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Retinal and Choroidal Imaging Update

Choroidal imaging A review

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Abstract

Being the most vascular tissue of the eye, importance of the choroid has been very well established in various retinal and chorioretinal diseases. Understanding of the choroidal structures has improved significantly since the evolution of enhanced depth imaging. Quantitative assessment of choroidal measurements has been found to be reproducible using different devices. This review article describes factors affecting choroidal thickness and choroidal changes in several diseases and reports its clinical importance. Evaluation of choroid would provide insight into the pathogenesis, treatment planning and follow up in chorioretinal diseases.

Keywords: Choroid, Choroidal imaging, EDI, Enhanced depth imaging, VKH, Retinitis pigmentosa, Swept source OCT

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Introduction

Choroid being the most vascular tissue in the eye, plays an important role in the pathophysiology of various ocular diseases. It provides nutrition to the outer retinal structures. Its role is established in various chorioretinal diseases such as central serous chorioretinopathy,[1] Vogt–Koyanagi–Harada disease,[2] high myopia-related chorioretinal atrophies,[3] age related macular degeneration,[4] and polypoidal choroidal vasculopathy.[5] Quantitative assessment of choroid has been very challenging with traditional imaging modalities such as indocyanine green angiography and ultrasonography due to limited resolution and repeatability.[6,7]

Recent advances in optical coherence tomography including *enhanced depth imaging* have significantly improved understanding of the choroid. The outer limit of the choroid and the sclera cannot usually be reliably identified using conventional spectral domain optical coherence tomography (SD-OCT) due to scattering of light from pigmented retinal pigment epithelium (RPE) layer as well as decreasing sensitivity and resolution with increasing displacement from zero-delay. In SD-OCT, depth information is encoded as different frequencies of the interference spectrum. With increasing depth into tissue, echoes occur further from the point of detection, which is known to be the ''zero delay line.'' For a retinal OCT, zero delay line is positioned at posterior vitreous to provide clear image of retinal structures. By moving the joystick closer to the eye, zero delay line is focused at the retinal structures to provide better resolution choroidal images. Image averaging, eye tracking, high-speed scanning and low speckle noise produce high-quality choroid images with EDI-OCT.[8]

Swept source OCT (SS-OCT) is another device that uses a frequency swept laser with a narrowband light source that is rapidly tuned over a broad optical bandwidth that enables the measurement of interference at different optical frequencies or wavelengths sequentially over time.[7] No spectrometer or line camera is needed for the Fourier transformation. This

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increases the imaging speed up to 300,000 axial scans per second and allows a deeper penetration of the sampling beam. SS-OCT offers several potential advantages over SD-OCT, including increased sensitivity through the full imaging depth, decreased fringe washout, better axial resolution over a broad imaging range, and higher detection efficiencies. Being a longer wavelength, it has the potential to image choroid much better than conventional SD-OCT.[9]

Choroidal imaging using different instruments

Choroidal imaging and thickness measurements have been reported with several commercially available OCT systems including the Cirrus (Carl Zeiss Meditec Inc, Dublin, CA, USA), Topcon 3DOCT 2000 (Topcon Corporation, Tokyo, Japan), Optovue RTVue (Optovue Inc., Fremont, CA, USA), Bioptigen (Bioptigen Inc., Research Triangle Park, NC, USA) and the Heidelberg Spectralis (Heidelberg Engineering, Heidelberg, Germany). Spectralis OCT has eye-tracking ability, low speckle noise and averaging (up to 100 B-scans). Cirrus HD-OCT (Carl Zeiss Meditec) lacks eye-tracking ability and can only perform 20 B-scans at a time for each measurement.[10]

Yamashita et al. performed subfoveal choroidal thickness measurements using three different SD-OCTs: Heidelberg Spectralis-OCT (Spectralis), Cirrus HD-OCT (Cirrus), and Topcon 3D OCT-1000 Mark II (Topcon) and reported a high intraclass correlation coefficients (up to 0.98) as well as high interrater correlation coefficients (up to 0.95) with Spectralis, Cirrus, and Topcon.[11] The intermachine correlation coefficient was also significantly high among the machines ($P < 0.001$, Spearman), 0.97 (Spectralis-Cirrus), 0.96 (Cirrus-Topcon), and 0.98 (Topcon-Cirrus). Similarly, Branchini et al. also reported a high reproducibility in choroidal thickness measurements among Zeiss Cirrus HD-OCT (Carl Zeiss Meditec Inc., Dublin, CA), Heidelberg Spectralis (Heidelberg Engineering, Heidelberg, Germany), and Optovue RTVue (Optovue Inc., Fremont, CA).[10]

While comparing choroidal thickness measurements between SD-OCT and SS-OCT, Matsuo et al. reported that the choroid measured with SS-OCT was thicker than that measured with SD-OCT instruments, and, thus, the choroidal thickness should not be compared between the SD-OCT and SS-OCT instruments.[12]

Choroidal thickness measurements

The choroidal thickness so far has been measured manually perpendicularly from the outer edge of the hyperreflective retinal pigment epithelium (RPE) to the inner sclera (choroid–sclera junction) at 500 microns interval from the fovea using the SD-OCT software. Choroidal thickness measurements in normal subjects appear to be highly reproducible.[13,14] Shao et al. reported very high reproducibility with a mean difference of 3.14 ± 13.1 μm between the observers.[15] Rahman et al. reported that a change >32 mm in subfoveal choroidal thickness probably exceeds interobserver variability.[14] Similarly, Chhablani et al. reported highly reproducible manual segmentation of choroid for choroidal volume measurements using the built-in automated retinal segmentation software on Spectralis SD-OCT.[16]

Choroidal imaging in healthy subjects

Subfoveal choroidal thickness was reported in normal range from 191 ± 74.2 to 354 ± 111 microns.[13,14,17–20] This variation could be due to the effect of ethnic differences also. The choroid is thickest subfoveally and thins nasally more than temporally. Inferior macular choroid has been measured thinner than the superior macular choroid.[21]

Barteselli et al. reported that the mean choroidal volume was $0.228 \pm 0.077\ mm^3$ for the center ring and $7.374 \pm 2.181\ mm^3$ for the total (Early Treatment Diabetic Retinopathy Study) ETDRS grid.[22] The nasal quadrant showed the lowest choroidal volume, and the superior quadrant showed the highest choroidal volume. The temporal and inferior quadrants did not show different choroidal volume values. Ouyang et al. reported that the thickest choroid was found in the outer superior subfield, whereas the thinnest choroid was located in the outer nasal subfield. They reported that the optic nerve head could be a better center to study the regional differences in choroidal thickness compared to foveal thickness.[21]

Factors affecting choroidal thickness

Age related choroidal thinning in healthy eyes have been reported by numerous studies.[13,18,20] Margolis et al.[18] reported 15.6 microns decrease in choroidal thickness every decade, similarly 14 microns decrease every decade was reported by Ikuno et al.[19] Ding et al. reported that this age-related thinning occurs only in age older than 60 years.[20]

Bidaut-Garnier et al. reported mean subfoveal choroidal thickness of 341.96 ± 74.7 μm in children.[23] Choroidal thickness correlated with age ($R^2 = 0.056$, $P = 0.0017$), height ($R^2 = 0.0292$, $P = 0.028$), and weight ($R^2 = 0.0274$, $P = 0.033$) but not with gender ($P = 0.25$). It was also inversely correlated to the axial length ($R^2 = 0.065$, $P = 0.0008$). The nasal choroid appeared thinner than in the temporal area ($P < 0.0001$). Read and Park associates reported similar results.[24,25] Read et al. reported choroidal thinning in myopic children compared to non-myopic children. They reported that the thinning of the choroid was greater than what would be predicted by a simple passive choroidal thinning with axial elongation.[26]

Wei et al. reported that the subfoveal thickness decreases by 15 microns for every increase in myopic refractive error of 1 D, or by 32 microns for every increase in axial length of 1 mm.[17] Fujiwara et al. reported that choroidal thickness decreases by 12.7 μm for each decade of life and by 8.7 μm for each diopter of increasing myopia.[27]

Gender might play a role in choroidal thickness. Li et al. reported that women have a thinner choroid than men.[28] In contrary, adult men have been reported to have thicker choroid than adult females.[22] However, in children, Mapelli et al.[29] reported a thicker choroid in females with slight significance ($P = 0.056$), similar to results from the Copenhagen Child Cohort 2000 Eye Study.[30] The reason proposed for this difference is that the puberty promotes choroidal thickening in girls, an effect that may be mediated by the pubertal growth spurt. Chen et al. reported no interocular difference in choroidal thickness with 95% limits of agreement of −80 to +83 microns.[31]