Advances in OCT Improve Understanding of Disease States

Developments have led to successful imaging of several retinal pathologies.

BY JAY S. DUKER, MD

Optical coherence tomography (OCT) is a useful imaging tool that identifies the anatomy of the retina and quantifies retinal, intraretinal and nerve fiber layer thickness. Despite limitations seen in earlier models, which include poor imaging of retinal layers, new technologies such as ultrahigh resolution OCT (UHR-OCT) (Figure 1) and spectral OCT systems offer aid from this and other typical problems.

Tissue microstructures are cross-sectionally imaged at a high resolution with OCT scans.[1] Light reflects the tissue and measures the variation of reflectivity to determine the distance between the tissue's reflective layers. It works much like an ultrasound.

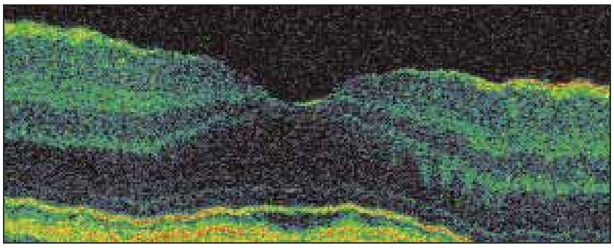
Axial resolution of the OCT is determined by the bandwidth. Broader bandwidths create better resolutions and therefore finer axial resolutions. The standard OCT resolution is approximately 10 µm, however, UHR-OCTs may have an axial resolution as fine as 1 to 2 µm.[2] In the presence of these lower axial resolutions, it has been possible to image distinct retinal pathologies[3-4] with better visualization of retinal layers at the photoreceptor, external limiting membrane, ganglion cell and vitreoretinal interface levels.

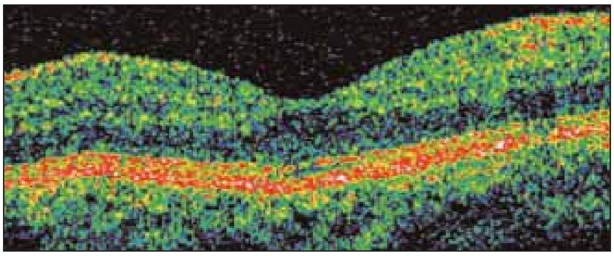
Because UHR-OCT scans show alterations to the reflective layers, it is possible to better understand and identify the retinal layers and their role in disease states. UHR-OCT technology strengthens our understanding of these disease states. When compared with simultaneous corresponding standard OCT scans (Figure 2), it increases our interpretation ability.

At the Hawaiian Eye 2006 meeting in Maui, I presented information on this advancing technology of OCTs.[5] Femtosecond lasers are currently used for the majority of UHR-OCTs, and the increased resolution has caused an upsurge in understanding the pathologies and pathophysiologies of diseases including Stargardt's disease, retinitis pigmentosa, macular holes before and after surgery (Figure 3), lamellar holes, age-related macular degeneration, central serous chorioretinopathy, rhegmatogenous retinal detatchment and white dot syndromes.[4,6] An in vivo comparison may be drawn between UHR-OCT and optical biopsy; a correlation between histology and UHR-OCT has been demonstrated in both the monkey and pig retina.[7,8]

Whereas standard commercial OCTs calculate total retinal and retinal nerve fiber layer thickness, UHR-OCTs can also calculate intraretinal thickness levels including photoreceptor outer-segment thickness. Changes to photoreceptor outer-segment thickness found with an UHR-OCT system determined loss of visual acuity in Stargardt's disease patients.[9]

This OCT advancement does have limitations. UHR-OCT imaging time is approximately three times longer than a standard commercial OCT (OCT3000 or StratusOCT; Carl Zeiss Meditech, Oberkochen, Germany). Longer imaging times, which limit the number of OCT scans you can perform, are due to an increased number of pixels per image as well as an increased number of axial





Figures 1, 2. UHR-OCT scan of a normal retina (top). Standard OCT of a normal retina (bottom).

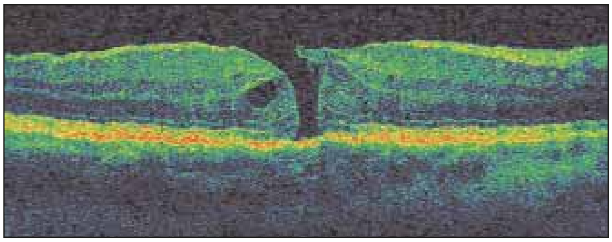


Figure 3. An UHR-OCT image of a stage 2 macular hole.

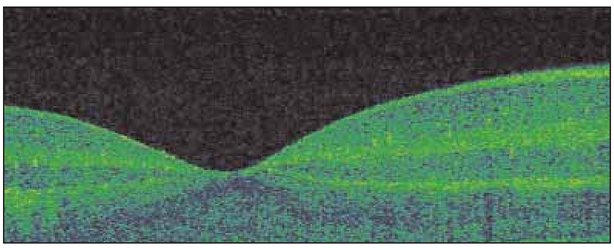


Figure 4. Ultrafast UHR-OCT of a normal retina.

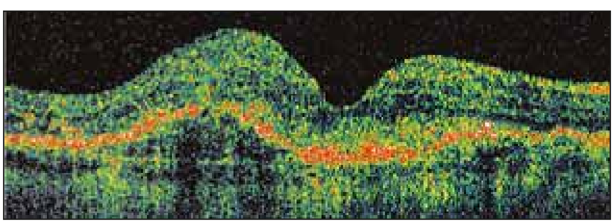


Figure 5. UHR-OCT of occult choroidal neovascularization.

and transverse motion artifacts.

Computer cross-correlation algorithms may be used to correct for these motion artifacts, however, it compromises the true topography of the retina.

Another limitation is the light source. Femtosecond lasers are costly and not easily maintainable. The use of superluminescent diode light sources is surfacing, and these may provide a more user-friendly and less expensive interface. These light sources can produce spectral bandwidths comparable to femtosecond lasers.[10]

Spectral, or high-speed OCTs are a second recent advancement in this technology. Such spectral domain images measure tissue layer depth by distinguishing the echo time delays of light on the tissue. All layers of retinal tissue may be detected at the same time, and imaging speeds have increased approximately 50 to 100 times compared with standard commercial OCTs.[11-13] Spectral OCTs are quicker because of the simultaneous scan, but also because the reference mirror does not need to be moved.

Spectral OCTs heighten the amount of axial scans in each image, which in return increases image quality and allows for an adequate visualization of intraretinal architecture. Short acquisition time is not sacrificed, and the light source's bandwidth is not increased. These are distinct advantages over standard commercial OCTs.

The number of axial scans is also beneficial for the area of retinal coverage in the image. Because the coverage is increased, small abnormalities not detected in a standard system may be seen with spectral OCTs. Additionally, compared with standard commercial OCTs, retinal and nerve fiber layer thickness maps are more precise with spectral OCTs. If high-speed UHR-OCTs are used, the advantage is being able to image more intraretinal layers.

Three-dimensional OCT data are also attainable with the increased coverage afforded by spectral OCTs. It is possible to compare various OCT images by reconstructing the fundus image; this may also be compared with a fundus examination or fluorescein angiography.

Detection sensitivity is also higher in spectral OCTs compared with standard systems because the reflected light is measured altogether.[14-17] Because of the higher detection sensitivity, high-speed imaging is possible. With my colleagues, I recently reported that spectral UHR-OCTs are capable of acquisition rates of 16,000 axial scans per second.[13] This scan has an approximate 2.1 µm axial resolution (Figure 4). Figure 5 is an example of occult chorodial neovascularization.

As OCT technology advances, it is possible to improve the quality of imaging without sacrificing speed and accuracy. As OCT imaging is an important tool in retinal practice, it is crucial that we continue to improve on it and look to future developments as a way to increase our understanding of the pathology and pathophysiology of retinal eye diseases. ■

1. Huang D, Swanson EA, Lin CP, et al. Optical coherence tomography. *Science.* 1991;254:1178-1181.
2. Drexler W, Morgner U, Kartner FX, et al. In vivo ultrahigh-resolution optical coherence tomography. *Optics Letters.* 1999;24:1221-1223.
3. Drexler U, Morgner R, Ghanta K, et al. Ultrahigh-resolution ophthalmic optical coherence tomography. *Nature Medicine.* 2001;7:502-507.
4. Drexler W, Sattmann H, Hermann B, et al. Enhanced visualization of macular pathology with the use of uhtra-high-resolution optical coherence tomography. *Archives of Ophthalmology.* 2003;121:695-706.
5. Duker JS. Ultrahigh Resolution Optical Coherence Tomography (UHR OCT) — An Advancing Technology. Presented at Retina 2006 during Hawaiian Eye 2006. Jan. 15-20, 2006. Maui, Hawaii.
6. Ko TH, Fujimoto JG, Duker JS, et al. Comparison of ultrahigh- and standard-resoultion optical coherence tomography for imaging macular hole pathology and repair. *Ophthalmology.* 2004;111:2033-2043.
7. Anger EM, Unterhuber A, Hermann B, et al. Ultrahigh resolution optical coherence tomography of the monkey fovea. Identification of retinal sublayers by correlation with semithin histology sections. *Exp Eye Res.* 2004;78:1117-1125.
8. Gloesmann M, Hermann B, Schubert C, et al. Histologic correlation of pig retina radial stratification with ultrahigh-resolution optical coherence tomography. *Invest Ophthalmol Vis Sci.* 2003;44:1696-1703.
9. Ergun E, Hermann B, Wirtitsch M, et al. Assessment of central visual function in Stargardt's disease/fundus flavimaculatus with ultrahigh-resolution optical coherence tomography. *Invest Ophthalmol Vis Sci.* 2005;46:310-316.
10. Ko TH, Adler DC, Fujimoto JG, et al. Ultrahigh resolution optical coherence tomography imaging with a broadband superluminescent diode light source. *Optics Express.* 2004;12:2112-2119.
11. Swanson EA, Izatt JA, Hee MR, et al. In vivo retinal imaging by optical coherence tomography. *Optics Letters.* 1993;18:1864-1866.
12. Nassif NA, Cense B, Park BH, et al. In vivo high-resolution video-rate spectral-domain optical coherence tomography of the human retina and optic nerve. *Optics Express.* 2004;12:367-376.
13. Leitgeb RA, Drexler W, Unterhuber A, et al. Ultrahigh resolution Fourier domain optical coherence tomography. *Optics Express.* 2004;12:2156-2165.
14. Hausler G, Linduer MW. "Coherence radar" and "spectral radar" — new tools for dermatological diagnosis. *Journal of Biomedical Optics.* 1998;2:21-31.
15. Swanson EA, Huang D, Hee MR, et al. High-speed optical coherence domain reflectometry. *Optics Letters.* 1992;17:151-153.
16. Leitgeb R, Hitzenberger CK, Fercher AF. Performance of Fourier domain vs. time domain optical coherence tomography. *Optics Express.* 2003;11.
17. De Boer JF, Cense B, Park BH, et al. Improved signal-to-noise ratio in spectral-domain compared with time-domain optical coherence tomography. *Optics Letters.* 2003;28:2067-2069.