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OCT with Tunable Focus - Towards Quantification of Ocular Opacifications

Ireneusz Grulkowski*[a], Pablo Artal[b]

[a]Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, ul. Grudziadzka 5, 87-100 Toruń, Poland
[b]Laboratorio de Óptica, Universidad de Murcia, Campus de Espinardo, E-30100, Murcia, Spain
[#]corresponding author email: igrulkowski@fizyka.umk.pl
**Presenting author*

1. Introduction

Intraocular light scattering affects the contrast of the image created on the retina thus reducing the vision quality. Although one can consider the ocular components transparent, the microstructural changes (that are associated with aging or other factors) lead to the increase in intraocular light scattering. Therefore, the opacification of ocular structures is associated with vision-affecting diseases such as corneal dystrophies, crystalline lens cataracts, vitreous floaters etc.

Optical coherence tomography (OCT) is a non-invasive imaging modality enabling generation of micrometer resolution, two-dimensional (2-D) cross-sectional images and three-dimensional (3-D) volumetric data presenting internal structure of optically scattering tissues. OCT detects light that is back-scattered / back-reflected at the optical inhomogeneitites within the ocular structures. Due to its high sensitivity, OCT enables detection of ultralow scattered light levels obtained from weakly scattering tissues such as the vitreous body.

As any optical imaging modality, OCT requires light to penetrate the tissue in order to generate the image. Therefore, design of efficient light delivery scenario is critical to extract information on the internal structure of the object. In this talk, we will present different approaches to increase the performance of OCT systems in terms of their ability to visualize weakly scattering structures of the eye. In particular, dynamic control of the optical beam focus allows for OCT image enhancement. In this paper, we will demonstrate a review of our studies on in-vivo enhanced three-dimensional visualization of vitreous and lens opacities in normal subjects and cataract patients of different ages using a swept source OCT.

2. Methods and results

The SS-OCT system was deployed to the Laboratory of Optics at the University of Murcia, Spain. The instrument operated at the central wavelength of 1050 nm. The system utilized a short external cavity wavelength tunable laser technology operating at the speed of 50 kA-scans/second, and it was optimized to perform crystalline lens imaging and vitreous imaging with high sensitivity. Volumetric images were used to effectively map the opacities and to generate en-face projection images of opacities. Different configurations of the interface with focus-tunable optics have been developed. Anterior segment imaging combined with focus tuning was realized by placing the electrically tunable lens (ETL) as the objective lens, and focus tuning enabled enhancement of the signal. What is more, the ETL was placed just before the beam hits the galvanometric scanners in the retinal mode. This enabled slight tuning of the effective focus in the retinal plane, which allowed for high-sensitive visualization of vitreo-retinal interface (Fig. 1).

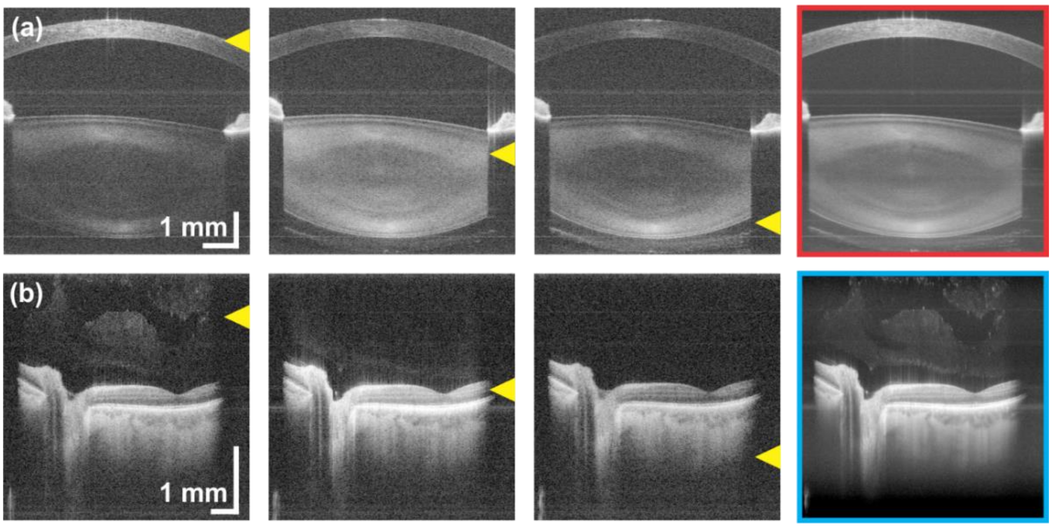

Fig. 1. SS-OCT imaging of the anterior segment (a) and the retina (b) with tunable focus. The composite images for both configurations generated by focus stacking are shown in the right column. The change in image quality for different current values of the ETL is demonstrated. Position of focus indicated with yellow arrows.

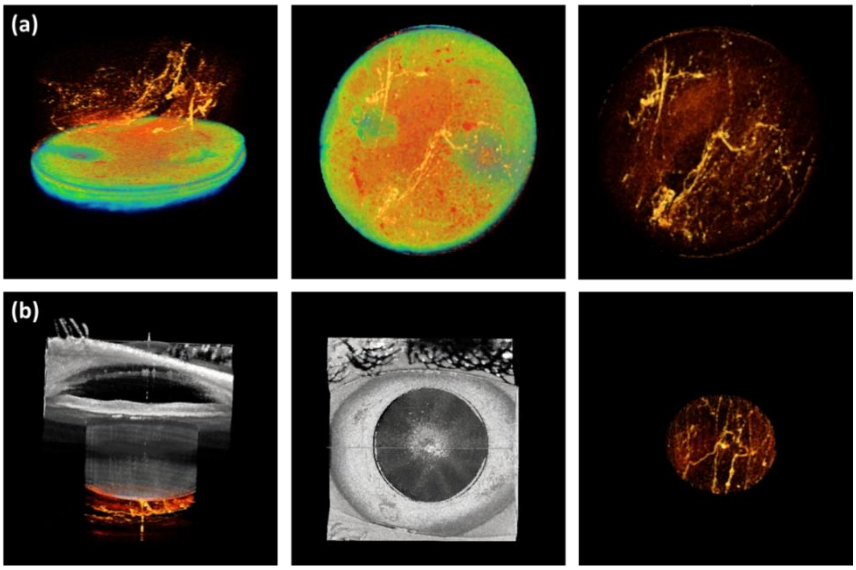

Fig. 2. Enhanced 3-D visualization of anterior (a) and posterior (b) vitreous opacifications in 42-yo subject using SS-OCT with tunable focus. Rendering of volumetric data set, en-face image, and maximum intensity projection (MIP)

The results demonstrated inhomogeneity of optical properties of the crystalline lens. Organization of the fiber cells in the lens resulted in the visualization of lenticular sutures and optical signal discontinuity zones in healthy subjects. Imaging of cataract patients revealed the changes in the transparency of the crystalline lens showing lens micro- and macro-scale features related to cataract such as cortical spokes, water clefts and enhanced scattering in the lens nucleus. On the other hand, vitreous imaging with SS-OCT allowed for visualization of gel vitreous, liquefied lacunae, Berger's space, retrolental laminae and fibrous opacifications. Quantitative analysis of light scattering was performed to describe the transparency and homogeneity of ocular structures. Regression analysis showed statistically significant correlations of introduced biomarkers with the age.

The proposed imaging platform can be a new-generation ophthalmic diagnostic tool in the fundamental studies as well as for objective clinical evaluation and management of eye diseases.

3. References

[1] Grulkowski I. et al,. "Volumetric macro- and micro-scale assessment of crystalline lens opacities in cataract patients using long-depth-range swept source optical coherence tomography," Biomed. Opt. Express 3821-3833 (2018).

[2] Grulkowski I. et al., "Swept source optical coherence tomography and tunable lens technology for comprehensive imaging and biometry of the whole eye," Optica 52-59 (2018).

[3] Gupta A. et al., "In vivo SS-OCT imaging of crystalline lens sutures," Biomed. Opt. Express 5388-5400 (2020).

[4] Gupta A. et al., "Age-related changes in geometry and transparency of human crystalline lens revealed by optical signal discontinuity zones in swept-source OCT images," Eye Vis. 46 (2023)