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آموزش مهارت‌های کاربردی در نوشتندگی و چاپ مقاله
Choroidal Mapping: a Novel Approach for Evaluating Choroidal Thickness and Volume

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There are a limited number of non-invasive imaging techniques available for assessing the choroid, a structure that may be affected by a variety of retinal disorders or become primarily involved in conditions such as polypoidal choroidal vasculopathy and choroidal tumors. The introduction of enhanced depth imaging optical coherence tomography (EDI-OCT) has provided the advantage of in vivo cross-sectional imaging of the choroid, similar to the retina, with standard commercially available spectral-domain OCT machines. In this article, we review this imaging technique and introduce choroidal mapping as a novel approach for obtaining accurate topographic and volumetric information on the choroid in normal and diseased states.

Keywords: Enhanced Depth Imaging Optical Coherence Tomography; Choroidal Map


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INTRODUCTION

Optical coherence tomography (OCT), since its introduction in the late 90s, has become an indispensable imaging technique for evaluation and management of retinal and optic nerve disorders. As a non-invasive test, enhanced depth imaging (EDI)-OCT enables cross sectional imaging of the retina with resolution approaching histologic sections. Current spectral domain (SD)-OCT devices are empowered by software capable of measuring retinal thickness and constructing retinal maps; these features are particularly useful in evaluating and comparing retinal structures in pathologic conditions such as macular edema and vitreoretinal interface disorders.

The choroid is a vascular compartment which provides oxygen and nourishment to the outer retina; it seems to play a pathophysiologic role in many disorders affecting the retina, such as age-related macular degeneration (AMD), central serous chorioretinopathy (CSC), polypoidal choroidal vasculopathy and Vogt-Koyanagi-Harada (VKH) disease.

Light scatter by the retinal pigment epithelium (RPE) and choroidal vasculature degrades the quality of images obtained from the choroid in conventional OCT methods. Nevertheless, in vivo cross-sectional visualization of deeper choroidal layers is now achievable with the recent introduction of EDI-OCT.

IMAGING TECHNIQUE

We obtained EDI-OCT images in eyes with dry and wet type AMD and compared them to that of normal eyes (Fig. 1). The novelty of our approach is to provide choroidal mapping and choroidal volume measurement...
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To obtain the choroidal image, we positioned the combined Heidelberg Spectralis device (Spectralis HRA+OCT, Heidelberg Engineering, Heidelberg, Germany) sufficiently close to the eye, obtaining an inverted image of the fundus; an alternative method was employing the automatic EDI mode of the apparatus. By applying these methods, the choroid approximates the zero-delay line, positioning the most sharply focused portion of the OCT scan at the level of the choroid. We selected a high resolution 19 line raster scan protocol to encompass the macula within a 20°×20° area (Fig. 2). The automatically plotted boundary lines of the retina were adjusted to choroidal boundaries; internal limiting membrane (ILM) to RPE/choroid junction, and RPE to choroid/sclera junction. The resultant images were viewed and measured with the Heidelberg Eye Explorer software (version 5.3) to produce a color coded topographic map of choroidal thickness and volume (Fig. 3).

The subfoveal area had the largest choroidal thickness (CT) in normal eyes (248.93±50.92 µm; mean subject age, 65.81 years; sample size, 32). Mean total choroidal volume (CV) in the central 3.45 mm macular zone was 2.32 µL in the normal group. We observed that the choroid gets thinner with age. With regression analysis, subfoveal CT was found to decrease 17.39 µm per each decade of age in normal subjects.

Mean CT and CV measurements within the ETDRS layout profile showed gradual nasal thinning of the choroid. These observations are similar to the results of previous EDI-OCT

**Figure 1.** Enhanced depth imaging optical coherence tomography scans in a normal eye (upper image), dry type age-related macular degeneration (AMD) (middle image), and wet AMD (lower image).

**Figure 2.** The high resolution 19 raster line scan protocol encompasses the macula within a 20°×20° area.
Figure 3. Choroidal map and volume measurement in nine sectors of the ETDRS layout profile across the central 3.45 mm zone in the macula after manual segmentation of choroidal thickness.

Figure 4. Choroidal thickness and volume by enhanced depth imaging optical coherence tomography in an eye with central serous chorioretinopathy; increased values are evident as hot colors in the choroidal map.
studies in normal eyes which have revealed highest CT at the fovea decreasing on both temporal and nasal sides, but more so nasally (Fig. 3).

We observed that mean subfoveal CT in wet AMD eyes was greater than that in dry AMD eyes (233.13±72.95 µm versus 217.82±74.52 µm) despite similar mean age in both groups. This pattern of difference was demonstrated at all measured locations across the macula, but was only statistically significant 1 mm temporal to the fovea. Similarly, measured CV values in wet AMD eyes were higher than dry AMD eyes; the differences were statistically significant at all locations except nasal sectors. Mean total CV in the central 3.45 mm macular zone in dry AMD eyes was 1.8 µL, the corresponding value was 2.32 µL in wet AMD eyes which is still larger than normal eyes.

In another subset of patients, we employed the 31 raster line pattern to generate a choroidal map in CSC. Subfoveal choroidal thickness in these subjects was 454±79 µ which is significantly larger than normal. Comparing the area of increased CT on choroidal maps with the area of hyper-permeability on indocyanine green angiography, we demonstrated that in 91% of patients the hyper-permeability region resides within the area of increased CT on choroidal maps (Fig. 4).

DISCUSSION

Ocular and systemic disorders associated with vascular changes can affect the choroid which itself contains rich vascular networks. Previous studies employing SD-OCT for choroidal evaluation measured CT at limited points.2-8 However, choroidal mapping can provide topographic and volumetric information in the entire macular area and in each subfield as defined by the ETDRS layout pattern. These measurements may more accurately exhibit choroidal structure.

In a study including 80 eyes of 40 healthy volunteers, Shin et al used SD-OCT applying a high resolution 6 radial scan protocol to obtain choroidal images.9 Each radial line averaged 8 B-scan images. The authors failed to reconstruct maps in 16.2 % of cases because of obscure choroidal boundaries limiting accurate segmentation. They reported that mean time for segmentation was 2.8 minutes. We were able to create topographic maps in all cases even in wet AMD eyes in which posterior shadowing of retinal lesions made the segmentation process somehow difficult in some cases. Because each section was composed of an average of 100 scans, image clarity was enhanced. The eye-tracking technology, which is a specific feature of Heidelberg devices, also improved image quality. Moreover, a 6-radial scan protocol cannot represent the entire macular area and encounters a higher probability of interpolation errors. We used the 19 line raster protocol, a denser scan in the macula which is more representative and valid for choroidal measurements, however, this required more effort and time for the segmentation process.

It seems that choroidal vascular changes play certain roles in the development of chorioretinal disorders. Figure 4 demonstrates increased CT in an eye with CSC, which is evident by the presence of hot colors in the choroidal map. Quantification of choroidal thickness and volume by EDI-OCT can help clinicians evaluate the efficacy of therapeutic intervention for pathologic features of the choroid such as choroidal hemangiomas (Fig. 5).10

Normal reference values for CT and CV can be established by various SD-OCT devices. This normative database can be used to analyze choroidal changes due to various pathologic states. We detected an increase in CT and CV in wet AMD eyes in comparison to dry AMD eyes, which approximated values in our normal control group.

Similar findings have been reported by recent EDI-OCT studies. Subfoveal CT has been reported to be increased in CSC and VKH disease, but reduced in high myopic chorioretinal atrophy and idiopathic macular hole.11-16

The importance of choroidal measurements may emphasize the necessity of creating automated segmentation algorithms similar to the retinal map analysis protocols for faster and more precise evaluation of choroidal structure.

In conclusion, choroidal mapping and
Figure 5. Enhanced depth imaging optical coherence tomography in a patient with choroidal hemangioma shows an irregular hypo-reflective space with maximum choroidal thickness of 712 µm within the lesion (upper image). One month after photodynamic therapy, thickness at the same point decreased to 273 µm (lower image). Used with permission from the Iranian Journal of Ophthalmology.

Conflicts of Interest
None.

REFERENCES


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