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Celebrating the Exponential Growth of Optoacoustic/Photoacoustic Imaging

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We are pleased to introduce the contributions to this JBO Special Section entitled “Celebrating the Exponential Growth of Biomedical Optoacoustic/Photoacoustic Imaging.” This title was chosen to reflect the strong growth of the field over the last two and a half decades. The diversity of papers in this special section bears witness to this, with contributions that encompass numerical modelling, advanced instrumentation, functional imaging, clinical translation, and novel biomedical applications.

Sharma et al. consider which near infrared (NIR) wavelengths provide the greatest penetration depth by undertaking Monte Carlo simulations of light transport and experimental studies. They examine the use of 800-nm and 1064-nm, wavelengths that are commonly used in deep tissue photoacoustic tomography. For the same incident fluence, it is reported that 800-nm provides greater penetration depth than 1064-nm, due to the higher effective attenuation coefficient of the latter wavelength. However, at 1064-nm the skin MPE is significantly higher than at 800-nm. A higher pulse energy can therefore be safely delivered to the surface of the skin, which more than compensates for the higher effective attenuation coefficient at 1064-nm, enabling a greater penetration depth to be achieved at this wavelength. Akhlaghi et al. undertake a comprehensive numerical simulation study with the aim of assessing the extent to which image quality metrics such as spatial resolution, SNR and penetration depth can be accurately predicted and used to identify optimum imaging parameters and inform instrument design. To achieve this, a Monte Carlo model of light transport was coupled with an acoustic propagation model to simulate photoacoustic images and the latter validated by comparison with experimental data. It was concluded that predicting image fidelity is achievable

but a quantitatively accurate prediction of SNR and penetration depth is more challenging due to the difficulties in fully accounting for the transducer response in the model.

The measurement of blood oxygen saturation (sO_2) using spectroscopic methods confers optoacoustic tomography with an important functional imaging capability. Three papers address this topic. Gehrung et al. describe an experimental arrangement for evaluating sO_2 measurement methods. The system comprises a vessel phantom perfused with blood, the oxygenation of which can be adjusted and monitored via an inline pO_2 sensor and a spectrometer to estimate the ground truth sO_2 . A similar system but comprising two independent perfusion circuits each with online pH and temperature sensors to facilitate the conversion of pO_2 to sO_2 is described by Zalev et al. The system was used to evaluate a statistical mapping approach for coding optoacoustic images with a relative rather than absolute measure of sO_2 . Simple linear spectroscopic inversions are often used to estimate sO_2 from multiwavelength photoacoustic images. However, their quantitative accuracy is questionable as they implicitly ignore spectral coloring, a known confounding factor. Through numerical simulations using a simple digital blood vessel phantom, Hochuli et al. investigate whether, by judicious choice of wavelength, spectral coloring can be minimized to the extent that accurate absolute sO_2 estimates can be obtained using a linear inversion. It is concluded that, while it may be possible, achieving even a modest degree of quantitative accuracy under the most benign conditions imaginable (e.g., perfectly reconstructed images) is challenging. With accuracy further dependent upon the instrumentation, image reconstruction process, and multiple experimental parameters, it is suggested that considerable caution should be exercised before applying linear inversions to *in vivo* data.

Several new imaging instruments and devices are described. Huynh et al. describe a photoacoustic analogue of the well known single pixel optical camera. This comprises

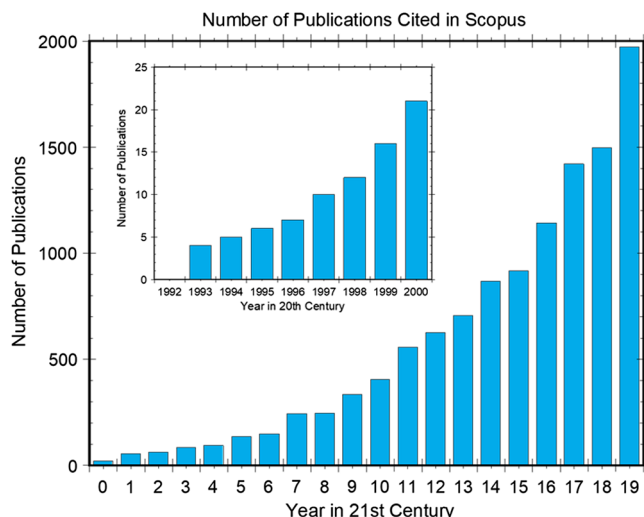


Fig. 1 Number of publications cited in Scopus based on search of the key words directly related to the biomedical depth-resolved optoacoustic/photoacoustic imaging.

a Fabry–Pérot (FP) polymer film ultrasound sensor that is illuminated with a widefield beam. The field reflected from the FP sensor is directed on to a DMD and then focused on to a single photodiode. By applying different patterns to the DMD and recording the output of the photodiode, a 3D photoacoustic image can be reconstructed within a compressed sensing framework. Images can then be reconstructed from fewer measurements than conventional point-by-point scanning techniques enabling faster image acquisition. [Dadkhah and Jiao](#) describe a multimodal microscopy system that integrates OCT, optical resolution photoacoustic microscopy and confocal microscopy. The distinctive feature of this work is a combined optical and mechanical system that enables large (cm-scale) fields of view and an OCT-guided dynamic focusing method that compensates for variation in surface topology. [Sathiyamoorthy and Kolios](#) describe a noncontact photoacoustic microscopy system that is reminiscent of early gas cell based photoacoustic instruments but with several notable differences. These include the use of a novel resonator design to enhance sensitivity. Additionally, the device configuration permits operation in backward mode whereby the rear surface of the sample is illuminated. This enables a tightly focused excitation beam to be used to achieve high resolution and also allows a conventional optical microscopy image to be acquired. It is suggested that the device could be inexpensively integrated with conventional microscopes to provide complementary absorption based photoacoustic contrast.

Clinical applications and translational research endeavours are represented by several papers. Breast cancer imaging, one of the earliest proposed applications of optoacoustic

tomography, is discussed in three papers. [Nyayapathi and Xia](#) provide a mini-review of the topic encompassing an overview of different imaging instruments and the relationship between breast tumor physiology and the parameters that can be gleaned from optoacoustic images. [Schoustra et al.](#) report a new embodiment of the Twente photoacoustic mammoscope that comprises a rotating assembly of multiple arc shaped detector arrays interleaved with optical fibres to deliver the excitation light and *in vivo* evaluation in healthy volunteers. The manuscript by [Zalev et al.](#) discussed earlier, although focussed on a method for estimating relative sO_2 , is set within the context of improving the differentiation between benign and malignant breast lesions via the provision of functional information that relates to tumor oxygenation.

[Das and Pramanik](#) investigate whether photoacoustic imaging can be used to characterise blood clots and monitor them during sonothrombolysis. Using a combined ultrasound and photoacoustic imaging system, the progression of the dissolution of clots and their final status are monitored via the changes revealed by both modalities. Clinical translation of this technique could be used to inform the treatment parameters of not only the sonothrombolysis procedure but also concurrent or subsequent clot dissolving drug therapy. [Kempinski et al.](#) describe a study in which swine blood vessels in the liver and pancreas are visualised *in vivo* following a laparotomy in order to assess the potential of photoacoustic guided abdominal organ surgery. In addition, they consider the important topic of defining laser safety limits for endoscopic use. [Yang et al.](#) describe a pilot study in which co-registered ultrasound and photoacoustic images of *ex vivo* samples of normal and malignant human colorectal tissues were acquired. By extracting metrics related to total haemoglobin concentration and the acoustic spectra of the photoacoustic and ultrasound signals, qualitative and quantitative differences between tumors and normal tissue are reported, suggesting photoacoustic imaging could play a role in the clinical assessment of colorectal cancer. Continuing the theme of cancer detection, [Sun et al.](#) report a new contrast agent based on glycol-chitosan-coated gold nanoparticles and evaluate its uptake in breast cancer cells. Compared to PEGylated gold nanoparticles, improved cellular uptake was observed resulting in the emission of strong tumor cell-specific photoacoustic signals.

We are indebted to the contributors of this special section, the reviewers for ensuring the high quality of the accepted papers and JBO editorial and production staff for their assistance. We hope that this special section represents a useful contribution to the field of optoacoustic/photoacoustic imaging science and technology, and will contribute to its future development and growth.