Choroidal Thickness Measurement in Highly Myopic Eyes Using SD-OCT

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BACKGROUND AND OBJECTIVE: To measure macular choroidal thickness (CT) using spectral-domain optical coherence tomography (OCT) and to investigate the correlation between CT and age, degree of myopia, and history of macular choroidal neovascularization (CNV).

PATIENTS AND METHODS: A cross-sectional study included 187 highly myopic eyes of 187 patients examined between January and December 2010. The choroid was imaged with spectral-domain OCT by changing the reference position from the vitreous to the choroid. CT was measured from the outer border of the hyperreflective line corresponding to the retinal pigment epithelium to the inner scleral border.

RESULTS: The mean age was 47.21 ± 14.24 years, the mean spherical equivalent refractive error was -13.66 ± 5.77, and the mean subfoveal CT was 100.71 ± 59.98 µm. CT was correlated negatively with age (P < 10^-3) and refractive error (P < 10^-3). Forty-two eyes had a history of CNV, the mean CT was 55.45 ± 24.46 µm, and this was significantly thinner than in eyes without CNV (P < 10^-3).

CONCLUSION: In highly myopic eyes, the choroid is thin and undergoes further attenuation with age and increasing myopia. In addition, these findings suggest that the choroid may play a role in the pathogenesis of CNV.

INTRODUCTION

High myopia is due to an excessive and progressive elongation of the globe resulting in multiple fundus changes, including lacquer cracks in Bruch’s membrane, choroidal neovascularization (CNV), and chorioretinal atrophy. The choroid accounts for most of the ocular blood flow and supplies nutrition to retinal pigment epithelium (RPE) cells and the outer retina. Thus, compromised choroidal circulation results in photoreceptor...
cell death and an irreversible, progressive, and severe loss of central visual function.\textsuperscript{1,3-7}

It is difficult to image the full thickness of the choroid because the pigment in the RPE and choroid impedes visualization by ophthalmoscopy, fundus photography, and fluorescein angiography.\textsuperscript{3,8,9} Indocyanine green angiography has good penetration, allowing visualization of choroidal vessels, but it does not provide cross-sectional information. Conventional B-scan ultrasonography provides poor axial and lateral resolution and has difficulty in differentiating the retina from the choroid.\textsuperscript{8,10} High-penetration OCT using a long-wavelength light source of approximately 1,050 nm allows visualization of the posterior choroid and sclera with higher scattering at the photoreceptors and pigment epithelium and a resultant lower signal from the deep choroidal tissue, but this device would not produce optimal retinal images.\textsuperscript{8,4,11,12}

Spectral-domain OCT (SD-OCT) uses an 830-nm infrared light source, which has high reflectivity and scattering at the RPE–Bruch’s membrane interface. This makes observations of the deep choroid difficult because the signal is attenuated, thus limiting studies of the deep choroid with OCT. However, patients with high myopia usually have choroidal thinning, which facilitates detection of the scleral interface.\textsuperscript{3}

The purpose of our study was to measure macular choroidal thickness using SD-OCT and investigate the correlation between choroidal thickness and age, degree of myopia, and history of macular CNV.

**PATIENTS AND METHODS**

A cross-sectional study was performed in 187 eyes of 187 patients with spherical equivalent of the refractive error greater than 6 diopters (D) of myopia and 49 healthy eyes matched for age examined at a referral center of medical retina in Tunisia between early January 2010 and early December 2010. The study was approved by the hospital’s ethics committee.

Patients enrolled in this study underwent a complete ophthalmic examination, including the recording of demographic data, the most recent refraction or the preoperative refraction in patients who had prior cataract or refractive surgery, best-corrected visual acuity (BCVA) testing, intraocular pressure measurement, dilated fundus examination, and fluorescein and indocyanine green angiography if necessary. Exclusion criteria included CNV due to causes other than myopia and history of retinal detachment or any vitreoretinal surgery.

OCT scans were performed with the 3D OCT-2000 (Topcon, Tokyo, Japan) with a wavelength of 840 nm, a scan rate of 27,000 A-scans per second, and an in-depth resolution of 5 to 6 µm. Reference position was set to “choroidal,” allowing us to obtain a tomogram with reduced noise at the choroid side, which is inside the retina. OCT scan patterns consisted of seven sections. The horizontal section going directly through the center of the fovea was used for choroidal thickness measurements.

The subfoveal choroid was measured from the outer portion of the hyperreflective line corresponding to the RPE to the inner surface of the sclera. In eyes with CNV, the subfoveal choroidal thickness was measured between Bruch’s membrane and the inner portion of the sclera. Measurements of subfoveal choroidal thickness were performed manually by two independent observers and the average of the two measurements was recorded and analyzed, with discrepancies greater than 15% being resolved by open adjudication with the senior author.

**Statistical Analyses**

The spherical equivalent of the refractive error was used for the statistical analyses. Snellen visual acuities were converted to logarithm of the minimum angle of resolution (LogMAR). The overall group was studied and then subgroup analysis of subfoveal choroidal thickness in eyes with and without CNV was performed. The Pearson coefficient was used to study the correlation between subfoveal choroidal thickness, age, and spherical equivalent of the refractive error. Multiple linear regression was used to evaluate age and spherical equivalent of the refractive error in regard to subfoveal choroidal thickness. A \( P \) value less than .05 was considered statistically significant. All data were analyzed using SPSS 13.0 (SPSS, Inc., Chicago, IL).

**RESULTS**

The mean age of the 187 examined patients with high myopia was 47.21 ± 14.24 years (range: 18 to 76 years) and 64 were men and 114 were women. The mean spherical equivalent of the refractive error was -13.66 ± 5.77 D (range: -6 to 26 D). The mean subfoveal choroidal thickness was 100.71 ± 59.98 µm (range: 23 to 278 µm) (Figure 1, Table 1).
TABLE 1

Clinical and Tomographic Characteristics in the Total Group and the Two Subgroups (Without CNV and With CNV) and Comparison Between the Two Subgroups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total Group</th>
<th>Without CNV</th>
<th>With CNV</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of eyes</td>
<td>187</td>
<td>145</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Mean age (y)</td>
<td>47.21 ± 14.24</td>
<td>46.53 ± 14.46</td>
<td>49.59 ± 13.32</td>
<td>.22</td>
</tr>
<tr>
<td>Mean SE (D)</td>
<td>-13.66 ± 5.77</td>
<td>-12.92 ± 5.97</td>
<td>-16.19 ± 4.34</td>
<td>.001</td>
</tr>
<tr>
<td>Mean subfoveal CT (µm)</td>
<td>100.71 ± 59.98</td>
<td>113.82 ± 60.87</td>
<td>55.45 ± 24.46</td>
<td>&lt; 10⁻³</td>
</tr>
</tbody>
</table>

CNV = choroidal neovascularization; SE = spherical equivalent of the refractive error; D = diopters; CT = choroidal thickness.

Figure 1. Cross-sectional imaging of the choroid using spectral-domain optical coherence tomography. Subfoveal choroidal thickness (CT) was measured vertically from the outer border of the retinal pigment epithelium to the inner border of the sclera. (A) CT of 255 µm in a normal eye of a 30-year-old man. (B) CT of 205 µm in an eye with -8.00 diopters (D) of a 20-year-old woman. (C) CT of 135 µm in an eye with -12.00 D of a 26-year-old man. (D) CT of 58 µm in an eye with -14.00 D of a 63-year-old man. (E) CT of 52 µm in an eye with -14.00 D of a 55-year-old woman.
The 49 healthy patients had a mean age of 47.36 ± 14.09 years (range: 19 to 72 years) \( (P = .947) \), a mean spherical equivalent of the refractive error of 0.229 ± 1.49 D (range: -3.5 to +3.5 D), and a subfoveal choroidal thickness of 280.04 ± 41.8 µm (range: 184 to 350 µm), which was significantly greater than subfoveal choroidal thickness in highly myopic eyes \( (P < 10^{-4}) \).

A significant correlation was found between age and the subfoveal choroidal thickness \( (r = -0.448, \ P < 10^{-3}) \) and between the spherical equivalent of the refractive error and subfoveal choroidal thickness \( (r = -0.755, \ P < 10^{-3}) \) (Figure 2, Table 2). Multiple linear regression resulted in a model with age and refraction as significant predictors of subfoveal choroidal thickness with regression \( (R^2) \) of 0.200 and 0.602, respectively \( (P < 10^{-3}) \) (Figure 2). The regression equation implied a decrease in subfoveal choroidal thickness of 0.97 µm per year of age \( (P < 10^{-3}) \) and a decrease of 7.3 µm per diopter of myopia \( (P < 10^{-3}) \) (Table 3).

There were 145 eyes with high myopia that did not have CNV. The mean age of these patients was 46.53 ± 14.46 years (range: 18 to 76 years) and 57 were men and 88 were women. The mean spherical equivalent of the refractive error was -12.92 ± 5.97 D (range: -6 to 26 D). The mean subfoveal choroidal thickness was 113.82 ± 60.87 µm (range: 26 to 278 µm, Table 1). A significant correlation was found between age and the subfoveal choroidal thickness \( (r = -0.494, \ P < 10^{-3}) \) and between the spherical equivalent of the refractive error and subfoveal choroidal thickness \( (r = 0.793, \ P < 10^{-3}) \). Multiple linear regression resulted in a model with age and refraction as significant predictors of subfoveal cho-
roidal thickness with regression ($R^2$) of 0.243 and 0.629, respectively ($P < 10^{-3}$) (Figure 2).

Forty-two eyes with high myopia had CNV. The mean age of these patients was 49.59 ± 13.32 years (range: 23 to 74 years) and 13 were men and 29 were women. Five eyes were treated with photodynamic therapy, 26 eyes were treated with intravitreal injection of bevacizumab, and 11 eyes were treated with both photodynamic therapy and intravitreal injection of bevacizumab. The mean spherical equivalent of the refractive error was -16.19 ± 4.34 D (range: -8 to 24 D), which was greater than the eyes without CNV ($P = .001$) (Table 1). The mean choroidal thickness was 55.45 ± 24.46 µm, and this was significantly thinner than in the subgroup without CNV ($P < 10^{-3}$) (Table 1). The regression equation implied a decrease in subfoveal choroidal thickness of 0.899 µm per year of age ($P < 10^{-3}$) and a decrease of 7.229 µm per diopter of myopia ($P < 10^{-3}$) (Table 3). No correlation was found between age and choroidal thickness, but a negative correlation was found between spherical equivalent of the refractive error and subfoveal choroidal thickness ($r = 0.572, P = .001$). The mean subfoveal choroidal thickness was less in eyes with previous photodynamic therapy (48.25 ± 4.91) compared to eyes with only intravitreal injection of bevacizumab (59.88 ± 5.17), but the difference was not statistically significant ($P = .111$).

**DISCUSSION**

In our study, mean subfoveal choroidal thickness in eyes with high myopia was 99.74 ± 59.7 µm. This value is significantly thinner than in healthy eyes in our study and in the reported choroidal thickness in normal eyes, which varies from 287 to 354 µm. Histological studies have demonstrated choroidal thinning and disappearance of the lamina of small choroidal vessels in highly myopic eyes.

The subfoveal choroidal thickness was inversely proportional to age with a decrease of 0.96 µm per year. This rate was comparable to the rate of choroidal thinning reported in normal eyes (1.56 µm/year) and in histological examination (1.1 µm/year). The choroid being a vascular structure, it may undergo structural and functional aging changes much like other microvasculature in the body. The microvascular loss may decrease the ability of the choroid to supply proper levels of oxygen and other metabolites to the RPE and outer retina. Our results also showed that the central choroidal thickness was significantly thinner in eyes with higher myopia ($P < 10^{-3}$). These results were comparable to those reported by Fujiwara et al, Ikuno et al, and Takahashi et al.

Histological studies of highly myopic eyes have shown several choroidal modifications, including the disappearance of large vessels and/or capillaries, displacement by fibrous tissue, the disappearance or disturbance of the RPE layer, and the consequent loss of the photoreceptors and outer retinal layers after severe choroidal atrophy.

The current study showed that choroidal thinning is more prominent in myopic eyes complicated by CNV with a mean subfoveal choroidal thickness of 51.71 ± 17.35 µm, which was comparable to the choroidal thickness reported in the literature (62.3 to 64.8 µm).
According to Wakabayashi and Ikuno,13 one mechanism is that the choriocapillaris, which is believed to be a major source of vascular endothelial growth factor, and the choroidal thinning at the fovea may lead to outer retinal hypoxic changes via factors such as hypoxia-inducible factor, resulting in vascular endothelial growth factor secretion at the fovea.18,19 Furthermore, Ikuno et al.20 identified choroidal thinning resulting from increased RPE/choroid curvature as a risk factor for myopic CNV.

This study has several limitations. There is currently no automated software to measure the choroidal thickness, and therefore all measurements were performed manually. The degree of myopia was not determined by axial length measurements but by automated refraction, unrecognized systemic conditions could have affected the thickness measurements, and the reproducibility of choroidal thickness measurements has not been well established.

This study showed that the choroid in highly myopic eyes is thin and undergoes further thinning with increasing age and degree of myopia. These findings suggest that abnormalities of the choroid may play a role in the pathogenesis of myopic degeneration and thus visual impairment. Additional study of the choroidal structure, associated with other studies of choroidal circulation, may provide useful insights into the disease and the potential for both diagnostic and treatment information.

REFERENCES