

Choroidal Imaging With Spectral-domain Optical Coherence Tomography

Enhanced depth imaging may lead to a broader understanding of the pathogenesis of several eye diseases.

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The choroid, which constitutes the middle vascular ocular layer sandwiched between the outermost sclera and the innermost retina, plays an important role in the pathogenesis of many diseases of the posterior segment of the eye. Adequate visualization of the choroid is still lacking despite advances in imaging technologies. Traditional imaging modalities, such as indocyanine green angiography and B-scan ultrasonography, are limited in image resolution and measurement accuracy. Enhanced depth imaging (EDI), a novel optical coherence tomography (OCT) technique, allows reproducible measurement of choroidal thickness. This article discusses clinical applications of EDI.

BACKGROUND

OCT is a noninvasive, noncontact, transpupillary imaging modality that has recently been introduced into clinical practice. It uses light waves to obtain high-resolution cross-sectional images of the retina, creating an *in vivo* “optical biopsy” of the macular area. Unfortunately, the posterior choroid and sclera are difficult to image with today’s commercially available OCT systems. These systems all use a light source of approximately 800 nm, which results in scattering of the signal at the photoreceptor and retinal pigment epithelium (RPE) layers and a resultant weak signal from the choroid (Figure 1).

Nidek Co. (Gamagori, Japan) has developed an investigational OCT device that uses a light source of 1060 nm. The longer wavelength allows greater penetration of the ocular tissue than currently commercially available OCT

systems. Visualization of the choroidoscleral interface is possible with this technology, as well as accurate measurement of choroidal thickness.¹ Given that there are currently no 1060 nm OCT systems on the market, and that retinal visualization and resolution may be compromised by the change of wavelength, systems like this one are unlikely to become available soon. However, accurate measurement of choroidal thickness has been reported with the Cirrus HD-OCT 4000 (Carl Zeiss Meditec, Inc., Dublin, CA) and the Spectralis (Heidelberg Engineering, Heidelberg, Germany).²⁻⁴

The detailed physics behind the production of the OCT depth-resolved signal are beyond the scope of this review. Briefly, during spectral domain OCT (SD-OCT) imaging, a beam of low coherence light from a superluminescent diode is split through a beam splitter into a sample and a reference beam. Light from the sample beam is directed toward the tissue of interest—in this case the posterior segment—and, depending on the composition of the internal structures, the sample beam is reflected towards a detector with different echo time delays. The reference beam is reflected from a reference mirror toward another detector. The reflected beams of light are compared and combined into an interference pattern called the spectral interferogram. This spectral interferogram is transformed using Fourier equations into an OCT image. In reality, two mirror images are generated. OCT instruments depict only one of these images. By convention, the image depicted is usually the one in which the retina faces up with the vitreous at the

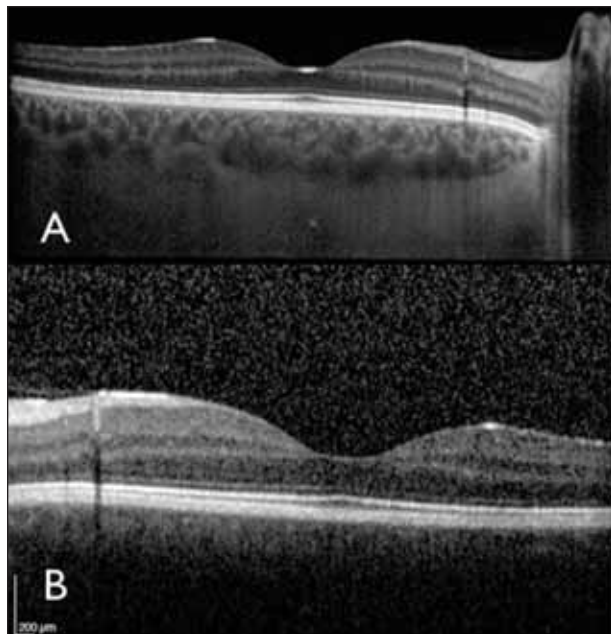


Figure 1. Comparison between EDI OCT scanning and conventional Spectralis OCT scanning of the same patient. EDI OCT (inverted mirror image) shows choroidal details and the choroidoscleral interface (A). Conventional OCT scanning showing no choroidal details (B).

top of the screen and the choroid toward the bottom (ie, the image with almost zero delay).^{3,4}

ENHANCED DEPTH IMAGING

EDI is a term coined by Spaide and collaborators,^{3,4} used to describe a novel choroidal OCT imaging technique with the Spectralis OCT system. If an OCT instrument is positioned closer to the eye, an inverted mirror image is obtained. This inverted mirror image has more information from the deep choroid than the normal noninverted image (Figure 1). If the OCT instrument has eye tracking and image averaging capability, as the Spectralis does, the signal-to-noise ratio is improved, resulting in improved visualization of the choroid. To obtain the best quality image, it is important to keep the image straight and the inverted image close to the top of the screen.

The most recent version of Spectralis software incorporates EDI into the scanning protocols. When the operator presses the EDI button, the software automatically inverts the image. Although there is currently no automated software available to measure choroidal thickness, it can be measured manually after the EDI image is obtained by using calipers to measure the distance from the outer border of the RPE to the inner surface of the sclera.



Figure 2. Comparison between EDI OCT scanning in two patients of different ages. A 10-year-old boy with a subfoveal choroidal thickness of 274 µm (A) and a 75-year-old man with subfoveal choroidal thickness of 145 µm (B).

Choroidal thickness in normal eyes and in eyes with central serous chorioretinopathy (CSC) has also been reported using the Cirrus OCT system.^{2,5} However, according to Spaide et al,⁵ the Cirrus OCT system lacks eye tracking, and the need to average the images makes this method less likely to improve the signal-to-noise ratio. Furthermore, it is unclear with the Cirrus where the peak of the sensitivity curve was placed within the image.⁵

CHOROIDAL THICKNESS

Measurement of subfoveal choroidal thickness with EDI with Spectralis is reproducible.^{3,6} Choroidal thickness varies according to location in relation to the macula.^{2,4} It is thinnest nasally, thickest subfoveally, and thinner temporally. The inferior macular choroid is thinner than the superior macular choroid. Two studies in which investigators measured subfoveal choroidal thickness in normal eyes found the mean values to be 287 µm and 332 µm.^{3,6} The variation is probably due to the difference in mean age of patients in the studies. In normal eyes, progressive choroidal thinning occurs over time at a rate of 1.56 µm per year in the subfoveal area (Figure 2).⁴

Axial length also appears to influence choroidal thickness. There is an inverse relation between myopia and choroidal thickness (Figure 3).⁷ In highly myopic

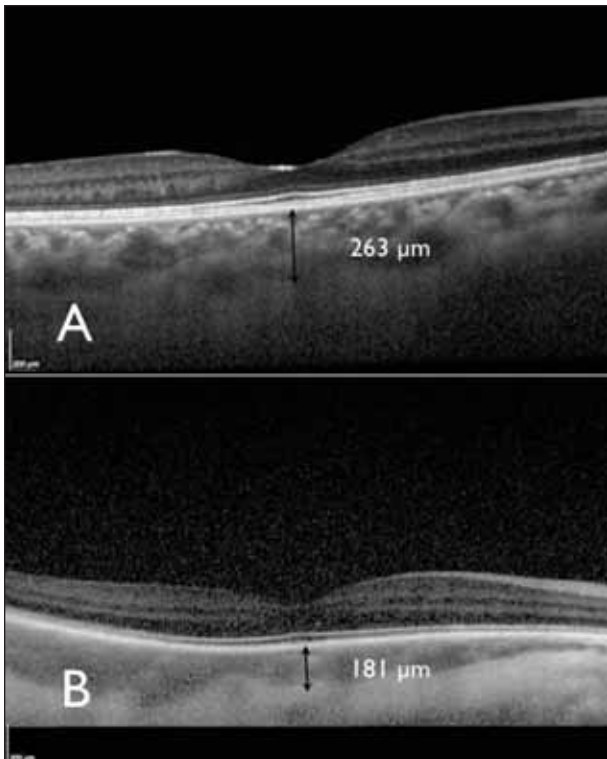


Figure 3. Comparison of EDI OCT scanning according to refractive status. A 43-year-old woman with no refractive error and a subfoveal choroidal thickness of 263 μm (A) and a 45-year-old woman with 8 D of myopia and a subfoveal choroidal thickness of 181 μm (B).

eyes (greater than 6 D), subfoveal choroidal thickness decreased by 12.7 μm for each decade of life and by 8.7 μm for each diopter of myopia.⁷ It is unknown what other factors affect choroidal thickness.

CLINICAL APPLICATIONS

Choroidal thickness is greater in CSC than in normal eyes.^{5,8,9} CSC is often difficult to differentiate from exudative age-related macular degeneration (AMD). Because treatments for these two conditions differ, it is important to make the distinction. Measuring choroidal thickness may help differentiate the two entities.

In AMD, choroidal thickness is often decreased (Figure 4). CSC is thought to arise from choroidal vascular hyperpermeability.¹⁰ Following successful treatment of active CSC with half-fluence photodynamic therapy, choroidal thickness decreases. Interestingly, in eyes treated successfully with laser photocoagulation, leakage resolves but choroidal thickness remains increased.⁹ Using EDI, Vance et al¹¹ have documented that sildenafil citrate increases choroidal thickness and may be a risk factor for CSC. Eyes with active Vogt-Koyanagi-Harada syndrome manifest

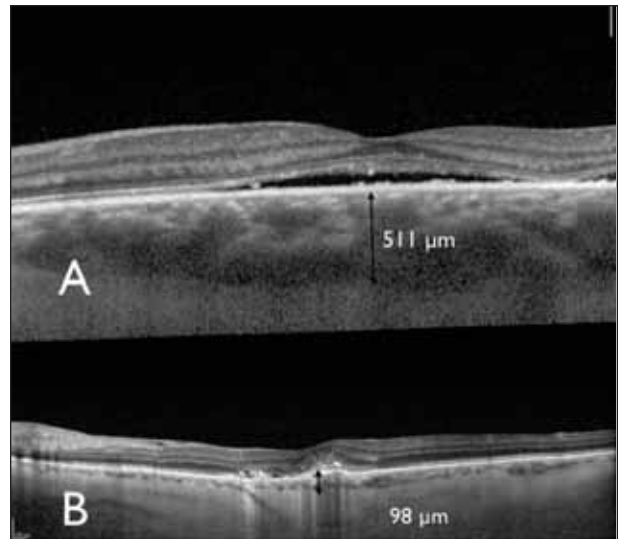


Figure 4. Differentiation between AMD and CSC using choroidal thickness. A 65-year-old man with active CSC with subfoveal choroidal thickness of 511 μm (A) and a 66-year-old man with exudative AMD and a subfoveal choroidal thickness of 98 μm (B).

increased choroidal thickness. Once the disease is controlled with corticosteroids, choroidal thickness returns to normal.¹²

In eyes with pigment epithelial detachment (PED) secondary to exudative AMD, conventional OCT techniques demonstrate an empty hyporeflective space in the internal structure of the PED. Using EDI, Spaide¹³ found that PEDs are often filled with material suggestive of choroidal neovascularization (Figure 5).

Spaide used EDI to describe a new clinical entity, age-related choroidal atrophy.¹⁴ In a cohort of 28 patients, mean visual acuity was 20/40, mean age was 80.6 years, and all eyes had a tessellated fundus. Almost one-third of eyes had concurrent late AMD. Glaucoma was present in more than one-third of patients. Mean subfoveal choroidal thickness was 69.8 μm . The loss of choroidal thickness was associated with loss of visible vessels, implying that age-related choroidal atrophy is a manifestation of small-vessel disease affecting the choroid.¹⁴

Reibaldi et al¹⁵ compared subfoveal choroidal thickness in 22 eyes with full thickness idiopathic macular hole with unaffected fellow eyes and healthy controls. They reported mean subfoveal choroidal thickness of 183.2 μm in eyes with macular hole and 196 μm in healthy fellow eyes, suggesting that bilateral thinning of the choroid may precede a macular hole.⁶ There was no correlation between subfoveal choroidal thickness and the diameter of the hole.

EDI has also been used to study inherited retinal dis-

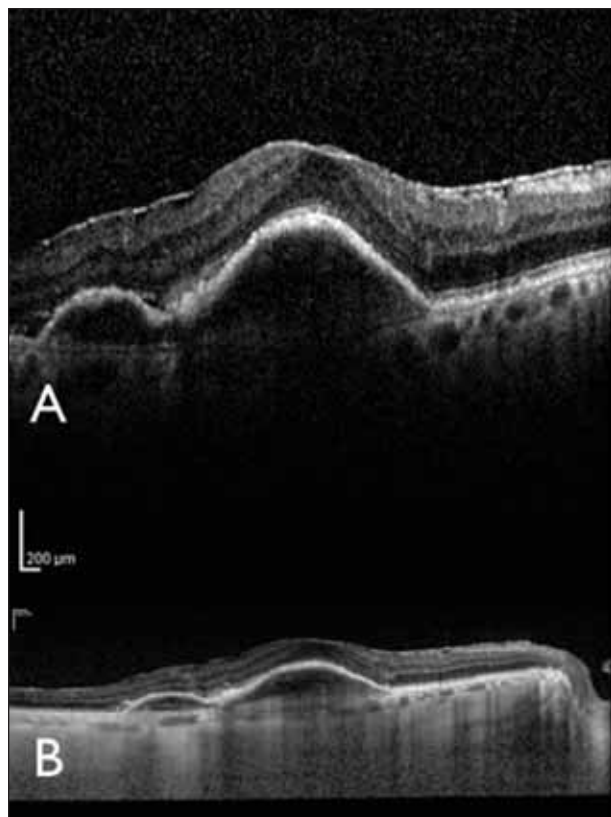


Figure 5. Comparison between conventional Spectralis OCT scanning and EDI OCT scanning of an eye with a pigment epithelial detachment (PED) associated with exudative AMD. In conventional Spectralis OCT scan, notice the hyporeflective area under the PED (A). In EDI OCT image of the same patient, notice that the area under the PED is no longer hyporeflective (B).

eases. According to Yeoh et al,¹⁶ choroidal thickness did not correlate with visual acuity or extent of retinal dysfunction on electrophysiology.

McCourt et al¹⁷ compared subfoveal choroidal thickness in eyes with varied ophthalmic pathologies with those of a normal cohort. They reported that eyes with glaucoma, diabetic retinopathy, and AMD had significantly thinner choroids than eyes of healthy patients. However, when age was taken into account as a confounding variable, the differences disappeared, underscoring the effect that age plays in determining choroidal thickness.

CONCLUSION

EDI of the choroid is a reproducible technique that allows measurement of choroidal thickness. Choroidal thickness may be used to differentiate between CSC and exudative AMD. Additionally, studying the choroid may

help us to gain insight into the pathogenesis of several diseases, such as AMD, CSC, and myopic maculopathy. ■

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