological research and the drug discovery process for non-invasively revealing information on the molecular basis of disease and treatment. An increasing availability of endogenous reporters such as fluorescent proteins and probes with physiological and molecular specificity enable insights to cellular and sub-cellular processes through entire small animals, embryos, fish and insects and have revolutionized the role of imaging on the laboratory bench. Here we show progress in optical imaging technology, performance and applications for regimes beyond what is achieved by modern microscopy, i.e. imaging of whole intact animals and model biological organisms. We demonstrate high resolution imaging capacity, through scattering tissues using advanced fluorescence and multi-spectral opto-acoustic tomography (MSOT) techniques developed for accurate and quantitative molecular investigations in tissues. We further demonstrate that cellular function and bio-chemical changes can be detected in-vivo, through intact tissues at high sensitivity and molecular specificity. Examples of imaging enzyme up-regulation, carcinogenesis and gene-expression are given with animal and clinical data. Limitations of the method and future directions are also discussed.

11.55 Discussion

12.15 FACILITATED PANEL DISCUSSION - INTRINSIC AND EXTRINSIC PROBES IN OPTICAL IMAGING

Chair – Professor Paul French, Imperial College London, UK

Panel Members:

Dr Heidrun Wabnitz, Physikalisch-Technische Bundesanstalt, Germany

Professor Adam Liebert, Institute of Biocybernetics and Biomedical Engineering, Poland

Dr Daniel Elson, Imperial College London, UK

Dr Adrien Desjardins, University College London, UK

13.30 Final remarks

13.45 End of day 3

13.45 Lunch

Organiser, speaker and chair biographies

Dr Topin Austin, University of Cambridge, UK (Panellist)

Topun Austin is a Consultant Neonatologist at Cambridge University Hospitals NHS Foundation Trust. He graduated from University College London, and it was here that he undertook his postgraduate research training under the supervision of Professors John Wyatt and Jeremy Hebden. His main research interest is in Perinatal Brain Injury and in the development of multimodal monitoring and imaging systems to identify vulnerable infants at an early stage. He has had a long and successful collaboration with the Biomedical Optics Research Laboratory at UCL; this has included working with the group in the development of a pioneering 3D optical imaging system to study regional blood volume and oxygenation from the neonatal brain. He is currently collaborating with the group in developing an integrated optical-EEG system to investigate neonatal brain function and seizure activity.

Professor Randall Barbour, SUNY Downstate Medical Center, USA (Panellist)

While originally trained as a biochemist, Dr Randall Barbour has focused his research efforts in the field of biomedical optics since 1985. His principal contributions include the first description of diffuse NIRS tomography in 1988, diffuse fluorescence tomography in 1995 and dynamic imaging in 1999. He has also gone on to develop a line of commercial NIRS imaging systems offered by NIRx Medical Technologies. These systems provide for 3D tomographic and topographic investigations of the head and other body structures and have been adopted for small animal use. Dr Barbour has been continuously funded by the NIH since 1993, has published more than 200 peer reviewed and conference reports and regularly serves on NIH study section reviews.

Professor Paul Beard, University College London, UK (Organiser and Chair)

Paul Beard obtained a BSc in Physics at UCL in 1987. Following a period at Marconi Underwater Systems Ltd developing passive fibre optic sonar arrays he returned to UCL and was awarded a PhD in photoacoustic spectroscopy in 1996. He is currently Professor of Biomedical Photoacoustics in the Department of Medical Physics and Bioengineering, UCL and holds an EPSRC Leadership Fellowship. His research interests lie in optical ultrasound detection, light transport and acoustic propagation modeling, quantitative photoacoustic image reconstruction, spectroscopic inversion methods and ultrasound metrology.

Dr Wolfgang Becker, Becker & Hickl GmbH, Germany (Panellist)

Dr Becker is a specialist of optical short-time measurement techniques and obtained his PhD in 1979 in Berlin, Germany. Since 1993 he is the head of Becker & Hickl GmbH in Berlin. His field of interest is development and application of time-correlated single photon counting techniques. He is an amateur astronomer and telescope maker and likes cats, skiing and beach volleyball.

Professor David Boas, Harvard Medical School, USA (Speaker)

Dr David A Boas is an Associate Professor at the Harvard Medical School and Associate Physicist at Massachusetts General Hospital in Boston, Massachusetts. He received his Bachelors Degree in Physics from Rensselaer Polytechnic Institute, Troy NY in 1991 and his Doctorate from the University of Pennsylvania, Philadelphia, PA, also in Physics. His research interests include the following: photon migration in highly scattering media with emphasis on diffuse optical tomography, clinical applications of diffuse optical tomography in brain and breast radiology and fundamental studies of brain function and stroke using diffuse optical tomography and optical microscopy. Dr Boas has been an Associate Editor of *Optics Express* and Guest Editor of *Medical Physics* and *Journal of Biomedical Optics*. He is a member of SPIE and the Optical Society of America (OSA), and has served as Conference Program Chair for various OSA topical meetings.

Professor Robert Boushel, University of Copenhagen, Denmark (Chair)

Robert Boushel is a professor in the Department of Biomedical Sciences, University of Copenhagen, and adjunct professor in the Department of Medicine, McGill University, and Department of Exercise Science, Concordia University, in Montreal. Primary research themes are cardiovascular regulation during exercise and mitochondrial function. Specific areas include the regulation of cardiac output, regional and microvascular blood flow in normoxia and hypoxia, and the matching of regional substrate delivery to muscle in relation to mitochondrial capacity. These topics are studied in healthy sedentary untrained and trained individuals and in clinical populations such as type 2 diabetes, COPD, and heart failure.

Professor Simon Cherry, University of California, USA (Speaker)

Simon R Cherry, PhD received his BSc(Hons) in Physics with Astronomy from University College London in 1986 and a PhD in Medical Physics from the Institute of Cancer Research, University of London in 1989. After a postdoctoral fellowship with Dr Edward Hoffman at UCLA, he joined the faculty in the Department of Molecular and Medical Pharmacology at UCLA in 1993. From 1998-2001 he was Associate Director of the UCLA Crump Institute for Molecular Imaging. In 2001, Dr Cherry joined UC Davis as a Professor in the Department of Biomedical Engineering and Director of the Center for Molecular and Genomic Imaging. Dr Cherry was Chair of the Department of Biomedical Engineering at UC Davis from 2007-2009.

Dr Cherry's research interests center around in vivo molecular imaging systems. A focus of his research is the development of very high resolution position emission tomography (PET) systems for preclinical imaging, in particular the development of the microPET scanner that was subsequently widely adopted in academia and industry. Additional interests include multi-modality imaging, especially the integration of PET with MRI, and optical molecular imaging techniques. Dr Cherry is a founding member of the Society of Molecular Imaging and a fellow of the IEEE, BMES and AIMBE. He serves on the Editorial Board of the journals *Physics in Medicine and Biology* and *Molecular Imaging and Biology*. In 2006, Dr Cherry was invited to give the Henry Wagner Distinguished Lectureship at the Society of Nuclear Medicine annual meeting and in 2007 Dr Cherry received the Academy of Molecular Imaging Distinguished Basic Scientist Award. Dr Cherry is the author of more than 190 peer-reviewed journal articles or book chapters in the field of biomedical imaging. He is also co-author of the 3rd edition of the textbook "Physics in Nuclear Medicine".

Dr Willy Colier, Artinis Medical Systems BV, The Netherlands (Panellist)

Willy Colier studied physics at the University of Twente in the Netherlands. In 1991 he started a PhD at the department of Physiology of the University of Nijmegen. He worked there on the application side as well as on the technical aspects of Near Infrared Spectroscopy. His PhD thesis, "Near Infrared Spectroscopy: Toy or Tool", was published in 1995. After this period he stayed working on NIRS in Nijmegen as a postdoctoral researcher for departments like Neurology, Geriatric Medicine and Physiology. Dr Colier was part of various national and international projects, like the BioMed Concerted Actions on NIRS. He published over 60 papers on NIRS and related subjects. In 2001 he started together with a colleague his own company, Artinis Medical Systems. The company is now one of the world leading companies on NIRS, but also in the field of radiological quality control.

Professor Chris Cooper, University of Essex, UK (Organiser and Chair)

Chris Cooper obtained a BSc in Biochemistry (Bristol, 1985) and a PhD in Biophysics (Guelph, Canada, 1989). From 1989-1992 he studied EPR spectroscopy at King's College London. In 1992 he was awarded a Medical Research Council Fellowship at University College London to study mitochondrial energetics in vivo using a combination of magnetic resonance and near infrared spectroscopy (NIRS). He moved to the University of Essex in 1995 when he received a Wellcome Trust Award in the area of nitric oxide interactions with

mitochondria. He was awarded a personal chair in Biochemistry in 1999. His current research interests focus on oxygen transport and utilisation in biology and medicine.

His in vitro studies explore the free radical (nitric oxide, superoxide) reactivity of myoglobin, haemoglobin and mitochondrial cytochrome oxidase. His in vivo studies focus on the use of NIRS to measure oxygen utilisation non-invasively, with particular emphasis on measurements of cytochrome oxidase. He has been actively involved in the development of haem therapeutics, in particular the creation of non-toxic blood substitutes.

He sits on the Executive Committee of the British Biophysical Society, the International Advisory Panel of the Mitochondrial Physiology Society and the editorial panels of Essays in Biochemistry and Free Radical Research.

Professor Rinaldo Cubeddu, Politecnico di Milano, Italy (Panellist)

After his Doctor degree in Physics at the University of Pavia in 1967, he joined the Politecnico of Milan, where he became full professor in Physics in 1986. During his academic career he was elected to institutional positions as Director of the Physics Department and Member of the Academic Senate. At present he has been re-elected as Director of the Department. He is Head of the Laboratory of Photonics for Health, Food and Cultural Heritage and he is responsible for the activity in the field of Biomedical Optics and Laser Application in Biomedicine in the Institute for Photonics and Nanotechnology of the Italian National Research Council and in the European Large Scale Facility CUSBO Center for Ultrafast Science and Biomedical Optics).

During his activity he has been member of both national and international committees and coordinator of national and international projects. At present he is coordinator of the VII FP project Neuropt on Optical Brain Topography. He has also been chair and co-chair of international conferences. He has been member of the Editorial Board of Physics in Medicine and Biology.

His research activity, documented by more than 200 publications in international reviews, has been devoted to the development of laser systems for applications in biology and medicine. Within this research field he has been among the first to develop and utilize innovative time resolved instrumentation in the picosecond and femtosecond time domain. The main applications have been in the fields of fluorescence diagnosis and the characterization of optical properties of tissues in vivo. In particular for fluorescence diagnosis it can be reported the use of a FLIM (Fluorescence Lifetime Imaging) system for a clinical study on skin cancer, while for the Photon Migration field it can be mentioned the applications to optical mammography and brain functional imaging. The instrumentation developed has been also used for fruit quality evaluation and for diagnostic purposes on art works in Cultural Heritage.

Professor Joseph Culver, Washington University in St Louis, USA (Chair)

Dr Culver obtained his PhD in physics at the University of Pennsylvania with Dr Robin Hochstrasser and Dr Arjun G Yodh developing ultrafast laser spectroscopy. For a postdoc, he switched to the field of Biomedical Optics, and worked in collaboration with Dr Britton Chance and once more with Dr Yodh. He then took an Instructor faculty position (2001-2003) at Massachusetts General Hospital (MGH) and Harvard Medical School in the Department of Radiology working in the Athinoula A. Martinos Center for Biomedical Imaging. While at MGH Dr Culver earned an NIH K25 "Mentored Quantitative Research Career Development" award. In 2003 he moved to Washington University to join the Department of Radiology, where he is now an Associate Professor. His research program is focused on developing imaging technology for both preclinical molecular imaging and human functional neuroimaging.

Dr Adrien Desjardins, University College London, UK (Panellist)

Adrien Desjardins will join the Faculty of the Department of Medical Physics and Bioengineering at University College London in early 2011. He received his PhD from the Harvard Biophysics Program and the Harvard-MIT Health Sciences and Technology Program in 2007. Currently, he's a Senior Scientist at Philips Research, focused on developing novel optical sensors and miniature imaging systems to improve interventional procedures. Adrien grew up in Toronto, Canada, and received his bachelor's degree in mathematics and physics from the University of British Columbia in 2001. He did his doctoral work on several topics in optical coherence tomography, including angle-resolved optical coherence tomography and high-speed volumetric imaging of the cardiovascular and gastrointestinal systems, under the supervision of Brett Bouma and Gary Tearney. His doctoral work included a position at the MIT Spectroscopy Lab under the supervision of Michael Feld. At UCL, Adrien will develop a wide-ranging research program with a strong emphasis on translating medical physics from the laboratory to the clinic.

Dr Turgut Durduran, The Institute of Photonic Sciences, Spain (Chair)

Dr Turgut Durduran is an assistant professor at ICFO-The Institute of Photonic Sciences, Barcelona, Spain. He leads the "Medical Optics Group" which develops optical clinical monitors and imagers for neurology and oncology.

Dr Daniel Elson, Imperial College London, UK (Panellist)

Dr Daniel Elson is a senior lecturer in surgical imaging in the Department of Surgery and Cancer and the Hamlyn Centre for Robotic Surgery, Institute of Global Health Innovation and Institute of Biomedical Engineering, Imperial College London. He received his undergraduate degree and PhD in Physics at Imperial College in 1999 and 2003. Research interests are based around the development and application of photonics technology to multispectral and polarization resolved surgical imaging and sensing, endoscopy, and fluorescence lifetime imaging. Recent projects have involved the development of illumination and vision systems for endoscopy combining light sources such as LEDs and laser diodes with computer vision techniques for image mosaicing, stereo detection and simultaneous localisation and mapping. These devices are being applied in minimally invasive and flexible robotic assisted surgery systems for single incision and natural orifice transluminal surgery.

Professor Clare Elwell, University College London, UK (Organiser and Speaker)

Clare Elwell is Professor of Medical Physics in the Department of Medical Physics and Bioengineering, University College London (UCL). She obtained her BSc in Physics with Medical Physics in 1988 from the University of Exeter, where she also completed her MPhil (1991) whilst working as a Clinical Physicist running urodynamics, respiratory function and sleep studies. Following a move to UCL she completed a PhD in 1995 investigating the application of near infrared spectroscopy to measurements of cerebral haemodynamics in adults. She now leads the Near Infrared Spectroscopy Research Group in the Biomedical Optics Research Laboratory at UCL and holds honorary positions at University College London Hospital and the National Hospital for Neurology and Neurosurgery.

Professor Elwell's research focus is on advanced instrumentation development, improved data analysis methods and application of near infrared spectroscopy technologies in the clinical and life sciences. Her current research projects include multimodal monitoring of adult patients with traumatic brain injury, application of optical topography to monitor cerebral haemodynamics in children undergoing cardiothoracic procedures, development of mathematical models of cerebral physiology to aid data interpretation and the investigation of functional activation in the developing brain.

She is an Executive Committee Member of the International Society on Oxygen Transport to Tissue.

Professor Marco Ferrari, University of L'Aquila, Italy (Speaker)

Past appointments and Education:

- Feb 1988-Oct 2000: Associate Professor of Biochemistry, University of L'Aquila
- July 1986-Jan1988: Visiting Assistant, Johns Hopkins University, Baltimore, USA
- Dec 1982-June 1986: Researcher, "Istituto Superiore Sanità", Rome
- July 1977: Doctor in Medicine, I University of Rome

Research topics:

Since the 1980 he has been involved in the study of brain/muscle oxygenation pathophysiology by non-invasive near infrared (NIR) (700-1100 nm) spectroscopy (NIRS) using different techniques (continuous wave, time and frequency resolved methods) he contributed to develop in collaboration with several international labs and industries. The NIRS methods are based on the principle that tissues are relatively transparent to the light in NIR range and that the main chromophores are represented by oxyhaemoglobin and deoxyhaemoglobin. Author of more than 120 peer reviewed publications. The main recent areas of interest are: 1) investigation of the frontal cortex haemodynamic changes upon different cognitive and motor stimuli by non invasive multi-channel functional NIRS; 2) understanding of the mechanism of brain/muscle fatigue during exercise. Editorial board member of the Journal of Near Infrared Spectroscopy, and Journal of Biomedical Optics.

Professor Paul French, Imperial College London, UK (Chair)

Professor Paul French was awarded the BSc Degree in Physics in 1983 and the PhD degree (for work on femtosecond dye lasers) in 1987 from Imperial College London. In 1988 he was a visiting professor at the University of New Mexico working on femtosecond dye lasers and in 1989 he was awarded a Royal Society University Research Fellow at Imperial, where he joined the academic staff in 1994. From 1990 to 1991 he worked on ultrafast all optical switching in optical fibres at AT&T Bell Laboratories, Holmdel, NJ. He is currently a Professor of Physics at Imperial College London and is Head of the Photonics Group. His research has evolved from ultrafast dye and solid-state laser physics to biomedical optics. Today his group develops and applies multidimensional fluorescence imaging technology for molecular cell biology, drug discovery and clinical diagnosis with a strong emphasis on fluorescence lifetime imaging (FLIM) using microscopy, endoscopy and tomography. Paul French is a Fellow of the Institute of Physics, the European Physical Society and the Optical Society of America and holds a Royal Society Wolfson Research Merit Award.

Dr Adam Gibson, University College London, UK (Chair)

Adam Gibson is a medical physicist at University College London. He trained as a hospital physicist and completed a PhD in Electrical Impedance Tomography before joining UCL's Biomedical Optics Research Group. He has developed techniques for 3D optical tomography of head and breast and is currently building up a multimodality imaging research group which aims to develop new methods for generating and analysing novel medical images.

Professor Gorm Greisen, Neonatology, Rigshospitalet and University of Copenhagen, Denmark (Speaker)

Professor of paediatrics and head of neonatology at Rigshospitalet and the University of Copenhagen. Thesis on cerebral blood flow in mechanically ventilated infants 1989. Research in neonatal brain circulation, brain function, brain injury, and neurodevelopmental follow-up. Some experience with health services in developing countries. Some research and writings in clinical and research ethics. Involved in the European Society of Paediatric Research. 200 publications. J-index 31.

Professor Takafumi Hamaoka, Ritsumeikan University, Japan (Speaker)

Takafumi is Professor and deputy director of Sport and Health Science at Ritsumeikan University. He has conducted a research regarding control of muscle oxidative metabolism using near-infrared spectroscopy and proton- and phosphorus-magnetic resonance spectroscopy with Professor Britton Chance in the Department of Biochemistry and Biophysics, University of Pennsylvania in 1990-1991. He has continued muscle research in the department of preventive medicine and public health, Tokyo Medical University in 1991-2002 and National Institute of Fitness and Sports in 2002-2010. He was a member of Editorial Board, Environmental Health Perspectives (NIH, USA) in 1997-2003. He is currently a fellow of American College of Sports Medicine and a member of Executive Board, Japanese Society of Physical Fitness and Sports Medicine. He has received a Research Award, Tokyo Metropolitan Government in 1991, a Best Poster Award, 2nd Congress of Asian Federation of Sports Medicine in 1996, a Young Investigators Award, 1st Congress of European College of Sports Science in 1996, a Best Paper Award, Japanese Society of Applied Physiology in 1999, and a Best Research Award, Japanese Society for Medical and Biological Engineering in 2004. His research expertise is sports medicine, environmental medicine, control of muscle oxidative metabolism, control of muscle hemodynamics, and muscle near-infrared spectroscopy.

Professor Jeremy Hebden, University College London, UK (Organiser and Chair)

After obtaining a PhD in astronomy and spending two years in Arizona exploring high resolution methods for mapping stellar atmospheres, I spent five years at the University of Utah investigating new optical imaging techniques for functional imaging of human tissues. I pioneered the experimental development of time-resolved methods which overcome the blurring effects of scatter. A Wellcome Trust Senior Fellowship enabled me to establish a group at UCL devoted to the development of clinical prototypes for optical imaging of human subjects, with particular emphasis on the study of the premature infant brain at risk of damage resulting from hypoxia-ischaemia. My group has developed a time-resolved instrument for three-dimensional optical tomography, utilising unique source and detector technology. It has been used to produce the first whole-brain images of evoked functional activity in the newborn infant, and this work is now focussed on the study of seizure. In addition, we have built systems for mapping the haemodynamic response in the cortex to sensory stimulation and other cognitive activity, and to acquire EEG measurements simultaneously. I currently hold the appointment of Professor of Biomedical Optics, and was appointed Head of the Department of Medical Physics & Bioengineering at UCL in 2008.

Professor Elizabeth Hillman, Columbia University, USA (Organiser and Speaker)

Elizabeth Hillman PhD is Assistant Professor of Biomedical Engineering and Radiology at Columbia University in the city of New York. She received her PhD in Medical Physics from University College London in 2002, working on the development of time-resolved optical tomography for neonatal brain imaging. Following her PhD Dr Hillman worked for a start-up company in Boston, MA, and then completed post-doctoral training and became junior faculty at Massachusetts General Hospital, Harvard Medical School developing novel high-resolution optical methods for exposed brain imaging. In 2006 she moved to Columbia University to establish her own lab which specializes in using light to capture information from living tissues on length scales from microns to centimeters using techniques including two-photon microscopy, laminar optical tomography, dynamic contrast enhanced molecular imaging and hyperspectral imaging. A particular focus of her research is using these techniques to explore the relationship between neuronal activity and blood flow in the brain. Dr Hillman is an Associate Editor for Biomedical Optics Express, and a Topical Editor for Applied Optics. She is the recipient of NSF CAREER, Human Frontier Science Program and Wallace Coulter Foundation Early Career awards. She has authored 39 peer reviewed articles and over 53 scientific abstracts.

Professor Yoko Hoshi, Tokyo Institute of Psychiatry, Japan (Speaker)

Yoko Hoshi has been a Research Director of Integrated Neuroscience Research Team at Tokyo Institute of Psychiatry since 2000. She is a project leader of "Research on Neural Basis of 'Kansei' and its Visualization" supported by Tokyo Metropolitan Organization for Medical Research. She graduated from School of Medicine Akita University and received a MD degree. She was trained as a pediatrician at Hokkaido University, and then started basic research on NIRS, including the biochemistry of mitochondria, and its application especially to neuroscience at Research Institute of Electronic Science, Hokkaido University in 1988. She received a PhD from School of Medicine Hokkaido University in 1990. Her recent research interests are neural mechanisms of emotion & brain development, and developing new optical techniques.

Dr Aparna Hoskote, Great Ormond Street Hospital for Children NHS Trust & University College London, Institute of Child Health, UK (Panellist)

Dr Aparna Hoskote is a Consultant Paediatric Cardiac Intensivist responsible for the care of the patients on the Cardiac Intensive Care Unit at Great Ormond Street Hospital since 2004. The Cardiac Intensive Care Unit is a quaternary referral centre for children with congenital heart disease before and after congenital heart surgery including heart and heart-lung transplantation, severe cardiac failure due to acquired causes, primary pulmonary hypertension, large airway disease as well as for infants and children with intractable respiratory or cardio-respiratory failure needing ECMO or bridge to heart transplantation on mechanical assist devices.

Dr Hoskote leads on a theme of neuromonitoring, neuroprotection and long-term outcome to improve service delivery and ultimate quality of life. She has established collaboration with well established research groups:- University College London, Medical Physics (Professor Clare Elwell) to study brain and tissue oxygenation by Near Infra-Red Spectroscopy (NIRS) on ECMO as well as multi-site NIRS and optical topography, The Department of Developmental Cognitive Neurosciences, ICH (Prof Vargha-Khadem) looking at hippocampal volumes and memory impairment in TGA and ECMO survivors, University of Leicester and National Perinatology Unit recruiting neonates with hypoxaemic respiratory failure to the multicentre RCT - Neonatal ECMO Study of Temperature (NEST) funded by the British Heart Foundation; and The Hospital for Sick Children, Toronto in a multicentre RCT of hypothermia after cardiac arrest and follow-up neurodevelopmental outcome.

Dr Hoskote's research focus is to establish measures to identify neurological impairment and neurodisability pre and post major cardiac surgery, to study the effect of neuroprotective interventions and outcome and to study cerebral haemodynamics with NIRS as an early marker of brain ischaemia.

Professor Matthias Kohl-Bareis, University of Applied Sciences Koblenz, Germany (Chair)

After finishing his physics course at Berlin university with a thesis on atomic physics, Matthias Kohl-Bareis started with work in medical optics. During his PhD he used optical methods for the detection and therapy of cancer. As a postdoc fellow at University College London with D. Delpy and M. Cope he developed instrumentation and methods of diffuse optical spectroscopy. This was followed by a few years with A. Villringer working on optical brain imaging both in humans and animals at Charité, Humboldt University Berlin. Since 2001 he is professor at RheinAhrCampus, University of Applied Sciences Koblenz, Germany, with interests in optical monitoring of brain and muscle.

Professor Thomas Krucker, Novartis Institutes for BioMedical Research Inc. and the Scripps Research Institute, USA (Speaker)

Thomas Krucker joined the Novartis Institutes for BioMedical Research in 2005 to head up the molecular imaging efforts. He was previously at The Scripps Research Institute in La Jolla (CA) where he remains an Adjunct Professor at the Molecular and Integrative Neurosciences Department. Dr Krucker obtained his PhD in Neuropharmacology from the University of Zürich in Switzerland.

Professor Adam Liebert, Institute of Biocybernetics and Biomedical Engineering, Poland (Panellist)

Adam Liebert received his MSc in fine mechanics from Warsaw University of Technology and PhD in biomedical engineering from the Institute of Biocybernetics and Biomedical Engineering of the Polish Academy of Sciences. In years 2001-2004 he worked at Physikalisch-Technische Bundesanstalt in Berlin as a postdoctoral fellow on development of brain imaging technique based on time-resolved near infrared spectroscopy. Currently he is associated professor and head of the Department of Biophysical Measurements and Imaging of the Institute of Biocybernetics and Biomedical Engineering in Warsaw. His main area of interest is application of near infrared spectroscopy in tissue oxygenation assessment and development of brain perfusion evaluation methodology based on time-resolved measurement of diffusely reflected light during injection of optical contrast agent as well as detection of fluorescence of the exogenous dye circulating in the tissue. He deals also with laser-doppler perfusion measurement and imaging. He developed novel methods of laser-doppler signal processing and tests potential applications of this technique.

Dr Atsushi Maki, Hitachi, Japan (Panellist)

Dr Maki received his MS degree in 1990 and was awarded a PhD in 1997, both in Mechanical Engineering from Keio University in Japan.

Dr Maki currently works for in the Business Incubation Division for Hitachi Ltd. His research interests include optical technology for the measurement of biological tissue and organs, developmental state of human brain functions, mental states of human brain functions and applied brain science.

Awards received include the R & D 100 Awards from MIT press (2002), Okouchi Memorial Prize (2003), Japanese invention award (2004) and the Prize of Science and Technology from the Ministry of Education, Culture, Sports, Science and Technology (2007).

Professor Gunnar Naulaers, University Hospitals Leuven, Belgium (Chair)

- Degree of Medical Doctor at Katholieke Universiteit Leuven in 1990. Postgraduate training in Paediatrics and Neonatology 1990-1997 at the University Hospital Leuven.
- Staff member Neonatal Intensive Care Unit at the department of Paediatrics, University Hospital Leuven since 1997.
- Head of the neonatal intensive care unit, University Hospitals Leuven, since 2007.

Research :

- 2002-2004 : Clinical Doctoral Grant A6/5 – CM. D 11.354, Fund for Scientific Research, Flanders, Belgium.
- 2003 : PhD Doctor in Medical Sciences with the thesis : Non-invasive measurement of the cerebral and splanchnic circulation by near-infrared spectroscopy. Acta Biomedica Lovaniensia 295; 2003
- 2006-2010 : Project for Fund for Scientific Research Flanders ZKB4380 G.0519.06 : Non-invasive measurement of the neonatal cerebral oxygenation and circulation.

- 2010 : Coordinator for Near-Infrared Spectroscopy in the HIP-trial (Management of Hypotension In the Preterm Extremely Low Gestational Age Newborn)
104 international publications ; 18 national publications.
- Promotor of the following PhD Thesis:
 - Joke Vanderhaegen. The effect of physiological and pathophysiological changes on the neonatal cerebral oxygenation as measured by near-infrared spectroscopy. Acta biomedical Lovaniensa 485; 2010
 - Anne Debeer. Antenatal interventions to promote lung maturation and growth in prematurity. Acta Biomedica Lovaniensa 506; 2010
 - Petra Lemmers. The clinical use of near-infrared monitored cerebral oxygen saturation and extraction in the preterm infant. Utrecht. May 2010.

Professor Vasilis Ntziachristos, Technische Universität München and Helmholtz Zentrum München, National Research Centre for Environment and Health, Germany (Speaker)

Vasilis Ntziachristos PhD is a Professor and Chair for Biological Imaging and the director of the Institute for Biological and Medical Imaging at the Technische Universität München and the Helmholtz Zentrum München. Prior to this appointment he has been faculty at Harvard University and the Massachusetts General Hospital. He has received his masters and doctorate degrees from the Bioengineering Department of the University of Pennsylvania and the Diploma on Electrical Engineering from the Aristotle University of Thessaloniki, Greece. His main research interests involve the development of optical methodologies for probing physiological and molecular events in tissues using non-invasive methods.

Professor Hellmuth Obrig, Max Planck Institute for Human Cognitive and Brain Sciences and Bernstein Centre for Computational Neuroscience, German (Speaker)

- 1985-1992 Medical training FU Berlin, Universität Wien, final year in London
- 1993-94 Dept. Neurology, Klinikum Großhadern Ludwig-Maximilians-Universität München
- 1994 Promotion, Dr. med.' Berlin
- 1994-2004 Dept. of Neurology Charité Berlin
- 2001 'Facharzt' (board certified neurologist)
- 2002 'Habilitation' Neurology
- 2004-2008 Senior Registrar Dept. Neurology, Charité, Berlin
- since 04/2008 Head of the Clinic for Cognitive Neurology, Universitätsklinikum Leipzig.

Research areas:

Non-invasive optical imaging in neuroscience and neurology; EEG; neurovascular coupling; stroke; language development; aphasia treatment.

Professor Brian Pogue, Dartmouth College, USA (Speaker)

Brian W Pogue, PhD is Dean of Graduate Studies at Dartmouth College and Professor of Engineering Sciences, Physics & Astronomy, as well as Professor of Surgery at Dartmouth Medical School. He has BSc and MSc degrees in Physics from York University and a PhD in Medical Physics from McMaster University, in Canada. He holds a Research Scientist appointment through the Wellman Center for Photomedicine at the Massachusetts General Hospital for ongoing research into photodynamic therapy imaging and dosimetry. He has published over 300 papers and abstracts in the areas of biomedical optics, diffuse spectral tomography, breast cancer imaging and photodynamic therapy of cancer. His research is funded through two program grants and several individual grants from the National Cancer Institute. He is Deputy Editor for the journal *Optics Letters* and editorial board member for *Medical Physics*, the *Journal of Biomedical Optics*, and the *Journal of Photochemistry and Photobiology B*.

Professor Kenneth Schenkman, University of Washington, USA (Panellist)

Kenneth A Schenkman, MD, PhD, is an Associate Professor of Pediatrics, Anesthesiology and Bioengineering (Adjunct) at the University of Washington. He is an attending critical care physician in the Pediatric Intensive Care Units at Seattle Children's Hospital and at Harborview Medical Center, both in Seattle. After receiving his M.D. from Indiana University he completed a pediatric residency at the Children's Hospital of Pittsburgh where he also served as Chief Resident. He trained in pediatric critical care at Children's Hospital in Seattle and received a PhD in Bioengineering from the University of Washington. He has an active research program developing optical spectroscopic technologies for clinical assessment of cellular oxygenation and mitochondrial function.

Dr Martin Smith, National Hospital for Neurology and Neurosurgery, University College London Hospitals, UK (Speaker)

Martin Smith is Consultant and Honorary Professor in Neuroscience Critical Care, and Director of neurosurgical critical care services, at the National Hospital for Neurology and Neurosurgery, University College London Hospitals. His major clinical and research interests are in the monitoring and management of acute brain injury, including the development and assessment of optical techniques to monitor cerebral haemodynamics, oxygenation and cellular metabolic status at the bedside, and the application of novel biomarkers of brain injury.

Martin is Vice President for Education and Scientific Affairs of the Society of Neuroscience in Anesthesia and Critical Care and Past President of the Neuroanaesthesia Society of Great Britain and Ireland. He is a member of the editorial board of the *Journal of Neurosurgical Anesthesiology*, guest editor of *Anesthesia and Analgesia* and editor of *Continuing Education in Anaesthesia, Critical Care and Pain*. He is the training programme director for the Academic Clinical Fellows in Anaesthesia and Intensive Care Medicine at University College London and head of the Respiratory, Anaesthesia and Critical Care Theme of the UCL/UCLH Comprehensive Biomedical Research Centre.

Professor Babs Soller, University of Massachusetts, USA (Panellist)

Dr Babs Soller received her PhD in Physical Chemistry from Princeton University, where she studied the spectroscopy of transition metal ions. Dr Soller is currently Professor of Anesthesiology at the University of Massachusetts Medical School. Her lab is exploring the application of near infrared spectroscopy for the continuous, noninvasive measurement of muscle oxygen, pH and blood hematocrit. The lab is also actively involved in investigating the clinical application of NIRS for the monitoring and care of critically ill patients and application in monitoring the deconditioning of astronauts in space. Dr Soller recently founded Reflectance Medical Inc. to commercialize the NIRS hardware and software invented by her laboratory. Dr Soller serves as Reflectance Medical's Chief Scientific Officer.

Dr Ilias Tachtsidis, University College London, UK

Ilias is a Wellcome Trust fellow based in the biomedical optics research laboratory (BORL) in medical physics and bioengineering in UCL.

His educational background is in Electronics Engineering and Medical Physics. Ilias joined BORL to study for his PhD in 2001 under the guidance of Prof. Dave Delpy. His main research interests are both in the development and use of optical techniques in medicine. Currently Ilias work is centred on the development of the next generation of brain tissue optical spectrometers and their clinical application in both adults and neonates.

Professor Gentaro Taga, The University of Tokyo, Japan (Speaker)

Gentaro Taga received a bachelor's degree in Pharmaceutical Sciences from University of Tokyo in 1989. He received a PhD in Pharmaceutical Sciences from University of Tokyo in 1994 on a modeling study of the neuro-musulo-skeletal system for human locomotion under supervisor Prof. Hiroshi Shimizu. From 1994 to 1995, he was a JSPS postdoctoral fellow at Professor Masatoshi Murase's biophysics laboratory, Yukawa Institute for Theoretical Physics, Kyoto University and at Professor Jim Collins's laboratory, Neuromuscular Research Center, Boston University. In 1995, as an assistant professor he joined Prof. Kunihiko Kaneko's research group of complex systems, Department of Pure & Applied Sciences, University of Tokyo. In 1998 he stayed at Prof. Shinsuke Shimojo's psychophysics laboratory, California Institute of Technology as a HFSP short-term fellow. Since 2000, he has been a faculty member of Graduate School of Education, University of Tokyo. He was a principal investigator of PRESTO (1999-2002), SORST(2002-2003), and CREST(2003-2009) of Japan Science and Technology Agency and led research projects on developmental brain sciences using a novel neuroimaging technique. Currently, he is a professor at Graduate School of Education, University of Tokyo.

Professor Bruce Tromberg, University of California, USA (Speaker and Chair)

Dr Tromberg is the Director of the Beckman Laser Institute and Medical Clinic (BLI) at the University of California, Irvine (UCI) and principal investigator of the Laser Microbeam and Medical Program (LAMMP), an NIH National Biomedical Technology Center. He is a Professor in the departments of Biomedical Engineering and Surgery and co-leads the Onco-imaging and Spectroscopy Program in UCI's Chao Family Comprehensive Cancer Center. Dr Tromberg completed a Hewitt Foundation postdoctoral fellowship in Photomedicine at the BLI in 1989 and has been a member of the BLI faculty since 1990. He received a BA in Chemistry from Vanderbilt University and a PhD in Chemistry from the University of Tennessee as a Department of Energy Fellow at the Oak Ridge National Lab. His research interests are in Biophotonics and Biomedical Optics, including diffuse optics, non-linear microscopy, and photodynamic therapy.

Dr Heidrun Wabnitz, Physikalisch-Technische Bundesanstalt, Germany (Panellist)

Heidrun Wabnitz received her diploma in physics (1979) and PhD (1982) from the University of Jena, Germany. Her project was focused on the investigation of orientational relaxation of dye molecules in solution by methods of picosecond spectroscopy. Following a postgraduate fellowship at the University and at the Institute of Physics of the Belorussian Academy of Sciences in Minsk, she continued her work at University of Jena in the fields of picosecond spectroscopy of molecules and time-resolved laser scanning microscopy. In 1991 she joined the Department of Biomedical Optics of Physikalisch-Technische Bundesanstalt in Berlin. Her research interests include propagation of short light pulses in biological tissues, optical mammography, and are currently focused on time-resolved near-infrared spectroscopy of the human brain. She is involved in instrumental and methodological developments as well as their application in clinical studies and leads related projects.

Professor Lihong Wang, University of Washington, USA (Speaker)

Lihong Wang earned his PhD degree at Rice University. He holds the Gene Beare Distinguished Professorship at Washington University. His textbook entitled Biomedical Optics won the Goodman Book Writing Award. He edited the first book on photoacoustic tomography. He has published >220 journal articles and delivered >250 invited talks. He is a fellow of the AIMBE, IEEE, OSA, and SPIE. He is the Editor-in-Chief of the Journal of Biomedical Optics. He chairs the annual conference on Photons plus Ultrasound, and chaired the 2010 Gordon Conference on Lasers in Medicine and Biology and the 2010 OSA Topical Meeting on Biomedical Optics. He is a chartered member on an NIH study section. He serves as the founding chairs of the scientific advisory boards for two companies commercializing photoacoustic tomography. He received FIRST and CAREER awards. He has received 26 research grants as PI with a budget of \$28M. He invented or discovered

dark-field confocal photoacoustic microscopy (PAM), optical-resolution PAM, photoacoustic Doppler sensing, photoacoustic reporter-gene imaging, microwave-induced thermoacoustic tomography, exact reconstruction algorithms for photoacoustic tomography, frequency-swept ultrasound-modulated optical tomography, Mueller-matrix optical coherence tomography, optical coherence computed tomography, and oblique-incidence reflectometry. His Monte Carlo model of photon transport in scattering media is used worldwide.

Professor Martin Wolf, University Hospital Zurich, Switzerland (Chair)

PD Dr Martin Wolf received his MS degree in electrical engineering from the Swiss Federal Institute of Technology (ETHZ) in Zurich Switzerland in 1990. His focus was on biomedical and power engineering. During his PhD (ETHZ 1997) he specialized in biomedical optics, i.e. near infrared spectroscopy to investigate tissue oxygenation. As a postdoctoral research associate he worked at the Clinic for Neonatology, University Hospital Zurich until 1999, when he joined the Laboratory for Fluorescence Dynamics at the University of Illinois at Urbana-Champaign. He developed imaging methods to non-invasively study hemodynamics and oxygenation of the brain and muscle. Since 2002 he heads the Biomedical Optics Research Laboratory at the Clinic of Neonatology, University Hospital Zurich, where he currently expands the research in biomedical optics to many clinical fields. In 2004 he became lecturer of the University Zurich and in 2009 at the ETHZ. He is academic affiliate of the Biomedical Engineering Cluster, Switzerland's first Masters Program in Biomedical Engineering, and member of the Center for Imaging Sciences and Technologies and the Neuroscience Center Zurich, all at ETH.

Professor Arjun Yodh, University of Pennsylvania, USA (Speaker)

Arjun G Yodh is the *James M. Skinner Professor of Science* and the *Director* of the Laboratory for Research on the Structure of Matter at the University of Pennsylvania, Philadelphia, PA. His home department is Physics & Astronomy, and he holds a secondary appointment in the Department of Radiation Oncology in the Medical School. Yodh received his BSc from Cornell University and his PhD from Harvard University. He joined the UPenn faculty in 1988 following a two-year postdoctoral fellowship at AT&T Bell Laboratories. His current interests span condensed matter physics, biomedical optics & biophysics, and the optical sciences. Yodh's biomedical optics laboratory explores a variety of issues ranging from fundamental studies of light transport, image reconstruction and optical technology development, to identification of relevant clinical problems. Current research is using diffuse optical tools for functional imaging/monitoring of hemodynamics in brain, breast & muscle, for monitoring tumor responses during cancer therapy, and for investigation of new dosimetry schemes in photodynamic therapy.

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