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introduction to the feature issue

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Advances in Technology and Applications of Optical Sensing and Imaging for Biomedicine: introduction to the feature issue

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Abstract: This feature issue of Biomedical Optics Express, titled "Advances in Technology and Applications of Optical Sensing and Imaging for Biomedicine," presents a curated collection of 21 original research articles that highlight recent innovations at the intersection of optical engineering, biomedical imaging, and clinical application. The contributions span six major areas: microscopy (5), multimodal imaging (1), optical biosensors (4), optical coherence tomography (7), photoacoustic imaging and spectroscopy (3), and tissue optics and spectroscopy (1). Collectively, these works demonstrate progress in developing high-resolution, label-free, and real-time optical platforms for disease detection, functional imaging, therapy monitoring, and point-of-care diagnostics. By integrating advances in hardware design, computational imaging, and translational research, this issue reflects the growing impact of optical technologies on personalized and precision medicine. We hope this collection inspires continued interdisciplinary collaboration and innovation across the biomedical optics community.

1. Introduction

Optical sensing and imaging technologies are now crucial in biomedical research and clinical diagnostics, providing tools with high spatial and temporal resolution, non-invasive nature, real-time feedback, and label-free analysis. These are the key features of a broad range of applications—ranging from molecular diagnostics and tissue characterization to therapy guidance and monitoring of health. As technological and computing advances continue to develop at the crossroads of photonics, bioengineering, and data science, the biomedical optics field is rapidly evolving in terms of both fundamental knowledge and translational development.

This special issue of Biomedical Optics Express, entitled 'Advances in Technology and Applications of Optical Sensing and Imaging for Biomedicine', features a set of 21 high-quality papers that demonstrate the richness and ongoing innovation of the field. Contributions are made in six thematic areas.

Five articles in this issue focus on advances in microscopy, showcasing innovations across system design, imaging contrast, and biomedical application. Highlights include a deep-learning-based autofocus method for whole slide imaging, a 3D-printed fluorescence microscope capable of studying cell responses to high-power radiofrequency exposure, and an insulated cryofixation and cryo-micro-optical sectioning tomography pipeline for high-resolution, label-free metabolic imaging of whole kidney. Additional contributions introduce a compact Bessel light-sheet platform for live zebrafish imaging and demonstrate the diagnostic value of multiphoton fluorescence lifetime imaging microscopy for rare skin disorders. Together, these studies illustrate the expanding role of microscopy in delivering detailed structural and functional insights across diverse biological contexts [1–5].

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One article on multimodal imaging introduces a compact fiber-based system combining shortwave infrared reflectance and Raman spectroscopy for non-invasive skin cancer diagnosis. By integrating structural and molecular analysis in a single probe, the system accurately distinguishes benign from malignant lesions in vivo without contrast agents, highlighting its potential for rapid, label-free clinical assessment [6].

Four articles focus on optical biosensors, showcasing cutting-edge platforms for rapid, label-free detection in clinical biomarkers and environmental targets. These include a machine learning-assisted surface-enhanced Raman scattering (SERS) system for oral cancer diagnosis, a dual-frequency microfluidic impedance cytometer for white blood cell profiling, a fiber-optic interferometric glucose sensor based on hydrogel response, and a recombinase polymerase amplification (RPA)-terahertz spectroscopy approach for ultrasensitive microbial detection. Together, these contributions highlight the growing precision, speed, and adaptability of optical biosensors in real-world diagnostics [7–10].

Seven papers address advancements in optical coherence tomography (OCT), spanning innovations in hardware, image processing, and clinical application. Highlights include visible-light OCT for animal retinal imaging, deep-learning models for 3D retinal lesion segmentation, motion artifact correction for handheld imaging, and polarization-sensitive OCT for skin tissue classification. Additional work presents cost-efficient swept-source OCT systems and techniques for multi-task segmentation and speckle noise reduction, reinforcing OCT's expanding role in high-resolution, non-invasive imaging [11–17].

Three articles advance photoacoustic imaging (PAI) and spectroscopy by developing methods to achieve quantitative molecular mapping with high fidelity. Innovations include photoacoustic-ultrasound dual-mode imaging using sparse decomposition, non-negative sparse reconstruction for brain tumor hemoglobin mapping, and deep-learning-driven spectral unmixing to resolve multiple chromophores. These techniques push PAI toward more accurate, quantitative, and biologically informative imaging at depth [18–20].

One article in tissue optics and spectroscopy introduces a frequency-domain near-infrared spectroscopy (NIRS) method enhanced by mechanical perturbation to improve cerebral oxygenation monitoring. By inducing hemodynamic oscillations and extracting oxygenation changes with heightened sensitivity, this approach presents a promising pathway for functional brain imaging using compact, label-free optical devices [21].

Collectively, this collection highlights the overlap of optical system design, signal processing innovation, and clinical expertise. Through a combination of innovations in hardware, algorithm, and biomedical use, this feature collection documents the momentum of a field headed in the direction of ever-more precise, accessible, and transformative diagnostic and sensing technologies. We hope the collection will help promote the future interdisciplinary research in medical photonics and continue to spur development in the translation of optical technologies into practical solutions in medicine and healthcare.

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