Enhanced Depth Imaging Optical Coherence Tomography

Ian Y. Wong, MRCS, FHKAM (Oph); Hideki Koizumi, MD, PhD; Wico W. Lai, MD, FHKAM (Oph)

ABSTRACT

Imaging the choroid with conventional commercial spectral-domain optical coherence tomography (SD-OCT) has been difficult, mainly because of difficulty in signal transmission beyond the retinal pigment epithelium. A recent modification to the standard technique, termed enhanced depth imaging optical coherence tomography (EDI-OCT), was able to image the choroid with reasonable clarity using commercial SD-OCTs. The aim of this article was to review the technique, principle, recent findings, and possible future developments regarding EDI-OCT. A MEDLINE search on all published articles on EDI-OCT was performed up to December 2010. The principle behind EDI-OCT was discussed. Modification to the conventional technique in image acquisition was described and illustrated with figures. EDI-OCT findings in various retinal and choroidal diseases were discussed. Advantages and disadvantages were also discussed. EDI-OCT has proved to be a promising novel technique in imaging the choroid. [Ophthalmic Surg Lasers Imaging 2011;42: S75-S84.]

INTRODUCTION

The introduction of optical coherence tomography (OCT) has revolutionized the understanding of the eye.1-4 It has the advantage of providing the user an in vivo cross-sectional image of the retina, which could not be achieved with other means of imaging. A detailed outline from the inner vitreoretinal interface to the outer retinal pigment epithelium could be visualized. Presence of vitreoretinal adhesion, retinal thickening, and intraretinal or subretinal fluid collection can be seen with high precision. Quantification of retinal thicknesses is also possible where serial changes may be useful in documenting progression of disease, either in retinopathies or glaucoma.5-7

The choroid, which accounts for most ocular blood flow,8 may be affected in several disease states, such as polypoidal choroidal vasculopathy and choroidal melanoma. It is also prone to suffer from age-related degeneration, microvascular artherosclerotic changes, and changes inherent to other microvascular systems.9-12 An understanding of the choroid using non-invasive imaging techniques has been limited. For
instance, imaging of the choroid with OCT was not entirely possible. This was because the wavelength of the light source used to image the retina was not long enough to penetrate into the choroid. This was due to wavelength dependent light scattering and signal loss that occur in the image path, decreased sensitivity away from zero-delay, and the various inherited limitations with Fourier transformation. The common commercially available OCTs employ a wavelength of 800 nm, whereas those capable of choroidal imaging are in the range of 1,060 nm. One would have to use a light source nearer to the infrared region to penetrate into the choroid. This was not possible for most commercially available OCTs, because clarity for retinal structures would be compromised. Following the introduction of a new imaging technique, referred to as “enhanced depth imaging optical coherence tomography” (EDI-OCT), choroidal imaging with standard commercially available spectral-domain OCT (SD-OCT) was made possible. This review provides the reader with an up-to-date account of this technique and the various findings published to date.

**METHOD**

A literature search on MEDLINE was performed on key words “optical coherence tomography,” “enhanced depth imaging,” “spectral domain OCT,” and “choroid” up to December 2010. Search results were limited to those published in English and studies on human subjects only.

**Principle of EDI-OCT**

In SD-OCT, a broadband light source is employed to image the retina. Interference signal is then generated by comparing the signal received to that from a reference arm. The interferogram obtained will then undergo Fourier transformation to form scattering amplitudes. This will then be analyzed and reformed into the retinal image obtained on the capturing screen. In SD-OCT, the real image is always accompanied by an inverted image. However, only one of the two images is generally shown on the capturing screen (ie, the upright real image). In the real image, the inner part of the retina is shown facing up and the choroid is shown at the bottom of the screen.

The reasons why the choroid cannot be imaged clearly could be attributed to (1) decreasing sensitivity and resolution with increasing displacement from zero-delay, (2) decreased maximal dynamic range inherent in Fourier domain systems, (3) wavelength dependent light scattering and signal loss in the image path, and (4) the lateral width of the defocused imaging beam. When the instrument is moved closer to the eye to image deeper layers, the inverted image is displayed such that the choroid is shown facing up (ie, closer to zero-delay) while the inner retina is facing down. This has the effect of delivering the most closely focused portion of the illumination at the level of the choroid or the inner scleral border. Hence, the choroid can be imaged at higher sensitivity.

The wavelength employed by most SD-OCTs is able to give a relatively low signal-to-noise ratio and, by averaging more frames, a relatively clear and noise-free image could be obtained. Therefore, EDI-OCT is a simple modification of the conventional SD-OCT technique, made possible by a slight displacement of the image capturing machine, and computerized image averaging.

**Standard Procedure**

There are several SD-OCTs available commercially, but to date, only the Heidelberg Spectralis OCT (Heidelberg Engineering, Heidelberg, Germany) and the Cirrus HD-OCT (Carl Zeiss Meditec Inc., Dublin, CA) have
been described to be capable of performing EDI-OCT.\textsuperscript{13,20} Here we explain the principle using the Heidelberg Spectralis OCT, as previously described by Spaide et al.\textsuperscript{13}

After positioning the patient and achieving focus, the OCT machine is slightly pushed toward the patient such that an inverted image is obtained on the capturing screen. Because image quality is best toward zero-delay (ie, top of the screen), the inverted image is captured when it is as close to the top as possible. Special attention is needed to avoid capturing a folded image (ie, when the machine is not close enough to the eye and the image has not yet been inverted completely). To enhance clarity and reduce noise signal, each image should be averaged from 100 frames. Eye-tracking technology also improves image quality and acquisition time (Fig. 2). The appearance of an EDI-OCT image of a normal line scan through the fovea is shown in Figure 3.

A recent software update by Heidelberg incorporates EDI-OCT as an added feature. The software update (version 5.3) automatically inverts the capturing screen and positions zero-delay inferiorly instead of superiorly. In doing so, the operator can acquire the EDI-OCT images with increased ease because now the image is upright, rather than inverted. However, this feature is only available in the updated Heidelberg Spectralis software, whereas for the Cirrus HD OCT, acquisition using the inverted-image technique is still required. Despite advancement in image acquisition, automated choroidal thickness measurement is still unavailable at the time of writing this review.

Image processing is done with the standard Heidelberg Explorer software. Because no automatic measuring software for EDI-OCT exists, manual measurement has to be done on each image (Fig. 4). Choroidal thickness is defined as the distance between the outer border of the retinal pigment epithelium and the inner scleral border.
Thickness Profile Along the Macula

In a pilot study by Margolis and Spaide, 54 normal eyes were studied. The choroidal thickness was measured at 500-µm intervals along a 6-mm horizontal line centered on the fovea (ie, measurements were made from 3 mm nasal to the fovea to 3 mm temporal to the fovea). Results showed that the choroid was thickest underneath the fovea, with a mean of 287 µm. Choroidal thickness decreased on both sides of the fovea, but more so nasally, and was found to be thinnest at the nasal end of the imaging line (ie, 3 mm nasal to the fovea). The choroid is the most vascular structure within the eye, and the fovea, situated at the center of the macula, has the highest photoreceptor density and metabolic activity. The metabolic demand has to be met by the choroidal circulation because there is no direct blood supply from the retinal circulation in the fovea. It is therefore reasonable to find the thickest part of the choroid to be located underneath the fovea, where the demand for oxygen is highest.

Correlation With Age

Margolis and Spaide also correlated choroidal thickness with age. It was found that the choroid gets thinner with age and the correlation was statistically significant at all points measured on the 6-mm line. With regression analysis, for instance, subfoveal choroidal thickness was found to decrease by 1.56 µm for each year of age. The choroid, being a vascular structure, is prone to be affected by systemic conditions such as hypertension and hyperlipidemia, and it is likely to undergo atherosclerotic and aging changes similar to other microvascular structures within our body. In a previous study on eye bank and autopsy eyes, the choroidal thickness was found to correlate negatively with age (decrease 1.1 µm per year of age). Results from histological examination may not necessarily agree with in vivo findings, mainly because (1) the tissue fixation method may have altered tissue texture and hence results may be altered and (2) choroidal thickness also reflects circulation but circulation ceases in diseased tissue, which may interfere with interpretation. Despite that, in vivo findings obtained by Margolis and Spaide confirmed that choroidal thickness measured in vivo follows the same pattern.

Measurements With Other SD-OCT

Margolis and Spaide did their measurements with the Heidelberg Spectralis. Manjunath et al. adopted their protocol and produced results with another model of SD-OCT, the Cirrus HD OCT. The differences between the Spectralis and Cirrus HD OCT were that Cirrus lacks eye-tracking ability and it can only perform 20 B-scans at a time for each measurement. In contrast, Spectralis is superior in that it has eye-tracking ability and can obtain 100 B-scans simultaneously. Despite that, Manjunath et al. were still able to produce comparable results in terms of variation in choroidal thickness along the macula and the negative correlation with age. Table 1 outlines the measurements of choroidal thicknesses obtained using these two models of SD-OCT. To date, the Spectralis and Cirrus HD OCT

---

**Table 1**

<table>
<thead>
<tr>
<th>Choroidal Thickness (µm) as Measured With Different Spectral-Domain Optical Coherence Tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Choroidal Thickness&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Temporal 3.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Temporal 2.5</td>
</tr>
<tr>
<td>Temporal 2.0</td>
</tr>
<tr>
<td>Temporal 1.5</td>
</tr>
<tr>
<td>Temporal 1.0</td>
</tr>
<tr>
<td>Temporal 0.5</td>
</tr>
<tr>
<td>Fovea</td>
</tr>
<tr>
<td>Nasal 0.5</td>
</tr>
<tr>
<td>Nasal 1.0</td>
</tr>
<tr>
<td>Nasal 1.5</td>
</tr>
<tr>
<td>Nasal 2.0</td>
</tr>
<tr>
<td>Nasal 2.5</td>
</tr>
<tr>
<td>Nasal 3.0</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean choroidal thickness as measured from outer border of retinal pigment epithelium to inner scleral border.

<sup>b</sup>Temporal 3.0 refers to measurement point 3.0 mm temporal to fovea on a horizontal line scan.

Heidelberg Spectralis is manufactured by Heidelberg Engineering, Heidelberg, Germany. Cirrus HD-OCT is manufactured by Carl Zeiss Meditec, Inc., Dublin, CA.

n/a = data not available.

---

(Fig. 3). Manual adjustments have to be done on the image captured. However, reproducibility was relatively good and measurement was possible in most cases.13,20
are the only commercial models of SD-OCT that were reported to be capable of performing EDI-OCT.

**FINDINGS IN PATHOLOGICAL CONDITIONS**

**Myopia**

Fujiwara et al. studied the EDI-OCT pattern of choroidal thickness in subjects with myopia of 6 dipters or more. A 6-mm horizontal scan line was used, centered on the fovea. Choroidal thickness was measured at 1,000-µm intervals along the line. The choroid was found to be thinnest at the nasal end. Thickness increased in a graded fashion toward the temporal side and reached maximum at the temporal end. This was in contrast to that in normal subjects, where thickness was highest under the fovea. A possible explanation was the presence of posterior staphyloma, which may have distorted the normal architecture of the choroid. Despite that, choroidal thickness correlated negatively with age and regression analysis showed a 1.27-µm decrease with each year of age. This was similar to that found in normal subjects. Furthermore, choroidal thickness was found to decrease with increasing myopia. An 8.7-µm decrease was found for each diopter of myopia.

Fujiwara et al. further subdivided the subjects into those who had myopic choroidal neovascularization (CNV) and those who did not. Results showed that in those who had had CNV, the choroid was thinner when compared to those who did not and the contour was distorted. This was because of either the effect of the CNV or the effect of treatment (ie, photodynamic therapy or anti-vascular endothelial growth factor injection), or a combination of both.

**Age-Related Macular Degeneration**

Before the description of the technique of EDI-OCT, imaging pigment epithelial detachment (PED) with OCT was difficult. It often appears as optically empty. Therefore, the pathogenesis of PEDs associated with age-related macular degeneration (AMD) has been controversial. Gass postulated that choroidal neovascularization (CNV) grows under the retinal pigment epithelium and spreads laterally and causes exudation. Accumulation of exudates increases the pressure between the choroid and retinal pigment epithelium and causes ballooning and PED formation. On the other hand, Bird and Marshall thought that abnormal interaction between the retinal pigment epithelium and Bruch’s membrane causes the formation of PEDs. It was thought that the Bruch’s membrane turns increasingly hydrophobic and impermeable to fluid with age, and fluid would accumulate underneath the retinal pigment epithelium during the normal outflow pathway. Hence a PED would form if enough fluid accumulates beneath the retinal pigment epithelium, and CNV forms as a secondary product. Other theories exist, but none have been conclusive.

With EDI-OCT, sensitivity and resolution is enhanced because the choroidal side of the image is placed closer to zero-delay. In a retrospective study of 22 eyes with PEDs associated with AMD, Spaide was able to image the inner contents with this new technique. In his study, the full extent of the choroid was imaged with this new technique in all eyes. The PED was filled with hyperreflective tissue seen overlying Bruch’s membrane, as outlined by arrowheads, was not seen clearly in (A).
late that the reflective substance represents CNV and should be part of the PED complex, but it was not being visualized before. In one particular case among his series, Spaide noted a reflective band underneath the retinal pigment epithelium inside the PED that also contained serous fluid. One week after treatment with ranibizumab, the band straightened and separated from the undersurface of the PED, followed by partial collapse of the whole PED. A month later, serous content was absent and the PED flattened out and was totally filled with the reflective substance, presumably CNV.15 Spaide concluded that PED in association with AMD is likely “neovascular in origin,” and that the Gass hypothesis is more likely to be the case.15

A point worth noting is that signals in the highest part of the PED tend to be blurred when performing EDI-OCT in subjects with large PEDs. This is because the higher the PED is, the further away it is from zero-delay. As mentioned earlier, signals are clearest nearer zero-delay. Because this is intrinsic to the principle of EDI-OCT, successful capturing of large PEDs may only be possible when future enhancement in OCT technique is available, possibly by enhancing the effective imaging depth and improving noise reduction algorithms.

Although the new findings may lead us to a deeper understanding of the pathogenesis of PEDs, there is still more to be done, histological correlation in particular. Also, further studies have to be done for other variants seen in the AMD spectrum (ie, geographical atrophy or classic CNV). Nevertheless, EDI-OCT proved to be a promising future development to allow us to improve the management and understanding of AMD.

Central Serous Chorioretinopathy

Central serous chorioretinopathy (CSC) is characterized by serous detachment of the neurosensory retina, sometimes accompanied by a serous PED. It was thought that vascular dilatation, congestion, and hyperpermeability of the choroidal vessels create an increased hydrostatic pressure within the choroid, leading to PED formation. This collection of fluid subsequently leaks into the subretinal space through focal leakage points, causing CSC formation.32-44 The above theories were backed up by studies using indocyanine green angiography.

With EDI-OCT, Imamura et al. have found new supporting evidence for these theories.44 In a study of 19 patients with CSC, they found a mean subfoveal choroidal thickness of 505 µm (standard deviation = 124 µm; range = 439 to 573 µm). This was higher than normative data reported previously.21,23 Among those who had unilateral CSC, choroidal thickness was also increased in the disease-free fellow eye.44 Increased choroidal thickness may represent increased circulation and vascular dilatation. This is in agreement with previous indocyanine green angiography studies, in that both eyes have increased choroidal circulation even if only one eye has clinically demonstrable CSC.59 There are several known risk factors for CSC, such as stress, pregnancy, sympathomimetic agent use, corticosteroid use, hypertension, and autonomic dysfunction.44-49 These are systemic risk factors rather than local ones, and the choroid is prone to be affected because it is a vascular structure with no autoregulation. The results demonstrated by Imamura et al. further confirmed this finding.44

In another study on CSC with EDI-OCT, Maruko et al. have shown that choroidal thickness is reduced after successful treatment with photodynamic therapy.50 In their study, 20 patients with CSC were treated with either laser photocoagulation or photodynamic therapy. Pre-treatment choroidal thickness was 345 µm in the laser photocoagulation group and 389 µm in the photodynamic therapy group. Choroidal thicknesses at 4 weeks were 340 µm in the laser photocoagulation group (P < .001) and 330 µm in the photodynamic therapy group (P = .2). There was a transient increase in choroidal thickness during the initial 2 days in the photodynamic therapy group that decreased at 4 weeks to a lower level than that at pre-treatment. Photodynamic therapy is capable of producing choriocapillaris damage and vascular remodeling in the choroid.51-59 Applying photodynamic therapy in CSC was thought to reduce vascular hyperpermeability and in return cessation of the pathological process.50 In contrast, those treated with laser photocoagulation did not have reduction in choroidal thickness, meaning hyperpermeability was not reduced. This was because the area of hyperpermeability was larger than the spot of focal laser applied.60,61 Although local effect was achieved around the laser spot, diffuse reduction in hyperpermeability was not observed; thus, choroidal thickness reduction was not evident. Although the study by Maruko et al. cannot be a guide for better treatment for CSC, it did highlight the value of EDI-OCT in future studies of CSC.
Inherited Retinal Diseases

EDI-OCT imaging in inherited retinal diseases is possible and correlates well with the clinical appearance of the disease. Yeoh et al. reported EDI-OCT imaging of the choroid in 20 patients with inherited retinal diseases, including Stargardt’s disease, macular dystrophy, cone/rod dystrophy, Best’s disease, Bietti’s disease, choroideremia, and bifocal chorioretinal atrophy. Although the subjects were heterogeneous in terms of etiology, some general principles were observed. It was found that choroidal thickness varied according to the type of disease, and the severity of the underlying disease. In general, choroidal thinning was observed where visible retinal or chorioretinal changes were present. Choroidal thinning may be focal or diffuse depending on the underlying retinal dystrophy, and was symmetrical bilaterally in all cases, which was in agreement with the bilateral nature of the respective inherited retinal disease. Yeoh et al. divided those with mild to moderate thinning from those with severe thinning. Mild to moderate thinning was thought to represent choriocapillaris atrophy secondary to retinal pigment epithelium cell death, whereas severe thinning was thought to be genetic in nature and caused atrophich changes in larger choroidal vessels.

Due to the retrospective nature, limited number of cases, and heterogeneity of etiologies, it was difficult to allocate a specific type of choroidal thinning pattern to one particular retinal disease. However, the study formed a framework for future studies in this regard.

Repeatability

Repeatability is critical when an imaging technique is to be implemented in practice. For EDI-OCT, there is no automated software to measure choroidal thickness. All measurements must done manually. This raises concern regarding inter-observer and inter-session repeatability.

Spaide et al. reported good inter-observer repeatability with the Heidelberg Spectralis (r = 0.93 right eye, r = 0.97 left eye; P < .001). Rahman et al. produced similar results and found that a change of more than 32 µm is likely to exceed inter-observer variability (inter-observer coefficient of repeatability was 32 µm, 95% confidence interval was 30 to 34 µm).

Although good inter-observer repeatability was produced with manual measurements, there are still difficulties sometimes. The main problems are the relatively lower resolution in choroidal images than in conventional retinal scans and the lack of eye-tracking in some models of OCT (only the Heidelberg Spectralis is currently able to perform eye-tracking for EDI-OCT). To enhance repeatability, automated measurement software should be developed for choroidal measurements and eye-tracking function should be ideally incorporated into every OCT machine.

DISCUSSION

Before the introduction of EDI-OCT, the means of assessing the choroid included contact ultrasonography, magnetic resonance imaging, and histological studies. Contact ultrasonography can provide an in vivo image of the choroid and can still function in the presence of dense media opacity (e.g., cataract), but it has low resolution and precise location of measurement is difficult. Magnetic resonance imaging is non-invasive, yet differentiation between retina, choroid, and sclera is difficult. Histological studies have disadvantages in that (1) the eye has to be removed for study, (2) tissue fixation may affect tissue texture, and (3) cessation of circulation may influence the histology.

Therefore, EDI-OCT has several advantages: (1) it uses a commercially available machine, (2) it is non-invasive, (3) it provides an in vivo account of the choroid, and (4) its operation is simple and has high repeatability. However, it is still limited by (1) the lack of automated choroidal thickness measurement software that requires manual measurement to be done, which can be time-consuming and creates bias; (2) the presence of media opacities, which hinders signal transmission and reception between the OCT and the choroid; and (3) the relative high cost of the SD-OCT machine. A summary of recent important findings in EDI-OCT is given in Table 2 for reference.

A dedicated automated software to measure choroidal thickness is clearly required. Further correlation in normal subjects is needed, for example in the pediatric population. Correlation in pathological conditions is also needed, especially in those of choroidal origin (e.g., choroidal nevus or polypoidal choroidal vasculopathy).

CONCLUSION

The introduction of EDI-OCT has provided new means of assessing the choroid with commercially avail-
### TABLE 2
Summary of Findings in Enhanced Depth Imaging Optical Coherence Tomography

<table>
<thead>
<tr>
<th>Investigator</th>
<th>No.</th>
<th>Pathology</th>
<th>Scanning Protocol</th>
<th>OCT Machine</th>
<th>Choroidal Thickness</th>
<th>Other Important Findings/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spai&quot;de et al., 2008(^{15})</td>
<td>17</td>
<td>Normal volunteers</td>
<td>7 sections, each comprised 100 averaged scans, within a 5 x 15 degree rectangle centered on the fovea, Eye-tracking mode on.</td>
<td>Heidelberg Spectralis</td>
<td>Mean 318 to 335 µm under fovea.</td>
<td>High reproducibility (r = 0.93 to 0.97; P &lt; .01).</td>
</tr>
<tr>
<td>Margolis &amp; Spai&quot;de, 2009(^{21})</td>
<td>30</td>
<td>Normal volunteers</td>
<td>7 sections, each comprised 100 averaged scans, within a 5 x 30 degree rectangle centered on the fovea, at 500-µm intervals from 3 mm nasal to fovea to 3 mm temporal to fovea, Eye-tracking mode on.</td>
<td>Heidelberg Spectralis</td>
<td>Mean 287 µm under fovea, Thinnest nasal end, thickest at fovea, gradual decrease in thickness from fovea to temporal end.</td>
<td>Negative correlation with age, decrease by 1.56 µm each decade of life.</td>
</tr>
<tr>
<td>Spai&quot;de, 2009(^{15})</td>
<td>22</td>
<td>AMD with PED</td>
<td>7 sections, each comprised 100 averaged scans, within a 5 x 15 degree or larger rectangle to encompass the PED and associated neovascularization, Eye-tracking mode on.</td>
<td>Heidelberg Spectralis</td>
<td>Not studied.</td>
<td>In 50% of cases, PEDs were entirely filled with hyperreflective tissue. In the remaining 50% of cases, PEDs contained hyperreflective tissue and serous fluid collection. Administrating ranibizumab caused PED to flatten and hyperreflective tissue inside to contract.</td>
</tr>
<tr>
<td>Fujiwara et al., 2009(^{34})</td>
<td>31</td>
<td>High myopia &gt; 6 D</td>
<td>7 sections, each comprised 100 averaged scans, within a 5 x 30 degree rectangle centered on the fovea, at 1,000-µm intervals from 3 mm nasal to fovea to 3 mm temporal to fovea, Eye-tracking mode on.</td>
<td>Heidelberg Spectralis</td>
<td>Mean 93.2 µm under fovea, Mean refractive error -11.9 D.</td>
<td>Negative correlation with age, (P = .006), decrease by 12.7 µm each decade of life. Negative correlation with refractive error (P &lt; .001), decrease by 6.7 µm each diopter of myopia. Negative correlation with history of choroidal neovascularization (P = .013).</td>
</tr>
<tr>
<td>Imamura et al., 2009(^{21})</td>
<td>19</td>
<td>CSC</td>
<td>Same as Margolis &amp; Spai&quot;de(^{21}) In addition, scanning was done before and after treatment, either by LP or PDT.</td>
<td>Heidelberg Spectralis</td>
<td>Mean 505 µm under the fovea (ie, mean 214 µm thicker than previously reported, P &lt; .001).</td>
<td>Choroidal thickness in the fellow eye had a mean of 461 µm, which was also higher than that reported in normals.</td>
</tr>
<tr>
<td>Maruko et al., 2010(^{66})</td>
<td>20</td>
<td>CSC</td>
<td>Same as Spai&quot;de et al.(^{21}) In addition, scanning was done before and after treatment, either by LP or PDT.</td>
<td>Heidelberg Spectralis</td>
<td>In the LP group, mean thickness was 345 µm before and 340 µm after treatment (Not significant, P &gt; .2). In the PDT group, mean thickness was 389 µm at baseline, 462 µm at day 2, 360 µm at 1 week, and 330 µm at 4 weeks (P &lt; .05 at all points).</td>
<td>Choroidal thickness was higher than normal in CSC. Subretinal fluid resolved in all cases after treatment. Changes in choroidal thickness were noted after PDT, but not after LP Suggested therapeutic mechanism difference between LP and PDT.</td>
</tr>
<tr>
<td>Yeoh et al., 2010(^{66})</td>
<td>20</td>
<td>Inherited retinal diseases</td>
<td>Scanning done on areas of focal retinal thinning, and adjacent areas of normal-looking retina, Eye-tracking mode on.</td>
<td>Heidelberg Spectralis</td>
<td>50% had no choroidal thinning and mean subfoveal choroidal thickness was 312 to 317 µm. Among the other 50%, some degree of thinning was found, ranging from mild, moderate, to severe. Thinnest choroid was 70 µm in the affected area; despite that, adjacent area was found to be normal.</td>
<td>Choroidal thickness correlated well with clinical appearance of retinopathy, and was found to be symmetrical. Extent of choroidal thinning dependent on the stage of disease. Choroidal thinning did not necessarily correlate with vision.</td>
</tr>
<tr>
<td>Rahman et al., 2010(^{66})</td>
<td>50</td>
<td>Normal volunteers</td>
<td>2 horizontal and 2 vertical line scans through the fovea, each averaged from 100 frames, Eye-tracking mode on.</td>
<td>Heidelberg Spectralis</td>
<td>Mean 332 µm under fovea.</td>
<td>Good repeatability was found. Intra-observer CR was 23, inter-observer CR was 32 to 34. A change of more than 35 µm was likely to exceed inter-observer variability.</td>
</tr>
<tr>
<td>Manjunath et al., 2010(^{66})</td>
<td>34</td>
<td>Normal volunteers</td>
<td>1 horizontal line scan through the fovea, measured at 500-µm intervals, along the line 2,500 µm temporal to 2,500 µm nasal of the fovea. Each line was averaged from 20 frames, without eye-tracking mode.</td>
<td>Cirrus HD-OCT</td>
<td>Mean 272 µm under fovea, Thinnest nasal end, thickest at fovea, gradual decrease in thickness from fovea to temporal end. Negative correlation with age (r = -0.62, P &lt; .0001).</td>
<td>Good inter-observer correlation (r = 0.92 to 0.93, P &lt; .0001). Poor retinal-choroidal thickness correlation (r = -0.23, P = .18).</td>
</tr>
</tbody>
</table>

**Notes:**
- OCT = optical coherence tomography; AMD = age-related macular degeneration; PED = pigment epithelium detachment; D = diopter; CSC = central serous chorioretinopathy; LP = laser photocoagulation; PDT = photodynamic therapy; CR = coefficient of repeatability.
- Choroidal thickness defined as distance between outer border of retinal pigment epithelium to inner scleral border.

Heidelberg Spectralis is manufactured by Heidelberg Engineering, Heidelberg, Germany. Cirrus HD-OCT is manufactured by Carl Zeiss Meditec, Inc., Dublin, CA.
able SD-OCTs. Its operation is simple, it is non-invasive, it provides an in vivo account of the choroid, and it has high repeatability. With this technique, choroidal changes in some retinal and choroidal diseases were revealed. New insights into the pathogenesis and treatment response were reported, which may light the path for future research. To date, published data regarding EDI-OCT are still limited. There is a demand for more work to be done.

REFERENCES


