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Photoacoustic Imaging and Sensing

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Photoacoustic imaging and sensing represent exciting and rapidly growing areas of research that hold great promise for addressing important biomedical applications. These methods are hybrid in nature, employing two distinct forms of energy. They employ a laser beam to illuminate biological tissue, which results in a small but rapid temperature rise. Under certain conditions, this can result in emission of ultrasonic waves. This physical process was reported by Alexander Graham Bell in the 1880s and is known as the photoacoustic effect. The photoacoustically induced wavefield data contain coded information about the distribution of absorbed optical energy within the tissue and are recorded by use of ultrasonic transducers placed outside of the tissue. The goal of photoacoustic imaging systems is to decode this information by producing images that depict this distribution.

A key feature of photoacoustic imaging methods, also known as optoacoustic imaging methods, is that they exploit optical contrast but employ ultrasonic detection principles. This results in a hybrid imaging system that can produce high-contrast images that possess high spatial resolution. Photoacoustic imaging systems often permit for imaging of much deeper structures than can be achieved by pure optical methods. While pure ultrasonic imaging methods can image deep structures at high spatial resolution, the image contrast based on differences in mechanical properties of tissue is typically much weaker than optical-based contrast for soft tissue. Photoacoustic imaging methods therefore combine the strengths of optical and ultrasonic imaging methods, while circumventing their limitations.

Photoacoustic imaging systems can be categorized as being computed tomography or scanning-based. In the former implementation, known as photoacoustic computed tomography (PACT), an image reconstruction algorithm is employed to produce a two- or three-dimensional estimate of the absorbed optical energy density, or related quantity, from knowledge of the recorded ultrasonic waves. A fixed transducer array can be employed to record these data quickly, thereby eliminating the need for any mechanical scanning. Dedicated PACT imaging systems are being currently investigated by several groups for small animal imaging applications and human breast cancer detection and management. On the other hand, in scanning-based photoacoustic imaging methods, the photoacoustic wavefields are detected by use of a focused ultrasonic transducer to form a

depth-resolved one-dimensional image directly. By scanning the transducer over a two-dimensional surface, a three-dimensional image can be obtained. While scanning can result in increased data-acquisition times as compared to PACT systems that employ fixed arrays, it can be employed with high-bandwidth transducers and small scanning step sizes to achieve micron-scale spatial resolution, or better, which facilitates photoacoustic microscopy applications. Both PACT and scanning-based methods can be implemented in spectroscopic mode and are able to provide functional imaging of physiological parameters. Such parameters include the concentration and oxygen saturation of hemoglobin and molecular imaging of biomarkers and gene expression products.

This special section of JBO contains manuscripts that report important findings on a variety of topics at the forefront of photoacoustic imaging and sensing research. These topics include technology and instrument development, PACT image reconstruction and image formation in scanning-based systems, basic imaging physics, and biomedical applications or translation of photoacoustic imaging clinical applications. In addition, Cox et al. provide a comprehensive review of the important topic of quantitative spectroscopic photoacoustic methods, which are key to unlocking the functional and molecular imaging capability of the technique.

We are confident that these manuscripts will be of interest to many researchers in the biophotonics community, particularly those who have been working in the area of photoacoustics. We hope that this special section will foster the continued growth of the field of photoacoustic imaging and sensing by exposing the broader biophotonics community to its current research avenues. Finally, we would like to thank all of the authors who contributed to this special section, as well as the reviewers whose hard work ensured its high quality.

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Special Section Guest Editors