

Neurophotonics

Neurophotonics.SPIEDigitalLibrary.org

Advances in Retinal Imaging

Ji Yi
Alfredo Dubra
Sina Farsiu

Advances in Retinal Imaging

Ji Yi, PhD

Boston University
E-mail: jiyi@bu.edu

Alfredo Dubra, PhD

Stanford University
E-mail: adubra@stanford.edu

Sina Farsiu, PhD

Duke University
E-mail: sina.farsiu@duke.edu

The retina is a peripheral part of the central nerve system (CNS) and shares many similarities with the cerebral cortex. They both have layered anatomy, the same types of functional elements and neurotransmitters, and similar vascular organization and blood-tissue barriers. With far fewer neuronal cell types and simpler anatomical structures, the retina is an excellent target for studying neural circuitry and neurovascular coupling. Meanwhile, approximately 80 percent of information from the outside world is processed as visual perception,¹ and retina-related blindness is a significant disabling condition that poses a huge healthcare burden worldwide.² Because the human retina is directly accessible by light, optical retinal imaging is a unique field that brings together biology, engineering, data science, and clinical applications, creating a highly dynamic, sustainable, and vibrant ecosystem. This special section of *Neurophotonics* Volume 6, Issue 4, testifies to such an ecosystem, encompassing a broad range of topics in instrumentation, methods, and applications for advanced retinal imaging.

Innovation of instrumentation and methods remains the major driving force in retinal imaging. [J. D. Malone et al.](#) developed a handheld spectrally encoded coherence tomography and reflectometry (SECTR) system for high-speed, wide-field optical coherence tomography (OCT) and OCT angiography (OCTA). The device addresses the clinical needs for bedridden or pediatric patients, or patients with physical disabilities that impair movement. Adaptive optics scanning laser ophthalmoscope (AOSLO) is another major retinal imaging modality, achieving diffraction-limited resolutions by correcting the wavefront aberration of the ocular optics. [Y. Wang et al.](#) reported a clinical AOSLO device using a low-cost bimorph deformable mirror. Such efforts to make AOSLO cheaper and more accessible facilitate more clinical applications. In improving OCT image quality, [P. Zhang et al.](#) implemented a temporal-averaging method to effectively reduce inherent speckles. The resulting images revealed fine retinal structures in mouse, such as retinal ganglion cell body, and subcellular structure in photoreceptors, which would otherwise be difficult to capture with the speckle present.

Visible light OCT (vis-OCT) continues to be a fast-developing direction. The short visible light wavelength warrants

high axial and transverse resolutions, and reduction of the speckle noise further enhances the image contrast and quality ([I. Robinoff et al.](#)). The strong spectral contrast of hemoglobin in visible wavelength allows the quantification of hemoglobin oxygen saturation (sO_2), and the inner retinal oxygen metabolism when combining Doppler blood flow measurements ([S. Pi et al.](#)). Contrasting vis-OCT to simultaneous near-infrared OCT, elastic scattering spectroscopic analysis could potentially detect ultrastructural changes prior to the changes in the tissue morphology ([W. Song et al.](#)).

Beyond imaging the retinal structures, several methods in this special section aim to quantify various functionalities. Using an ultrasonic stimuli, optical coherence elastography (OCE) is reported to measure Young's modulus at the optical nerve head *ex vivo* ([Z. Du et al.](#)), a potentially useful tool in studying glaucoma pathology. An interesting study by [C. Stiebing et al.](#) demonstrated the feasibility of non-resonant Raman scattering in isolated human retina under an irradiant power complying with laser safety requirements. If proven in living retina in the future, this method can provide valuable molecular contrasts complementing other structural imaging modalities. Retinal oxygen metabolism is also reported as an important function indicator (by [S. Pi et al.](#) and by [W. Song et al.](#)), given the retina is one of the most energy-demanding tissues in the whole human body.

The rapid development of imaging methods calls for significant efforts in data processing, particularly to develop quantitative imaging metrics for clinical applications. [A. Camino et al.](#) reported an algorithm to quantify the "focal perfusion loss" (FPL) area in choriocapillaris and found correlation between FPL, the capillary density, and age-related macular degeneration (AMD). [E. Arthur et al.](#) quantified the fractal distribution of the retinal circulations and found that reduced vascular branching complexity is associated with cognitive impairment. We also witness a rapid adaptation of deep learning (DL) algorithms in retinal imaging data. An example in this special section is the use of a DL network to provide better quality control and filter out ungradable OCT volumes in clinics ([A. R. Ran et al.](#)), rather than simple signal strength provided in commercial devices.

Finally, we emphasize that clinical applications are, and will continue to be, the major motivation for technical innovation and development. Three major retina-related blinding diseases (i.e., glaucoma, AMD, and diabetic retinopathy) together affect more than 12 million people in United States

© The Authors. Published by SPIE under a Creative Commons Attribution 4.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI.

of America alone, and are expected to double in 2050 according to the National Eye Institute.³ Among the eleven papers in this special section, five present preclinical or clinical studies covering retinal conditions such as ocular hypertension, early optic neuropathy, AMD, and retinitis pigmentosa. An interesting study uses the retina as an easy accessible surrogate for detection of dementia (E. Arthur et al.). With the increasing prevalence of dementia (e.g., Alzheimer's disease), we should expect more studies to explore specific retinal imaging markers for early detection of neurodegenerative disorders in the future.

In summary, clinical applications in retina-related conditions motivate technical innovations that in turn can shed light into biology and pathology. This relation creates a fast-

evolving yet sustainable system across multiple disciplines that collectively will broadly benefit the scientific community, clinical practices, and individual health.

References

1. C. Haupt and A. B. Huber, "How axons see their way—axonal guidance in the visual system," *Frontiers in Bioscience* **13**, 3136–3149 (2008).
2. M. D. Pascolini and S. P. Mariotti, "Global estimates of visual impairment: 2010," *Brit. Jnl. Ophthalmology* **96**, 614–618 (2012).
3. National Eye Institute, "Eye health data and statistics," 2012, U.S. National Institutes of Health, <https://www.nei.nih.gov/learn-about-eye-health/resources-for-health-educators/eye-health-data-and-statistics>.