# In vivo imaging of vitreous opacities with full-eye-length SS-OCT

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Transparency of ocular structures affects contrast in the retinal image and has an impact on visual quality [1]. The most common opacities form in the crystalline lens of aging eye, which result in cataract formation [2-4]. However, visual function can be also altered by the opacities in the vitreous body – a connective tissue forming a gel-like structure made of water, collagen fibers and hyaluronan [5-7]. Optical imaging of vitreous is challenging due to its transparency [8,9]. Whole vitreous imaging *in vivo* can be performed using ultrasound but the resolution of the images is limited. Other techniques used for *in vivo* or *ex vivo* imaging of the vitreous body include dark-field slit microscopy, slit-lamp biomicroscopy, scanning laser ophthalmoscopy and magnetic resonance imaging [6,10,11].

Optical coherence tomography (OCT) is a non-invasive imaging modality generating micrometer resolution, two-dimensional (2-D) cross-sectional images and three-dimensional (3-D) volumetric data on the internal structure of optically scattering and reflective tissues. In Swept-Source OCT (SS-OCT), a tunable light source and a high-speed detection system are used to rapidly image the eye. Highly sensitive detection of scattered light intensity in the eye and micrometer image resolution offer advantages over other existing technologies[12]. Enhanced visualization of vitreous with OCT has been mostly limited to the vitreo-retinal interface [13-15].

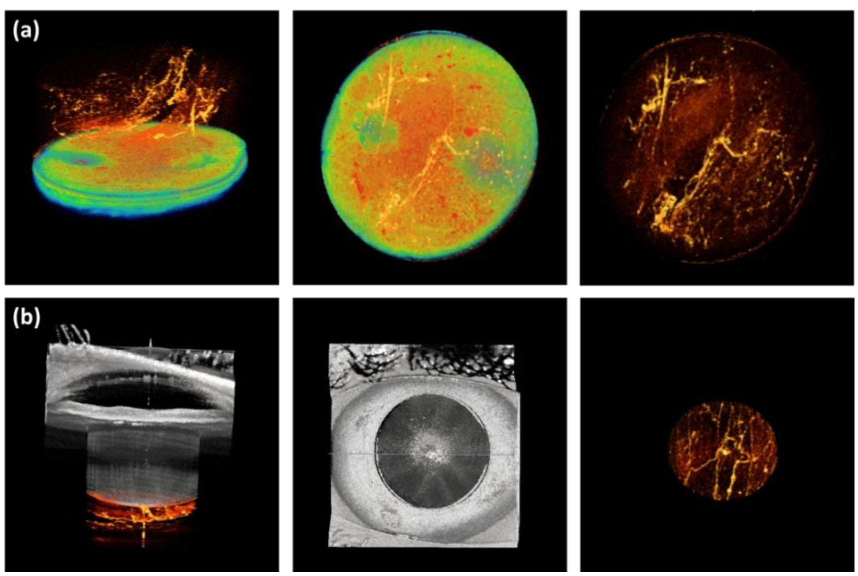


Figure 1. Enhanced 3-D visualization of anterior (a) and posterior (b) vitreous opacifications in 42-yo subject using SS-OCT with tunable focus. Rendering of volumetric data set, en-face image, and maximum intensity projection (MIP) [17].

**In this presentation, we demonstrate a novel operational modality of long-depth-range imaging that aims at *in vivo* enhanced visualization of vitreous opacities using an optimized SS-OCT instrument. The platform implements focus tunable optics to account for the eye refraction and to maximize the field of view. It is able to obtain cross-sectional images through the entire axial length of the vitreous body (from posterior lens to the retina).**

We have developed a high speed swept-source OCT instrument operating at a central wavelength of 1050 nm for long-range imaging. The system utilizes a short external cavity wavelength tunable laser technology operating at the speed of 30 kA-scans/second, and will be optimized to perform vitreous imaging with high sensitivity. During scanning, the electrically tunable lens (ETL) changes its focal distance enabling signal enhancement at different depths of the vitreous body. The final vitreous image is a sum of the images obtained for different focusing states, with enhanced signals from the vitreous opacities[16].

In the preliminary study, we performed 2-D and 3-D imaging of the eye in the anterior and posterior vitreous using a raster scan pattern consisting of 300 x 300 A-scans. 3-D rendering of acquired data sets is demonstrated in Fig. 1[16]. The opacities are characterized by enhanced light scattering, and manifest as a hyperintensive signal below the posterior interface of the crystalline lens or in front of the retina. The following steps will aim at optimizing the system for vitreous imaging and characterization of macro- and micro-architecture of the vitreous body. We will demonstrate the performance of this system in visualizing vitreous opacities that commonly cause floaters, primarily the posterior vitreous cortex in patient with posterior vitreous detachment and vitreous fibers in myopic eyes. Patients will undergo ophthalmic examination with vision testing including contrast sensitivity function. OCT scanning will be followed by ultrasound imaging.

In conclusion, implementation of focus tunable optics into SS-OCT enables visualization of *in vivo* microstructural changes in vitreous, primarily as related to opacifications. We will demonstrate the ability of this OCT imaging system to characterize vitreous opacities and compare the images with ultrasound. SS-OCT can be a useful diagnostic tool in the high-resolution evaluation and management of vitreous opacities.

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## REFERENCES

1 Artal, P. Optics of the eye and its impact in vision: a tutorial. *Adv. Opt. Photon.* **6**, 340-367, (2014).
2 Artal, P. *et al.* An Objective Scatter Index Based on Double-Pass Retinal Images of a Point Source to Classify Cataracts. *PLoS One* **6**, e16823, (2011).
3 de Castro, A. *et al.* Three-Dimensional Cataract Crystalline Lens Imaging With Swept-Source Optical Coherence Tomography. *Invest. Ophthalmol. Vis. Sci.* **59**, 897-903, (2018).
4 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* **9**, 3821-3833, (2018).
5 Coupland, S. E. The pathologist's perspective on vitreous opacities. *Eye* **22**, 1318-1329, (2008).
6 Sebag, J. *Vitreous in Health and Disease* (Springer, New York, 2014).
7 Garcia, G. A. *et al.* Degradation of Contrast Sensitivity Function Following Posterior Vitreous Detachment. *Am. J. Ophthalmol.* **172**, 7-12, (2016).
8 Sebag, J. Imaging vitreous. *Eye* **16**, 429-439, (2002).
9 Sebag, J. Seeing the invisible: the challenge of imaging vitreous. *J. Biomed. Opt.* **9**, 38-46, (2004).
10 Mamou, J. *et al.* Ultrasound-Based Quantification of Vitreous Floaters Correlates with Contrast Sensitivity and Quality of Life. *Invest. Ophthalmol. Vis. Sci.* **56**, 1611-1617, (2015).
11 Milston, R., Madigan, M. C. & Sebag, J. Vitreous floaters: Etiology, diagnostics, and management. *Surv. Ophthalmol.* **61**, 211-227, (2016).
12 Grulkowski, I. in *Handbook of Visual Optics, Volume Two: Instrumentation and Vision* (ed Pablo Artal) (CRC Press - Taylor & Francis Group, 2016).
13 Liu, J. J. *et al.* Enhanced Vitreous Imaging in Healthy Eyes Using Swept Source Optical Coherence Tomography. *PLoS One* **9**, e102950, (2014).
14 Uji, A. & Yoshimura, N. Microarchitecture of the Vitreous Body: A High-Resolution Optical Coherence Tomography Study. *Am. J. Ophthalmol.* **168**, 24-30, (2016).
15 Takahashi, A., Nagaoka, T. & Yoshida, A. Enhanced vitreous imaging optical coherence tomography in primary macular holes. *Int. Ophthalmol.* **36**, 355-363, (2016).
16 Grulkowski, I. *et al.* Swept source optical coherence tomography and tunable lens technology for comprehensive imaging and biometry of the whole eye. *Optica* **5**, 52-59, (2018).