

Applications for OCT Enhanced Depth Imaging

The technology is providing previously unavailable insights into choroidal pathologies.

REVIEWED BY RICHARD F. SPAIDE, MD

Optical coherence tomography (OCT) has been a valuable addition to the ophthalmic diagnostic armamentarium. Introduced by researchers at Massachusetts Institute of Technology in the early 1990s,¹ this imaging modality has allowed ophthalmologists to see the eye from a different perspective. The cross-sectional images it provides of the retina are analogous to histology slices, but in living tissue. These images, sometimes likened to a “virtual biopsy,” are obtained in a noninvasive, noncontact office-based imaging procedure that has rapidly become an integral part of standard ophthalmic practice. When multiple adjacent slices are combined in newer, high-speed spectral-domain OCT (SD-OCT) systems,² images of 3D blocks of tissue can be created, revealing even more previously unavailable information about the geometry of the posterior pole of the living eye.

Despite the utility of this imaging modality, conventional OCT has its limits. Imaging of the choroid, the vascular layer beneath the retina, is difficult in most individuals.³ The near-infrared 800 nm light source that is used in conventional OCT systems is scattered by the photoreceptor layer, and as a result the signal reflected from the choroid is weak. Devices that use a longer center wavelength have the potential to provide images deeper in the choroid,⁴ but there is decreased resolution compared with conventional OCT light sources with similar bandwidths, limiting its utility in clinical practice.

We have described a method to obtain images of the choroid using conventional SD-OCT.³ Since our original publication of enhanced-depth imaging (EDI) OCT of the choroid in 2008 we have published numerous papers describing methods of using this technique to image the choroid and sclera and have made what we believe are useful observations. This article reviews some of what we and others have learned with EDI OCT and the promise of this new technology (See Figures 1-5).

BACKGROUND

In SD-OCT, light from a broadband source is used to illuminate the eye. Light returned from the posterior pole is compared with a reference beam, and an interference pattern is generated. Software then converts the interferogram data into an OCT image. However, with increasing depth there is decreased resolution of the image and decreased signal intensity. Postsignal processing has only limited ability to extract image information from deeper structures.

Processing of the interferogram data actually produces 2 mirror images, but by convention only 1 is displayed by commercial OCT systems. In familiar conventional OCT displays, the retina is shown facing up, and deeper layers of tissue are toward the bottom of the image. We do not see the inverted mirror image that is generated under the right-side-up image.

By taking advantage of characteristics of the Spectralis OCT system (Heidelberg Engineering, Heidelberg, Germany), including eye tracking and the ability to average up to 100 separate OCT scans at any location, we devised a method of obtaining more information about the choroid. With the device placed closer to the eye than in normal practice, an inverted image with the most tightly focused illumination at the level of the choroid or inner sclera is obtained.³ In our EDI OCT investigations, we obtained inverted images of sections composed of 100 averaged scans from a rectangle focused over the fovea or other area of interest.

EDI OCT is easy to perform and provides detailed images of the choroid through an undilated pupil. Because the Spectralis instrument also records a scanning laser ophthalmoscopic image simultaneously, the exact location of the scan can be determined. This capability provides the potential to conduct repeated measurements in groups or in individuals to follow patterns of choroidal thickness in health and disease.

The fall-off in sensitivity with SD-OCT varies with a number of factors, but the resolution of the OCT and the capability of the interferometer are the most important. Similar to ultrasonography, a higher resolution is associated with more roll-off of sensitivity. Interferometer capability is constrained by the need to keep clinical instruments at a relatively low purchase price.

WHAT WE HAVE LEARNED

In our initial series,³ we used EDI OCT to measure choroidal thickness in healthy volunteers with undilated pupils. Mean choroidal thickness was 318 μm in the right eye and 335 μm in the left eye. There is no comparison figure from living humans to compare against our results. The widely quoted figure of 220 μm for choroidal thickness was obtained from casts of autopsy eyes nearly 100 years ago, and it is not known what effects this technique has on the thickness of the choroid. Our investigations and those of others confirm that measurements performed with this technology are reproducible.^{3,5}

Another series of normal eyes was measured with EDI OCT to evaluate variations in choroidal thickness and the association of choroidal thickness with age.⁶ Choroidal depth was measured at 500- μm intervals in a horizontal section spanning from 3 mm temporal to the fovea to 3 mm nasal to the fovea. In 54 eyes of 30 patients, average age 50.4 years (range 19 to 85 years), the choroid was thickest beneath the fovea (mean 287 μm , standard deviation [SD] ± 76 μm), and thickness decreased rapidly nasally (mean 145 μm , SD ± 57 μm , 3 mm nasal to fovea). Choroidal thickness showed a negative correlation with age, decreasing by 15.6 μm with each decade of life. This finding suggests that decreasing choroidal thickness with age may play a role in the pathologies of some age-related eye diseases.

Choroidal thickness in highly myopic eyes (-6 D or greater) was also assessed.⁷ In 55 eyes of 31 patients measured, average age 59.7 years (range 24 to 90 years), the mean refractive error was -11.9 D (± 3.7 D). The mean subfoveal choroidal thickness of 93.2 μm (± 62.5 μm) was negatively correlated with age ($P = .006$), refractive error ($P < .001$), and history of choroidal neovascularization ($P = .013$). Subfoveal thickness decreased by 12.7 μm for each decade of life and by 8.7 μm for each diopter of myopia. These findings—that the choroid is very thin in highly myopic eyes compared with normal eyes and that it undergoes still further thinning with increasing age and degree of myopia—suggest that abnormalities of the choroid may play a role in the pathogenesis of myopic degeneration.

The structure of the choroid was also evaluated in various disease states. The internal structure of pigment

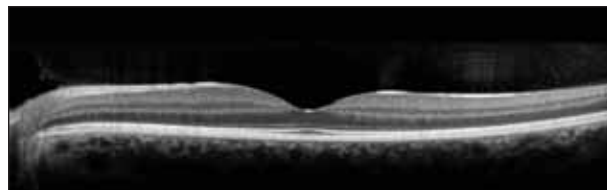


Figure 1. Standard SD-OCT image of a normal eye using the Spectralis platform. Note the excellent retinal details, but loss of discernible details from the choroid, just past the RPE layer.

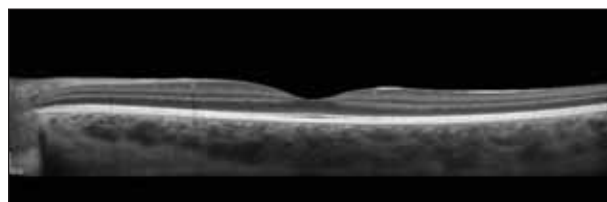


Figure 2. Enhanced depth imaging mode with Spectralis platform on the same eye. Retinal details are still retained, but now signal penetration into the choroid is improved. Choroidal vessel lumens are visible as is the choroid-scleral junction.

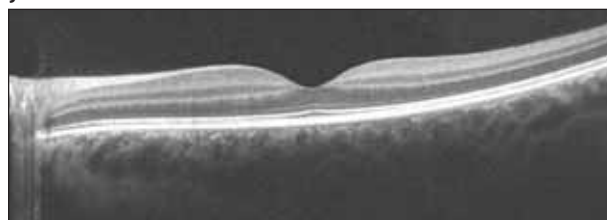


Figure 3. EDI imaging using Cirrus platform of same eye in Figure 1. Excellent retinal details are seen as well as visualization of structures within the choroid.

epithelial detachments (PEDs) in eyes with age-related macular degeneration (AMD) was examined using EDI OCT.⁸ Images encompassing the PED and surrounding neovascularization, if present, were compared with findings from fluorescein angiography (FA) and indocyanine green angiography (ICGA). EDI OCT showed the full extent of the choroid below PEDs in each of 22 eyes imaged. In half of the eyes, the PED cavity was filled with hyperreflective tissue, while in the other half the PED appeared to be filled with serous fluid and collections of reflective material. This material appeared to have characteristics of choroidal neovascularization on the back surface of the retinal pigment epithelium (RPE). Injections of intravitreal ranibizumab (Lucentis, Genentech) had the effect of flattening the PED and causing apparent contracture of the material within the PED. (These findings may help in the investigation of PEDs and retinal vascular anastomosis with choroidal neovascularization, and explain the pathogenesis of RPE tears.)

All figures courtesy of Richard F. Spaide, MD.

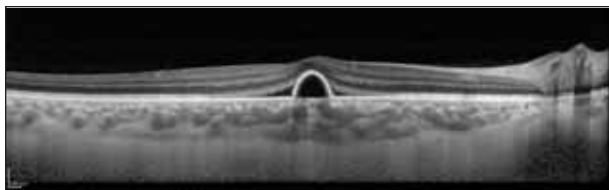


Figure 4. EDI image of a young female patient with central serous retinopathy. Note the pigment epithelial detachment and subretinal fluid. Of note, the choroidal layer is engorged and significantly thicker than normals.

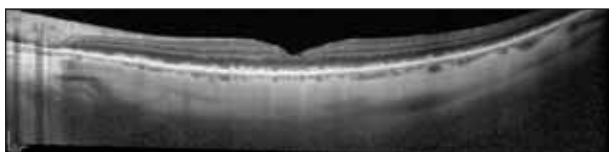


Figure 5. Age related choroidal atrophy is a condition identified through EDI imaging. Patients may have no evidence of geographic atrophy or dry AMD but still have gradual vision loss. Loss of choroidal thickness with decreased choriocapillaris blood flow may impact on neurosensory retinal function.

We evaluated choroidal thickness in patients with central serous chorioretinopathy (CSC),⁹ a disease that has been attributed to increased hyperpermeability of the choroidal vasculature. In 19 patients evaluated with EDI OCT, mean age was 59.3 years (SD 15.8 years), and 12 (63.2%) patients had bilateral clinical disease. Choroidal thickness in 28 eligible eyes was 505 μm (SD 124 μm), significantly greater than the choroidal thickness seen in normal eyes ($P \leq .001$). This finding of a very thick choroid in patients with CSC provides additional evidence that the condition may be caused by increased hydrostatic pressure in the choroid.

Subsequently, with colleagues in Japan, we used EDI OCT to measure choroidal thickness in patients after treatment of CSC with either laser photocoagulation or half-dose verteporfin photodynamic therapy (PDT).¹⁰ In both treatment groups subretinal fluid resolved, but choroidal thickness and hyperpermeability were reduced only in the PDT group. This suggests that PDT works by a different mechanism from laser photocoagulation and that it reduces the choroidal vascular hyperpermeability associated with CSC. So far we know that laser photocoagulation has a high recurrence rate while PDT does not. Perhaps the effects on the choroid play an important part.

As CSC is often difficult to distinguish from AMD clinically, and because treatments for these conditions differ, the increased choroidal thickness in CSC that is seen on EDI OCT may prove to be a valuable diagnostic measure.

EDI OCT can also be used to examine the posterior sclera. We used it to assess posterior anatomic changes in

patients with a dome-shaped macula, a condition in highly myopic eyes in which there is a convex elevation of the macula in comparison with a surrounding staphylomatous region.¹¹ Scleral thickness was measured using EDI-OCT in 23 eyes of 15 patients with this condition identified through routine OCT examinations. Mean patient age was 59.3 years (± 12.2 years), and mean refractive error in the eyes examined was -13.6 D (± 5.0) with best corrected visual acuity ranging from 20/15 to 20/800 (median 20/30). Mean subfoveal scleral thickness in these eyes was 570 (± 221) μm . In 25 eyes of 15 myopic patients with staphyloma but with no dome-shaped macula, mean subfoveal scleral thickness was 281 (± 85) μm ($P < .001$) even though myopic refractive error in both groups was similar. Scleral thickness measured 3 mm temporal to the fovea was not different in the 2 groups. Dome-shaped macula was therefore seen to result from relative localized scleral thickness variations under the macula in highly myopic patients, and it could not be categorized into any of the known types of staphyloma. These findings suggest the ocular expansion in myopia may be more complex than previously thought.

We also identified a new clinical entity, age-related choroidal atrophy, using EDI OCT.¹² In 28 eligible eyes of 17 patients, mean age 80.6 years (SD, ± 7.3 years), all eyes had a tessellated fundus appearance. Mean subfoveal choroidal thickness was 69.8 μm , and the choroid became even thinner nasally. In 18 eyes with no evidence of late AMD, the mean visual acuity was 20/40, pigmentary changes were seen in the macula potentially mimicking early AMD, and there was a dearth of choroidal vessels under the macula. Concurrent late AMD was found in the other 10 eyes, and glaucoma was seen in 6 patients (35.3%), all of whom had peripapillary atrophy. Loss of choroidal thickness was associated with loss of visible vessels, implying that this entity is a choroidal manifestation of small-vessel disease. Patients with age-related choroidal atrophy may be at higher risk for glaucoma.

Other instruments are capable of imaging the sclera as well. Manjunath and colleagues¹³ used the Cirrus HD OCT (Carl Zeiss Meditec, Dublin, CA) to measure the choroid in normal eyes, and this group confirmed our observation that choroidal thickness is increased in CSC.¹⁴

CONCLUSIONS

Despite the obvious promise of this technology, certain limitations of EDI OCT remain. The wavelength is not optimal to image the choroid, and therefore steps are needed to improve image quality. However, as previously noted, an OCT device designed specifically to image the choroid would not produce optimal images of the retina.

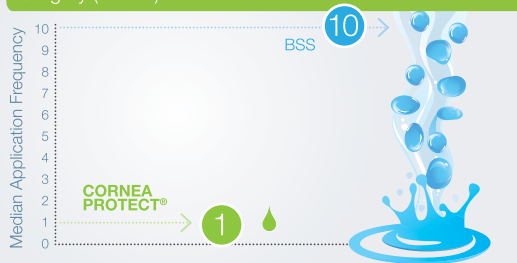
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Reference: 1. Chen Y-A, Hirschschall N and Findl O. Corneal wetting with a viscous eye lubricant to maintain optical clarity during cataract surgery. Submitted to *J Cataract Refract Surg* under review.

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COVER STORY

Another limitation of current technique is that, because 100 scans per section are used for averaging, the subject must be able to fixate with at least one eye during image acquisition. Software measurement of the thickness of the choroid, analogous to retinal thickness measurements that are currently available on standard OCT, would be useful. We are at an early stage in the development of this technology and automatic segmentation of the images with calculation of choroidal volumes would be a logical next step.

Even with these limitations, however, this method of imaging is easy and provides accessible, detailed images of the choroid that have not previously been available in clinical practice. Already we have seen that EDI OCT can help to differentiate AMD from CSC, and similar insights into the pathologies of other diseases of the choroid surely await investigators. We look forward to continued exploration of the promise of this exciting technology. ■

Richard F. Spaide, MD, is in private practice at Vitreous Macula Retina Consultants of New York in Manhattan and specializes in diseases of the retina and vitreous. He is a member of the Retina Today Editorial Board. Dr. Spaide can be reached at +1 212 861 9797.



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