A combination of polarization and Doppler-flow imaging for optical coherence tomography enhances image contrast without sacrificing acquisition speeds.

Corneal and anterior-segment optical coherence tomography (CAS-OCT) is an imaging mode used to obtain cross-sectional images of the anterior eye segment in a noncontact and noninvasive manner. CAS-OCT has been used in clinics for diagnosis and basic research of ocular diseases such as glaucoma. Although conventional OCT helps to visualize the distribution of backscattering intensities from tissues, unlike histological techniques it does not guarantee clear differentiation of individual tissues. To enhance the contrast of OCT images, the birefringence and Doppler flow of tissues have been measured as functional extensions of OCT. We have demonstrated that this multifunctional CAS-OCT (MF-CAS-OCT) can accurately visualize fibrous tissues and blood flow in the anterior eye segment.

For biomedical imaging, it is important to have good image-acquisition speeds to avoid image distortion due to the motion of the sample. Swept-source optical coherence tomography (SS-OCT), also known as optical frequency-domain imaging, demonstrates high-speed and highly sensitive acquisition, owing to the use of a wavelength-swept laser. This technique has been used for CAS-OCT to obtain 3D images. A technical challenge for using polarization-sensitive and Doppler-flow imaging in combination with SS-OCT is to apply these additional functions without compromising imaging speed.

In previous studies exploring the use of MF-OCT, the effective imaging speed had to be reduced to accommodate the additional functions of OCT. This is because two incident states of polarization are required to compensate for birefringence of the fiber-optic components. To avoid this, we used a method involving continuous polarization modulation to multiplex the two polarization states into the signal frequency.

The system consists of a fiber-based Mach-Zehnder interferometer with an electrooptic modulator (EOM) and a polarization-sensitive (PS) detection arm, as shown in Figure 1. The light source sweeps the wavelength, and the EOM generates modulated and nonmodulated linear polarizations in orthogonal directions. The modulation is applied to the intrawavelength scan of the light source, enabling multiplexing of the incident states of polarization into the signal frequency. The eye is illuminated and scanned using a transverse scanner. Interference occurs when the backscattered light from the eye and the reference light are combined. The PS detection arm detects the horizontally and vertically polarized signals individually. Demultiplexing of the detected signals and PS detection provide four A-lines (depth profiles) with a single depth scan. Depth-resolved birefringence of the sample is calculated from these signals. Using a highly dense transverse scan, Doppler flow can be measured simultaneously. The MF-CAS-OCT can thus incorporate these additional functions without compromising imaging speed. The improved imaging speed will greatly benefit 2D and 3D imaging

Continued on next page
Figure 2. Intensity (upper), phase-retardation (center), and bidirectional Doppler flow (lower) images of the anterior eye segment. The conjunctiva (C), lateral rectus muscle (M), and sclera (S) are indicated. Arrows in the lower image indicate Doppler flow of the anterior ciliary arteries.

A pilot study using this approach to image a healthy anterior eye segment showed additional contrast in the OCT images. Figure 2 shows the images with a vertical scan at the temporal side. The phase-retardation image showed strong birefringence of the lateral rectus muscle and inhomogeneous moderate birefringence of the sclera, indicating characteristic organizations of the muscle and collagen fibers, respectively. The bidirectional Doppler-flow image showed the anterior ciliary arteries in the conjunctiva, which were not visible in the intensity image.

MF-CAS-OCT can simultaneously acquire birefringence and Doppler flow and shows enhanced contrast of fibrous tissues in the anterior eye segment, including the sclera, muscles, and blood vessels. Further study will allow us to examine the tissue properties of normal and diseased eyes. Moreover, application of this technology is not limited to the anterior eye segment, as it can also be applied to retinal imaging and skin measurements.

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References


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