Spectral Domain Optical Coherence Tomography

The potential role of this technology in glaucoma.

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Optical coherence tomography (OCT) uses low-coherence interferometery to obtain cross-sectional images of ocular structures such as the retina, optic nerve, and cornea. In time-domain OCT imaging, tissue-reflectance information in depth (an A-scan) is gradually built up over time by moving a mirror in the reference arm of the interferometer. OCT B-scans are generated by acquiring several neighboring A-scans.

Time-domain OCT imaging has been commercially available for almost a decade and has become the cornerstone for retinal imaging. In the past 2 years, the FDA has approved several Fourier/spectral domain OCT (SDOCT) imaging devices. These machines acquire entire A-scans in one instance by measuring frequency components of reflected light at a given point in tissue. Information on depth is transformed from the frequency domain to the time domain, and a moving reference mirror is not necessary to obtain complete A-scans. For this reason, SDOCT can obtain images much faster—more than 100 times faster in some systems—than time-domain OCT.

What applications might SDOCT have in glaucoma?

POTENTIAL USES

The drastic increases in scanning speed with SDOCT facilitate the rapid acquisition of scanning patterns, such as the 3.4-mm circumpapillary scan used to characterize the retinal nerve fiber layer's (RNFL) thickness in time-domain OCT. The quickness with which these scans can be obtained minimizes the effect of ocular movements. Alternatively, users can rapidly acquire repeated scans at a given location. Averaging multiple scans reduces the image's noise level and may improve the quality of the scan. In addition, faster scanning makes possible the acquisition of new scanning patterns, including three-dimensional raster data sets (also referred to as 3-D data cubes), comprising volumes of tissue.

The 3-D data volumes of tissue obtained by raster scanning offer several unique advantages compared with traditional scanning methods. After acquiring a 3-D data cube, SDOCT software can sum the tissue-reflectance values along individual A-scans to create an OCT fundus (en-face) image (Figure 1). Operators may use these images to evaluate ocular motion that occurred during the scan. It is also possible to go back to a 3-D data cube to extract scanning patterns (eg, the 3.4-mm circumpapillary scan) after an imaging session has occurred. The new capabilities afforded by 3-D imaging may facilitate image registration, which could lead to more reliable and consistent measurements over time. Such an advance would enhance the longitudinal evaluation of

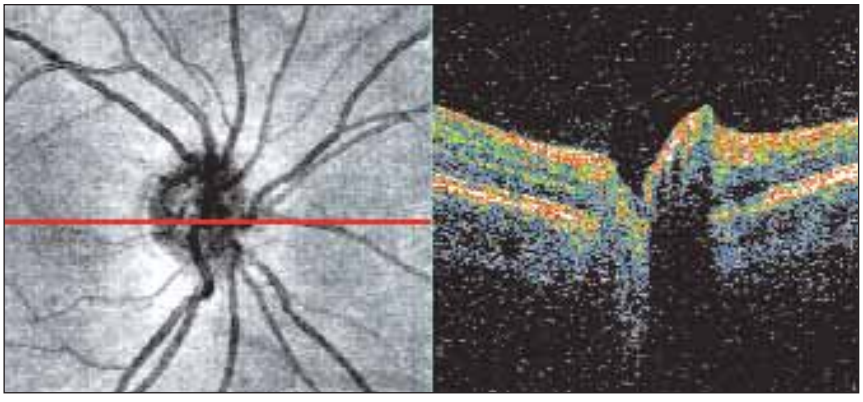
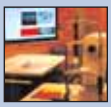


Figure 1. SDOCT image of the optic nerve head region of a healthy subject. The red line on the OCT fundus (en-face) image (A) indicates the location of the OCT B-scan (B).

A COMPARISON OF SDOCT DEVICES

DEVICE	MANUFACTURER	RESOLUTION	SCANNING SPEED
3D OCT-1000 	Topcon Medical Systems, Inc.	Axial resolution, 6 µm; transverse resolution, 20 µm	18,000 A-scans/second
Bioptigen SDOCT 	Bioptigen, Inc.	Axial resolution, 4.5 µm (or better with upgrade); transverse resolution, 10 µm	20,000 A-scans/second
Cirrus HD-OCT 	Carl Zeiss Meditec, Inc.	Axial resolution, 5 µm; transverse resolution, 25 µm	27,000 A-scans/second
Spectral OCT SLO 	OPKO Instrumentation/OTI OPKO Health, Inc.	Axial resolution, 5 to 6 µm; transverse resolution, 15 µm	27,000 A-scans/second
RTVue OCT 	OptoVue, Inc.	Axial resolution, 5 µm; transverse resolution, 15 µm	26,000 A-scans/second
SOCT Copernicus 	Optopol Technology SA	Axial resolution, 6 µm	25,000 A-scans/second
SOCT Copernicus HR 	Optopol Technology SA	Axial resolution, 3 µm; transverse resolution, 12 to 18 µm	55,000 A-scans/second
Spectralis HRA+OCT 	Heidelberg Engineering GmbH	Axial resolution, 3.5 µm digital and 7 µm optical; transverse resolution, 14 µm	40,000 A-scans/second
Spectralis OCT 	Heidelberg Engineering GmbH	Axial resolution, 3.5 µm digital and 7 µm optical; transverse resolution, 14 µm	40,000 A-scans/second

	FEATURES OF NOTE
	• FDA cleared
	• Device combines OCT technology and a nonmydriatic camera
	• Provides a 3-D virtual microscopic view of the retina
	• Accurate retinal registration software captures reproducible images of the retina to facilitate comparison of serial scans
	• Interfaces with Imagenet digital imaging system
	• Depth-independent resolution upgradeable to 3 µm or better
	• Real-time imaging
	• Flexible software suite for clinical research purposes
	• Versatility in subjects imaged
	• Only handheld SDOCT system
	• FDA cleared
	• Advanced algorithm automatically identifies precise placement of 1.73-mm–radius TSNIT circle centered on the optic nerve head
	• High-definition layer segmentation maps of internal limiting membrane and retinal pigment epithelium reveal fine details of histology and pathology in a 3-D display
	• Automated visit-to-visit registration provides verification of scan position and ensures reproducibility
	• FDA cleared
	• Visual function testing via microperimetry
	• Retinal nerve fiber layer thickness analysis with automatic change over time tracking
	• SLO for instantaneous and precise image registration
	• 3-D topographic analysis with automatic topographic changes over time
	• FDA cleared
	• Only device that can image the retina, glaucoma, and the anterior chamber
	• Unique macular ganglion cell analysis shows percentage loss from normal
	• Unique layer-by-layer assessment with comparisons to normative databases
	• FDA cleared
	• Glaucoma analysis based on cup-to-disc ratio and Disc Damage Likelihood Scale
	• Supports detection of RAPD (asymmetric relative afferent pupillary defect) to detect asymmetric optic nerve diseases
	• Glaucoma analysis based on cup-to-disc ratio and Disc Damage Likelihood Scale
	• Supports detection of RAPD (asymmetric relative afferent pupillary defect) to detect asymmetric optic nerve diseases
	• Doppler analysis (flow velocity estimation, in vivo measurements of blood flow in retinal vessels, maps of velocity distribution)
	• FDA cleared
	• Imaging modes include SDOCT, infrared, red-free, autofluorescence, fluorescein angiography, ICG angiography
	• Eye tracking
	• Wide field imaging
	• Network ready
	• Viewer software
	• Image noise reduction
	• Automatic re-scan
	• Confocal
	• FDA cleared
	• Imaging modes include SDOCT and infrared
	• Automatic re-scan
	• Eye tracking
	• Wide field imaging
	• Network ready
	• Viewer software
	• Upgradeable to HRA+OCT
	• Image noise reduction
	• Automatic reduction
	• Automatic re-scan
	• Confocal

glaucoma patients and glaucoma suspects. Moreover, operators can create thickness maps of retinal regions of interest by segmenting the RNFL on each frame of the 3-D data cube (Figure 2). Doing so may aid physicians' initial diagnosis of glaucoma by indicating areas of generalized thinning or focal defects, and it has the potential to assist with follow-up progression analysis as well.

In addition to volumetric scanning, some SDOCT devices offer a setting for simultaneous structural imaging and Doppler analysis. This technique may permit the measurement of the velocity of blood flow through the retinal vasculature, with the corresponding structural information acquired simultaneously. Other major features of SDOCT devices include the integration of OCT technology with preexisting imaging techniques such as microperimetry, fluorescein angiography, autofluorescence, red-free photography, and scanning laser ophthalmoscopy (SLO).

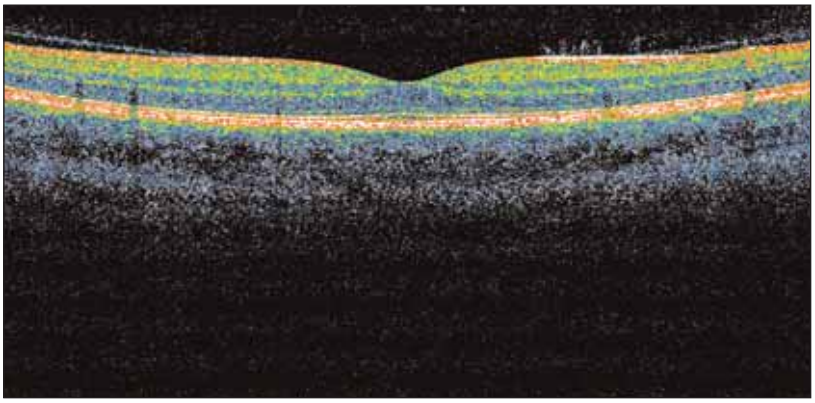


Figure 2. SDOCT image through the macular region of a healthy subject.

SDOCT DEVICES

For the details on several units, see *A Comparison of SDOCT Devices*. The information was valid at the time of this article's writing, but readers should realize that the software programs for many of these devices are modified frequently. What follow are highlights of some of the special features of several systems.

The 3D OCT-1000 (Topcon Medical Systems Inc., Paramus, NJ) allows the registration of the OCT data with the fundus images acquired with the system's color, nonmydriatic retinal camera. It is also possible to import fluorescein images and register them to OCT images.

Bioptigen SDOCT (Bioptigen, Inc., Durham, NC) is primarily marketed as a biomedical research tool. The system offers three types of application-specific scanning heads: clinical; handheld; and microscopic. Two different wavelengths are available for the light source: 1,310 nm and 840 nm. The company recommends the use of the 1,310-nm light source for imaging the anterior segment and small animal eyes as well as for ex vivo imaging. Bioptigen, Inc., suggests the 840-nm light source for imaging the eyes of small animals and the human retina. Doppler imaging is available on the system.

The software for the Cirrus HD-OCT (Carl Zeiss Meditec, Inc., Dublin, CA) offers registration to fundus images. Additionally, RNFL segmentation and maps of retinal layers can be created from OCT images, and a comparison with a normative database is also available.

The Spectral OCT SLO (OPKO Health, Inc., Miami, FL) combines OCT and SLO, with real-time registration of OCT and SLO images as well as an option for microperimetry. A normative database is available for comparing the RNFL's thickness and measurements of the optic nerve head, and the system allows the importation of fluorescein angiography and fundus images.

Operators can generate RNFL and inner retinal thickness maps using the RTVue-100's (OptoVue Inc., Fremont, CA) software. Automated quantitative data are provided for the macula and regions of the optic nerve head.

The software for the SOCT Copernicus HR system (Optopol Technology SA, Zawiercie, Poland) includes retinal and RNFL thickness maps as well as a system that tracks ocular motion. Doppler imaging is available, and analysis includes a map of velocity distribution.

The Spectralis HRA+OCT (Heidelberg Engineering GmbH, Heidelberg, Germany) offers a combination of OCT imaging with fluorescein angiography, autofluorescence, or red-free photography. The OCT system can track ocular movement.

LIMITATIONS

Although SDOCT imaging has several advantages over time-domain imaging and other ocular imaging techniques, there are some limitations and device-related issues still to be addressed. These machines tend to be costly. Also, the technique is relatively young and requires optimization in terms of the image's registration, processing, and acquisition. For example, ocular movements are still a substantial artifact, and the correction of motion still needs to be addressed. It should also be noted that, at this time, there are limited clinical data available attesting to the utility of SDOCT devices in terms of diagnostic assistance or the longitudinal evaluation of patients.

CONCLUSION

The SDOCT devices described in this article have the potential to improve the detection and monitoring of glaucoma, because these machines have higher resolution and faster scanning speeds than the traditional, commercial, time-domain OCT unit. SDOCT devices should increase the accuracy of measurements by minimizing the effect of ocular movement. They are also capable of 3-D raster scanning, which facilitates a thorough acquisition of data from the area of interest. This technology introduces the possibility of registering measurements from scan to scan and improving the detection of disease and its progression. In addition, Doppler analysis with SDOCT may shed new light on the perfusion of retinal tissue in diseased and healthy eyes. ❑

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