Enhancing tissue-contrast imaging of the anterior eye

Yoshiaki Yasuno, Arata Miyazawa, and Masahiro Yamanari

Polarization-sensitive optical coherence tomography enables tissue-sensitive visualization of the front of the eye.

Optical coherence tomography (OCT) has become one of the most important diagnostic tools in ophthalmology. Originally used to examine the posterior eye, which includes the retina and optic nerve, it now is being applied to the anterior eye, which includes the cornea and iris. The back of the eye has several tissue layers, each with different light-scattering properties. OCT uses these differences for image contrast that clearly distinguishes the posterior tissues. However, the scattering properties of anterior eye tissue layers are similar, so it is difficult to selectively obtain contrast with OCT.

There are several ways to increase OCT exogenous contrast, such as using nanoparticles and dye molecules, but they are somewhat invasive and thus not convenient for daily clinical use. However, OCT endogenous contrasts may be useful. Doppler OCT provides selective contrast of vasculature. Spectroscopic OCT, based on tissue absorption, may also improve contrast. And polarization-sensitive OCT (PS-OCT) enables birefringence (double refraction), which is strongly associated with tissue composition.

We are working on tissue-contrast OCT of the anterior eye using PS-OCT detection and signal processing. This method yields pseudo-color, tissue-contrast OCT images with various tissues displayed in different colors. It can be used to selectively contrast tissues of the anterior eye, including the cornea, conjunctiva, sclera, uvea, and trabecular meshwork.

We used a swept-source PS-OCT system with a probe wavelength of 1.3 µm. It enables 3D tomography based on standard scattering OCT and PS-OCT, which measures phase retardation. The depth resolution is 12 µm and the measurement speed is 20,000 depth scans/s. These specifications are superior to the corresponding quantities in ultrasound biomicroscopy, a standard modality for examining the front of the eye. Figure 1 shows an anterior eye segment using scattering OCT and PS-OCT.
We used a software algorithm to create a pseudo-color, tissue-contrast OCT image from the scattering and PS-OCT images.\(^6\) In this process, an operator first manually selects a reference region within tissues of interest. The algorithm maps the pixels in the reference regions to a 3D feature space with scattering OCT intensity, local extinction coefficient (depth-dependent signal decay of the scattering OCT), and the local birefringence derived from phase retardation.\(^7\) Multiple reference regions for several tissue types are selected, and the pixels in these regions are mapped to the 3D feature space as shown in Figure 2(a).

The reference map is used for tissue discrimination in the OCT image. Feature values are then calculated for each pixel and mapped in the feature space. The similarity between the pixel and the reference tissues is determined, as is a final pseudo-color pixel value. This process is repeated for all OCT image pixels. Finally, a pseudo-color, tissue-contrast OCT image is created, as shown in Figure 2(b). In this image, the cornea, conjunctiva, sclera, uvea, and trabecular meshwork are shown in different pseudo-colors. The yellow spot indicated by an arrow is the trabecular meshwork, which is an important site for glaucoma screening.

So far, the only features used with our method are the OCT intensity, extinction coefficient, and local birefringence. However, this feature-analysis algorithm can be used not only for PS-OCT, but also to get any type of additional contrast, including in Doppler OCT and spectroscopic OCT. Our method can be used to combine additional types of contrast with OCT contrast to realize comprehensive tissue-sensitive tomography.

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Author Information

Yoshiaki Yasuno, Arata Miyazawa, and Masahiro Yamanari
Computational Optics Group
University of Tsukuba
Tsukuba, Japan
http://optics.bk.tsukuba.ac.jp/COG/COGWiki/

Yoshiaki Yasuno leads the Computational Optics Group at the university, where he received his PhD in 2001 for work on spatio-temporal optical computing. His research focus is optical coherence tomography and ophthalmic imaging.

Arata Miyazawa, a PhD student, received his ME in 2009 from the university for using PS-OCT in dermatological investigation.

Masahiro Yamanari is a postdoctoral researcher who received his PhD in 2008 from the university for his work on PS-OCT.

References