Spectral-domain OCT in Practice

Our research and clinical experience with the Bioptigen SD OCT system.

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We have had the opportunity to use the Bioptigen (Bioptigen, Inc., Research Triangle Park, NC) spectral-domain (SD) optical coherence tomography (OCT) system extensively at the Duke Advanced Research in SD OCT Imaging (DARSI) laboratory in the Duke University Eye Center. The Bioptigen system has several features that we have taken advantage of in both research and clinical endeavors. In this article, we will review the system and describe how we have put this technology to use.

IMAGE ACQUISITION

Image acquisition speed sets all SD OCT systems apart from time-domain (TD) OCT. The Bioptigen system can acquire, process, and display 17,000 A-scans per second. This high speed allows high-resolution volumetric scanning across most of the macula and reduces the incidence of motion artifact compared to TD OCT. Another feature of SD OCT is high resolution. The axial (anterior-posterior) resolution for the Bioptigen system is 4.5 µm, and the lateral (nasal-temporal) resolution can be as little as 10 µm. (This is dependent on the optical properties of the eye being scanned.) A future plug-in upgrade will increase the bandwidth of the light source used for image acquisition and improve the axial resolution to less than 3 µm. The imaging depth is about 2 mm, represented by 1024 pixels in each A-scan. The high-axial resolution has allowed our lab to study in-depth retinal and subretinal pathology that is more difficult to visualize on TD OCT.

Unlike the lossy-compressed image output from some SD OCT systems, the Bioptigen system facilitates export and analysis of files by making the raw OCT data accessible to the user. The data can be exported in a raw format or as an .oct file. Even though the .oct file format is proprietary, it can easily be exported to and read by third-party software such as ImageJ (freeware Java version; National Institutes of Health; Bethesda, MD) and MATLAB (The MathWorks, Inc., Natick, MA) for postacquisition processing and analysis. The volumetric scans can also be exported as movies in the form of .avi files, while each individual B-scan can be exported in the .bmp format.

Image acquisition is highly customizable with the Bioptigen system. First, the user can set the exact location of scanning by utilizing the live video fundus image on the system's monitor. Second, when acquiring linear scans (a sequence of repeated SD OCT B-scans from a unique azimuthal position through an area of interest), the user can specify how many frames should be acquired, and then averaged, for noise reduction. Furthermore, the user can choose to acquire Doppler flow data during linear scanning. The more common mode of imaging, volumetric scanning, is also modifiable. Not only can the user specify the length, width, and sampling density of the scanned area, but a "mixed" scan can also be performed. In a mixed scan, the outer B-scans are acquired more rapidly at a lower sampling density (fewer lines per B-scan), and the central target B-scans are acquired more slowly at a higher sampling density (more lines per B-scan) for increased image detail. For example, twenty 1,000-line frames can be acquired and displayed within a 150-line x 150-frame volume in 2.5 seconds. This mixed density sampling is registered and displayed in the summed voxel projection (SVP), allowing the user to directly observe the registration of high-information content, low-noise frames within a volume generally free of motion artifacts, without the need for a secondary imaging system or post-processing step.

TRANSLATION OF DATA

Although a 3-D view of the retina is of great interest for comprehensive studies, often ophthalmic practitioners rely on 2-D representative images highlighting specific retinal features. For example, an SVP (Figure 1A) is a 2-D "en face" representation of the volumetric data that is constructed by collapsing all of the A-scans composing the volume scan
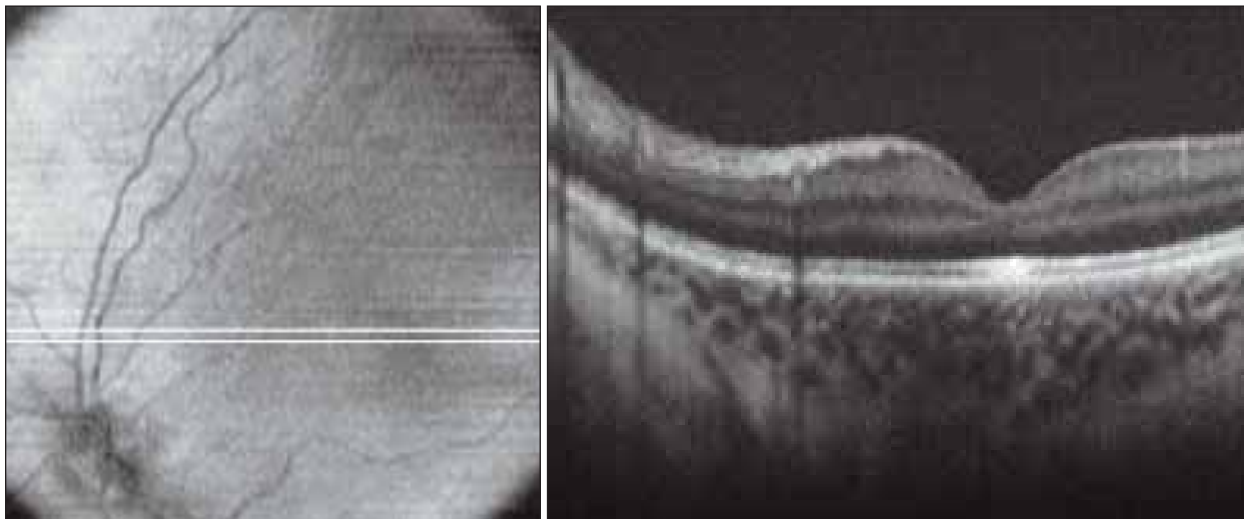
Figure 1. (A) Two-dimensional summed voxel projection image analogous to a fundus image is created by averaging all pixels of SD OCT B-scans along an axial line. **(B)** A registered and averaged B-scan from an exam of a young child under anesthesia. This B-scan is located in the area between the two white lines in (A).
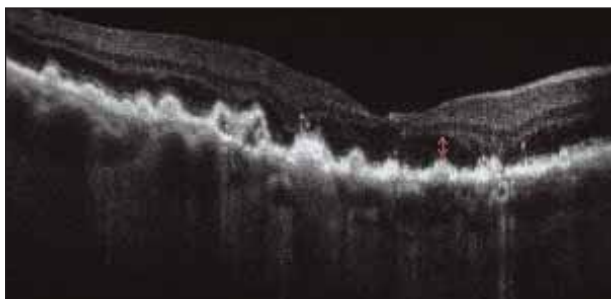

Figure 2. A registered and averaged B-scan from a patient with dry AMD. The red arrow indicates the photoreceptor layer thickness measurement.
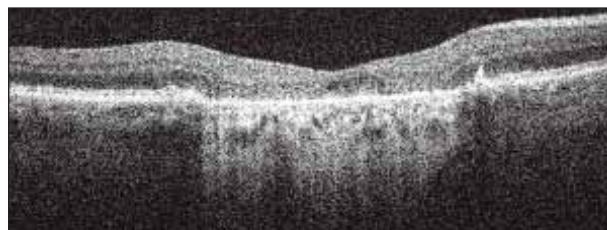

Figure 3. A raw B-scan captured from a patient with geographic atrophy.

along the anterior-posterior axis. Because of the shadowing of the vessels and the optic nerve on SD OCT, the SVP contains dark vessel patterns that appear similar to a grayscale fundus photograph. This SVP image can be used to determine the location of each individual OCT B-scan (Figure 1B) with respect to retinal landmarks. The information extracted from the SD OCT can be fused to other imaging modalities such as fluorescein angiography and fundus autofluorescence.[1] Exploring these correlations is important when attempting to integrate clinical information gained from multiple studies.

HIGH-AXIAL RESOLUTION

Our lab is extensively involved in investigating the tomographic features of drusen that occur in age-related macular degeneration (AMD).[2] Whereas most drusen can appear similar on color photography and TD OCT, we are now able to appreciate a significant amount of tomographic diversity (Figure 2). Differences in predominant internal reflectivity, homogeneity, shape, and confluence can now be observed and followed. Another area in which we have taken advantage of the high-axial resolution is in monitoring geographic atrophy.[3] In addition to the increased choroidal transmission commonly seen in areas of atrophy, now the actual transition from normal retina to atrophy of retinal pigment epithelium (RPE) can be visualized. This is manifested as abrupt thinning of the hyper-reflective band corresponding to the Bruch's membrane-RPE complex (Figure 3). Furthermore, thinning of the photoreceptor layer (PRL) and external displacement of the outer plexiform layer can be observed in these areas. Using the SVP, these PRL changes could possibly be correlated with

Figure 4. The Bioptigen handheld SD OCT scanner.

Figure 5. SD OCT imaging of the mouse retina the B-Scan (below) is located in the area between the two white lines on the summed voxel projection (above).

Figure 6. Screen shot of the DOCTRAP software. Drusen area is colored in yellow.

microperimetry to demonstrate the pathologic changes causing vision loss in areas of nonsensitive retina. We have also been able to investigate the quantitative and qualitative PRL changes over drusen in AMD (Figure 2).[4]

PORTABILITY FEATURE

While SD OCT is commonly used as a tabletop imaging unit, a unique feature of the Bioptigen system is the portability of the handheld scanner (Figure 4). We have utilized this portable scanner in both the operating room and the nursery, while examining children with or without anesthesia. Specifically, these handheld systems enable us to evaluate the extent of residual retinal damage from shaken-baby syndrome[5] and the spectrum of foveal architecture in pediatric ocular albinism.[6] One example of this includes SD OCT of the infant macula during examination under anesthesia (Figure 1). Our studies have shown comparable image quality between the handheld and conventional tabletop SD OCT systems. We have also found the handheld SD OCT useful for alternative research purposes, such as imaging small animal eyes (Figure 5).

IMAGE ANALYSIS

Most image analysis is currently performed on third-party software. Future software modifications, however, will include 3-D rendering, animated "fly-throughs," and retinal thickness reporting to aid in real-time patient care. Quantification of retinal and subretinal pathology is another feature that is facilitated by the access to the raw OCT data. Our lab has developed a software application, the Duke OCT Retinal Analysis Program (DOCTRAP),[7] that automatically segments drusen from each B-scan and calculates total volume with a high degree of sensitivity and specificity. Future versions will automate the morphologic analysis and classification of different types of drusen (Figure 6).
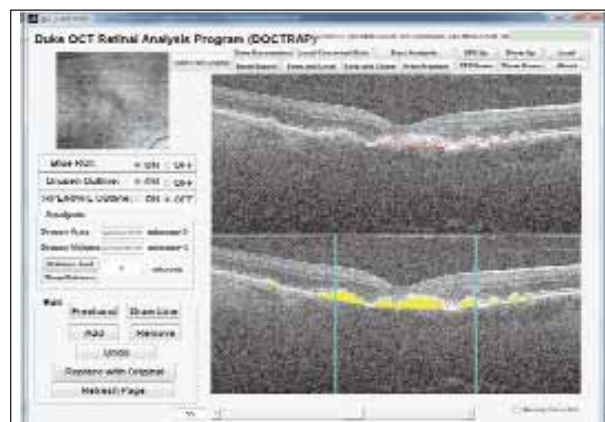
Overall, our experience with the Bioptigen SD OCT system has been positive, particularly for research applications; extension to the clinic will be facilitated by the addition of standard reports. The high-axial resolution allows improved visualization of important retinal and subretinal pathology. Image analysis and processing and data quantification are facilitated by the availability of the raw OCT data. Finally, the handheld scanner allows intraoperative and bedside image acquisition. ■

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