Macular Choroidal Thickness in Unilateral Amblyopic Children

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PURPOSE. To investigate the choroidal thickness (CT) in children with amblyopia through spectral-domain optical coherence tomography (SD-OCT).

METHODS. Thirty-seven children with unilateral amblyopia and 22 children with normal vision participated in the study. Cross-sectional images of the choroid of evaluated eyes were obtained by SD-OCT. The choroidal thickness was measured directly below the fovea and at eight other locations: 1 and 2 mm superior, temporal, inferior, and nasal to the fovea. The researchers compared the choroidal thickness among amblyopic eyes, fellow eyes of children with amblyopia, and the eyes of children with normal vision. Age, sex, refractive error, axial length, and best-corrected visual acuity were also recorded. A paired t-test was used to compare measurements between amblyopic eyes and fellow eyes in patients with amblyopia. A generalized estimating equation (GEE) was used to compare measurements among amblyopic eyes, fellow eyes, and control eyes, adjusting for the possible effects of age, sex, and axial length on CT. The correlation between choroidal thickness and other continuous variables was determined using the Pearson correlation coefficient.

RESULTS. The choroidal thickness at the fovea, 1 and 2 mm superior, 1 mm inferior, 1 mm nasal, and 1 mm temporal to the fovea was greater in amblyopic eyes and in fellow eyes of children with amblyopia than in the eyes of children with normal vision. The choroidal thickness at the fovea and 2 mm nasal to the fovea in amblyopic eyes was greater (P = 0.002, \( P = 0.043 \)) than in the fellow eyes of the children with amblyopia. The subfoveal CT in amblyopic eyes negatively correlated with axial length (r = –0.501, P = 0.002), but did not correlate with spherical equivalent, logMAR visual acuity, or age.

CONCLUSIONS. In the subfoveal area, the choroid was thicker in amblyopic eyes than in fellow eyes in children with amblyopia. Furthermore, differences were found in the choroidal thickness in both eyes of children with amblyopia compared with participants with normal vision. A thicker choroid is somehow related to amblyopia, and this may be a useful diagnostic parameter for amblyopia.

Keywords: choroidal thickness, OCT, amblyopia

Amblyopia is a developmental disorder of vision in which there is reduced visual acuity (typically unilateral), despite optimal refractive correction, in an eye that is structurally normal and free from pathology.1 The visual deficit is associated with the presence in early life of strabismus, anisometropia, or, less commonly, an obstruction along the visual axis (e.g., congenital cataract).2,3 Results of several human and animal investigations indicate that during the neonatal period, visual deprivation has an effect on the growth of cells in the lateral geniculate body4,5 and the visual cortex.9 Further, recent studies suggest that the amblyopic eye also may have retinal abnormalities, including changes to the retinal ganglion cells, the retinal nerve fiber layer (RNFL), and the optic nerve.7–10

The choroid is an integral structure in the eye that accounts for most of the ocular blood flow. It supplies nutrients to retinal pigment epithelial cells and the outer retina and contributes to the blood supply of the preliminary portion of the optic nerve. Thus, the choroid is of paramount importance to retinal and visual function. Thinning of the choroid may be involved in many retinal or optic nerve diseases, such as glaucoma,11 age-related macular degeneration,12 and diabetic retinopathy.13 In contrast, the choroid has been reported to be significantly thicker in central serous chorioretinopathy14 and Vogt-Koyanagi-Harada disease.15 In addition, some studies have found retinal abnormalities in amblyopic eyes.7–10 These findings suggest that the choroid may be involved in amblyopia. However, it is difficult to image the full thickness of the choroid because of the RPE layer.16 Recently, visualization of the choroid has become possible using commercial spectral domain optical coherence tomography (SD-OCT) instruments. Using SD-OCT, a variety of ocular pathologies were found to have primary or associated pathology located in the macular choroidal region, including central serous chorioretinopathy and myopia.17–19

The purpose of this study was to assess changes in the choroid in the amblyopic eyes, relative to fellow eyes, in
patients with amblyopia compared with the eyes of age-matched children with normal vision using SD-OCT.

METHODS

Ethics Statement
The review board of Wenzhou Medical University approved the study, which was performed according to the tenets of the Declaration of Helsinki for research involving human subjects. All child participants and their parents received information about the study and signed an informed consent document.

Inclusion and Exclusion Criteria
The inclusion criteria included the following: subjects needed to be aged younger than 12 years, be diagnosed with amblyopia (strabismic or anisometropic), have visual acuity in the amblyopic eye between 20/32 and 20/400, and have 20/20 or better vision in the other eye. Treatment status was not considered for study enrollment. Anisometropia was defined as an interocular cycloplegic spherical equivalent difference or astigmatism difference of 1.5 diopters (D) or more. Twenty-three children aged younger than 12 years with refractive error between −0.50 square diopters (DS) and +0.50 DS and visual acuity equal to or better than 20/20 in each eye were enrolled as control subjects. Exclusion criteria included: patients with organic eye disease, a history or evidence of intraocular surgery, history of cataract, glaucoma, retinal disorders, or laser treatment and children not cooperative enough for OCT examination.

Ophthalmic Examination
Cycloplegic refraction was performed 30 minutes after the use of three drops of cyclopentolate 1% (Cyclogyl; Alcon Couvreur, Purrs, Belgium), previously administered at 5-minute intervals. The refraction was measured with a table-mounted autorefractor (model KR-8900; Hasunuma-cho, Itabashi-ku, Tokyo, Japan). Five consecutive autorefractor readings were obtained from each subject, all of which were required to be within 0.25 D of each other. Spherical equivalent (SE) was calculated as the sum of the spherical plus the cylinders. Half of the cylindrical error. Clinical examinations included best-corrected visual acuity, reductive error, slit lamp examination, extraocular movements, intraocular pressure, an ophthalmoscopic exam, and axial length (using IOLMaster, version 5.0; Carl Zeiss Meditec, Jena, Germany).

Measurement of Choroidal Thickness
All subjects were examined using an enhanced depth imaging (EDI)s system (Spectralis OCT; Heidelberg Engineering, Heidelberg, Germany; wavelength: 870 nm; scan pattern: enhanced depth imaging), as reported previously.20,21 All examinations were performed between 3 and 5 PM to avoid diurnal variation.22 The right eye was studied first, followed by the left eye. The center of each volumetric measurement was adjusted to the center of the fovea. We averaged the EDI image for 100 scans using the automatic averaging system. Choroidal thickness was measured from the outer portion of the hyper reflective line corresponding to the RPE to the inner surface of the sclera (Fig. 1). The 1-line raster is a 6-mm line consisting of 4096 A-scans. In order to be included in this study, the images had to be at least 6 out of 10 in intensity and taken as close to the fovea as possible; therefore, the researchers chose to image the thinnest point of the macula, with the understanding that slight differences in positioning could affect the measured thicknesses. Using the electronic caliper within the OCT, the CT under the fovea was measured from the line corresponding to the Bruch’s membrane beneath the RPE to the inner scleral border in both the horizontal and the vertical scans. The average value of the measurement from the horizontal and vertical scans was defined as the subfoveal CT. Two observers, masked to whether the child was amblyopic or had normal vision, determined measurements. Each observer measured the same eye twice. Choroidal thickness was measured under the fovea using the scale supplied with the software, and at 1-mm intervals from the fovea to a distance of 2 mm in the nasal, temporal, superior, and inferior directions. The two observers discussed and repeated the measurements when there were discrepancies of more than 15% of the mean of the two values between the observers in two eyes in the study. The average thickness of the results from the two observers was used as the final CT reading.

Statistical Analysis
Statistical analysis was performed using statistical software (SPSS version 17.0; SPSS, Inc., Chicago, IL, USA). Descriptive...
statistical significance was assumed at \( P < 0.05 \).

### RESULTS

#### Demographic Data

A total of 39 patients with unilateral amblyopia were enrolled in the study. Of the 39 children with amblyopia that were enrolled, 37 were used for the analysis of choroidal thickness. Two were excluded due to poor scan image quality. Of the 37 children with normal vision, 22 were used for the analysis of choroidal thickness. One child was excluded due to a technical error in measuring axial length.

All children were Chinese. Among 37 patients with unilateral amblyopia, 25 were male and 12 were female. The mean age \( \pm SD \) was 8.51 \( \pm 2.00 \) (range from 5 to 12 years). Eleven patients had amblyopia in their right eye and 26 patients had amblyopia in their left eye. Best-corrected visual acuity in the amblyopic eye was between 20/52 and 20/400. Visual acuity in the fellow eye was equal to or better than 20/20 (Table 1).

Among 37 patients with unilateral amblyopia, 16 had strabismic amblyopia (which was not mixed anisometropia) and 21 had anisometropic amblyopia. Of the subjects with strabismic amblyopia, 11 were amblyopic with exotropia, four were amblyopic with exotropia, and one was amblyopic with dissociated vertical deviation.

The refractive error and axial length of the patients with amblyopia and control subjects are listed in Table 1. There was no significant difference between amblyopic eyes and fellow eyes in refractive error or axial length \( (P = 0.403, P = 0.303, \text{respectively, ANOVA LSD}) \) in subjects with strabismus. However, both amblyopic eyes and fellow eyes were more hyperopic than normal control eyes \( (P < 0.001, P < 0.001 \text{ANOVA LSD}) \), and the axial length was shorter in both amblyopic eyes and fellow eyes in subjects with strabismic amblyopia than in control eyes \( (P < 0.001, P = 0.006 \text{ANOVA LSD least significant difference [LSD]}) \). In patients with anisometropic amblyopia, the refractive error was more hyperopic, \( (P < 0.001, P < 0.001 \text{ANOVA LSD}) \), and the axial length was shorter \( (P < 0.001, P < 0.001 \text{ANOVA LSD}) \) in amblyopic eyes than in fellow eyes and in control eyes. There was no significant difference between fellow eyes and control eyes in refractive error \( (P = 0.106 \text{ANOVA LSD}) \) nor in axial length \( (P = 0.996 \text{ANOVA LSD}) \).

#### CT Between Amblyopic Eyes and Fellow Eyes in Children With Amblyopia

Using a paired \( t \)-test, the difference in subfoveal CT between the amblyopic eyes and the fellow eyes in children with unilateral amblyopia was statistically significant \( (P < 0.001) \). The mean subfoveal CT in amblyopic eyes was 349.08 \( \pm 56.40 \) \( \mu \)m, whereas the mean subfoveal CT in fellow eyes was 302.37 \( \pm 47.32 \) \( \mu \)m. The 1 mm superior, 1 mm inferior, 1 mm nasal, 2 mm inferior, and 2 mm nasal CT measurements were also statistically different between amblyopic and fellow eyes. Using the GEE with adjustment for axial length, only the subfoveal CT and CT at 2 mm nasal differed significantly between the amblyopic eyes and fellow eyes \( (P = 0.002, P = 0.043; \text{Table 2}) \).

#### CT in Anisometropic Amblyopic Eyes and Fellow Eyes in Children With Amblyopia

In the 21 patients with anisometropia, the CT measurements at the fovea, 1 mm superior, 1 mm inferior, 1 mm nasal, 2 mm inferior, and 2 mm nasal between amblyopic eyes and fellow
eyes were statistically significant using a paired \( t \)-test. When using the GEE with adjustment for axial length, only the CT at 2 mm superior and 2 mm nasal were significantly different between amblyopic eyes and fellow eyes (\( P = 0.045, P = 0.010 \); Table 3).

**CT in Strabismic Amblyopic Eyes and Fellow Eyes in Children With Amblyopia**

In the 16 strabismic patients with amblyopia, the differences of CT at the fovea and 1 mm superior to the fovea between amblyopic eyes and fellow eyes were statistically significant (\( P = 0.003, P = 0.047 \)) when using the paired \( t \)-test. After using the GEE analysis with adjustment for axial length, CT at the fovea and 1 mm superior fellow eyes were also greater in amblyopic eyes than in fellow eyes (\( P < 0.001, P = 0.044 \); Table 4).

**CT Between Patients With Amblyopia and Control Subjects**

For the emmetropic normal control group, the subfoveal CT was 265.04 ± 64.99 \( \mu \)m in right eyes and 261.66 ± 57.82 \( \mu \)m in left eyes; there was no significant difference between the eyes (paired \( t \)-test). For the control group, one eye was used for analysis: the right eye in 11 subjects and left eye in 11 subjects.

The subfoveal CT and 1 mm around subfoveal CT measurements were larger in both eyes of subjects with amblyopia compared with those in control eyes using the GEE, after adjusting for age, sex, and axial length. At the 2 mm inferior and the 2 mm temporal to the fovea, there were no significant differences between amblyopic eyes and control eyes, as well as between fellow eyes and control eyes (Table 5).

**Distribution of CT in Normal Control Eyes, Fellow Eyes, and Amblyopic Eyes**

In amblyopic eyes, fellow eyes, and control eyes, CT at 2 mm temporal was the thinnest. In amblyopic and fellow eyes, CT at 1 mm diameter of inferior, nasal, and temporal was larger than CT at 2-mm diameter. In control eyes, there was no significant difference between 1 and 2 mm measurements in superior, inferior, and temporal (\( P = 0.054, P = 0.324, P = 0.813 \), respectively, repeated ANOVA). The thickness distribution patterns were consistent among amblyopic eyes, fellow eyes, and control eyes in comparing CT at the nine locations (Fig. 2).

**Correlations Between Subfoveal CT and Age, Axial Length, and Spherical Equivalent in Amblyopic Eyes**

Pearson correlation was used to determine correlations between CT at the fovea and the spherical equivalent, age, and axial length of amblyopic eyes. Subfoveal CT was negatively correlated with axial length (\( r = -0.501, P = 0.002 \)), but was not correlated with spherical equivalent (\( r = 0.024, P = 0.890 \), logMAR VA (\( r = -0.011, P = 0.947 \)), or age (\( r = -0.305, P = 0.067 \)).

**DISCUSSION**

The results in this study revealed bilateral changes of CT in children with unilateral amblyopia compared with children with normal vision. Choroidal thickness at the fovea in unilateral amblyopic eyes measured by SD-OCT was much greater than in fellow eyes and in control eyes of children with

<table>
<thead>
<tr>
<th>Variable</th>
<th>Amblyopic Eye, ( \mu )m</th>
<th>Fellow Eye, ( \mu )m</th>
<th>Paired ( t )-Test (2-tailed) ( t )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subfoveal</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>3.604</td>
<td>0.002</td>
</tr>
<tr>
<td>1 mm superior</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>2.980</td>
<td>0.007</td>
</tr>
<tr>
<td>1 mm inferior</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>2.980</td>
<td>0.007</td>
</tr>
<tr>
<td>2 mm superior</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>1.777</td>
<td>0.091</td>
</tr>
<tr>
<td>2 mm inferior</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>2.290</td>
<td>0.035</td>
</tr>
<tr>
<td>2 mm nasal</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>3.618</td>
<td>0.002</td>
</tr>
<tr>
<td>2 mm temporal</td>
<td>56.30 ± 34.97</td>
<td>56.30 ± 34.97</td>
<td>1.821</td>
<td>0.084</td>
</tr>
</tbody>
</table>

Distribution of CT in Normal Control Eyes, Fellow Eyes, and Amblyopic Eyes

Table 2. Choroidal Thickness Between Amblyopic and Fellow Eyes in Amblyopic Group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Amblyopic Eye, ( \mu )m</th>
<th>Fellow Eye, ( \mu )m</th>
<th>Paired ( t )-Test (2-tailed) ( t )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subfoveal</td>
<td>349.08 ± 56.40</td>
<td>302.37 ± 47.32</td>
<td>4.961</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1 mm superior</td>
<td>351.98 ± 55.05</td>
<td>298.34 ± 57.88</td>
<td>3.714</td>
<td>0.001</td>
</tr>
<tr>
<td>1 mm inferior</td>
<td>314.49 ± 54.16</td>
<td>285.48 ± 49.60</td>
<td>3.180</td>
<td>0.003</td>
</tr>
<tr>
<td>1 mm nasal</td>
<td>510.10 ± 71.50</td>
<td>271.95 ± 60.89</td>
<td>2.813</td>
<td>0.008</td>
</tr>
<tr>
<td>1 mm temporal</td>
<td>317.72 ± 66.13</td>
<td>312.01 ± 52.06</td>
<td>0.521</td>
<td>0.605</td>
</tr>
<tr>
<td>1 mm superior</td>
<td>308.08 ± 70.50</td>
<td>287.21 ± 69.97</td>
<td>1.995</td>
<td>0.054</td>
</tr>
<tr>
<td>2 mm superior</td>
<td>289.25 ± 57.64</td>
<td>269.21 ± 46.83</td>
<td>2.098</td>
<td>0.043</td>
</tr>
<tr>
<td>2 mm nasal</td>
<td>256.94 ± 67.63</td>
<td>212.82 ± 67.09</td>
<td>2.981</td>
<td>0.005</td>
</tr>
<tr>
<td>2 mm temporal</td>
<td>279.84 ± 77.12</td>
<td>298.90 ± 66.96</td>
<td>1.286</td>
<td>0.206</td>
</tr>
</tbody>
</table>

Distribution of CT in Normal Control Eyes, Fellow Eyes, and Amblyopic Eyes

Table 3. Choroidal Thickness Between Amblyopic and Fellow Eyes in Children With Anisometric Amblyopia

<table>
<thead>
<tr>
<th>Variable</th>
<th>Amblyopic Eye, ( \mu )m</th>
<th>Fellow Eye, ( \mu )m</th>
<th>Paired ( t )-Test (2-tailed) ( t )</th>
<th>( P )</th>
</tr>
</thead>
</table>
normal vision. Furthermore, the subfoveal CT in fellow eyes of children with unilateral amblyopia was much greater than in those of the control group.

Little is known about the pathologic association between CT and overlying retinalopathies in amblyopia. Nishi\textsuperscript{25} studied the choroidal thickness in children with hyperopic anisometric amblyopia and found that the subfoveal CT was larger in amblyopic eyes than in fellow eyes and in control eyes, but there was no difference in subfoveal CT between fellow eyes and control eyes. Results from our study showed similar findings: subfoveal CT in anisometropic amblyopic eyes was larger than in fellow eyes. We also found CT in fellow eyes of subjects with anisometric amblyopia was larger than in control eyes. Furthermore, there were some differences between our study and Nishi’s. First, Nishi only studied CT in patients with anisometric amblyopia, whereas we included patients with anisometric amblyopia as well as strabismic amblyopia. Second, the refractive error was different between this study and Nishi’s. In Nishi’s study, the mean refractive error was $+5.97 \pm 1.86$ D in anisometropic amblyopic eyes, $+1.92 \pm 1.56$ D in fellow eyes, and $+2.75 \pm 2.38$ D in control eyes. The mean refractive error of amblyopic eyes was significantly more hyperopic than that of the fellow eyes; while the difference between amblyopic eyes and control eyes was not significant. In this study, the mean refractive error was $+4.29 \pm 1.84$ D in anisometropic amblyopic eyes, $+0.73 \pm 0.92$ D in fellow eyes in the anisometropic group, and $-0.02 \pm 0.28$ D in control eyes. The refractive error of amblyopic eyes was more hyperopic than in fellow eyes and in control eyes. There was no significant difference between fellow eyes and control eyes in refractive error. While the differences of refractive error could have some effect on the different outcomes seen in these two studies, the different ethnic groups evaluated, the relatively small sample sizes of amblyopia cases, and the lack of population-based control subjects were the main reasons for the inconsistencies between the results of our study and Nishi et al.

The choroid is a highly vascular structure that provides nutrients to ocular structures\textsuperscript{24} Its blood flow and thickness vary relative to intraocular pressure, perfusion pressure, and vascular regulatory factors.\textsuperscript{25–29} To date, there have been several reports of the normal range of foveal choroidal thickness in healthy eyes obtained by the use of various systems,\textsuperscript{20,30–35} which is reported to be between 272 and 448 μm. In the present study, subfoveal CT in children with normal vision was $265.24 \pm 59.78$ μm. The four previous studies using OCT to examine in vivo choroidal thickness in children have reported mean subfoveal choroidal thickness values of $357$ μm (from 23 Japanese children aged younger than 20 years)\textsuperscript{36}; $343$ μm (from 30 Korean children aged 4–10 years)\textsuperscript{37}; $315$ μm (from 43 children aged 3–18 years)\textsuperscript{38}; $330$ μm (from 194 Australians aged 4–12 years)\textsuperscript{39}. In this study, all of the children were Chinese, and all of the children with normal vision were emmetropic. These results may differ due to the measuring software or the OCT light source, differences in ethnicity, or differences in patient profiles, such as age, refractive error, or axial length.

Currently, the causative mechanism of amblyopia is thought to be the lack of adequate visual stimulation to the fovea during infancy, abnormal binocular interaction, incongruence of visual information received by the two eyes, or a mixture of these problems.\textsuperscript{40} Some researchers have reported that amblyopia is also associated with changes in retinal thickness\textsuperscript{7–9} and RNFL thickness.\textsuperscript{10,41} Yen\textsuperscript{42} hypothesized that the normal postnatal reduction (apoptosis) of retinal ganglion cells is arrested in amblyopia and predicted that this would cause increased RNFL thickness. Huynh\textsuperscript{2} suggested that the arrest of normal postnatal changes may result not only in increased RNFL thickness, but also would affect the normal maturation of the macula.

### Table 4. Choroidal Thickness Between Amblyopic and Fellow Eyes in Children With Strabismic Amblyopia

<table>
<thead>
<tr>
<th>Variable</th>
<th>Amblyopic Eye, μm</th>
<th>Fellow Eye, μm</th>
<th>Paired t-Test (2-tailed)</th>
<th>GEE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$t$</td>
<td>$P$</td>
</tr>
<tr>
<td>Subfoveal</td>
<td>349.23 ± 51.23</td>
<td>308.95 ± 54.44</td>
<td>3.558</td>
<td>0.003</td>
</tr>
<tr>
<td>1 mm superior</td>
<td>328.12 ± 57.97</td>
<td>298.58 ± 61.96</td>
<td>2.161</td>
<td>0.047</td>
</tr>
<tr>
<td>1 mm inferior</td>
<td>304.92 ± 45.79</td>
<td>296.39 ± 54.11</td>
<td>0.527</td>
<td>0.599</td>
</tr>
<tr>
<td>1 mm nasal</td>
<td>302.21 ± 52.04</td>
<td>285.40 ± 60.93</td>
<td>1.179</td>
<td>0.257</td>
</tr>
<tr>
<td>1 mm temporal</td>
<td>320.72 ± 55.42</td>
<td>306.65 ± 62.63</td>
<td>1.120</td>
<td>0.281</td>
</tr>
<tr>
<td>2 mm superior</td>
<td>290.22 ± 57.58</td>
<td>277.96 ± 77.97</td>
<td>0.910</td>
<td>0.377</td>
</tr>
<tr>
<td>2 mm inferior</td>
<td>284.35 ± 41.25</td>
<td>279.89 ± 53.81</td>
<td>0.380</td>
<td>0.709</td>
</tr>
<tr>
<td>2 mm nasal</td>
<td>231.84 ± 44.24</td>
<td>233.65 ± 60.38</td>
<td>−0.158</td>
<td>0.876</td>
</tr>
<tr>
<td>2 mm temporal</td>
<td>290.85 ± 82.20</td>
<td>285.81 ± 78.83</td>
<td>0.248</td>
<td>0.807</td>
</tr>
</tbody>
</table>

### Table 5. Choroidal Thickness Between Children With Amblyopia and Children With Normal Vision (GEE)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Amblyopic Eyes, μm</th>
<th>Fellow Eyes, μm</th>
<th>Control Eyes, μm</th>
<th>Amblyopic Eyes vs. Control Eyes</th>
<th>Fellow Eyes vs. Control Eyes</th>
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<td>$P_1$</td>
<td>$Z_2$</td>
<td>$P_2$</td>
<td>$Z_1$</td>
</tr>
<tr>
<td>Subfoveal</td>
<td>349.08 ± 56.40</td>
<td>302.37 ± 47.32</td>
<td>265.24 ± 59.78</td>
<td>3.74</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1 mm superior</td>
<td>331.98 ± 55.05</td>
<td>298.34 ± 57.88</td>
<td>253.52 ± 51.90</td>
<td>5.39</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1 mm inferior</td>
<td>314.49 ± 54.16</td>
<td>285.48 ± 49.60</td>
<td>246.79 ± 61.25</td>
<td>3.61</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1 mm nasal</td>
<td>310.10 ± 71.30</td>
<td>271.95 ± 60.89</td>
<td>224.69 ± 59.17</td>
<td>2.97</td>
<td>0.003</td>
</tr>
<tr>
<td>1 mm temporal</td>
<td>317.72 ± 66.15</td>
<td>312.01 ± 52.06</td>
<td>264.59 ± 55.24</td>
<td>2.49</td>
<td>0.013</td>
</tr>
<tr>
<td>2 mm superior</td>
<td>308.08 ± 70.50</td>
<td>287.23 ± 69.97</td>
<td>235.61 ± 41.98</td>
<td>7.26</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2 mm inferior</td>
<td>289.25 ± 57.64</td>
<td>269.21 ± 46.83</td>
<td>254.51 ± 63.80</td>
<td>1.90</td>
<td>0.057</td>
</tr>
<tr>
<td>2 mm nasal</td>
<td>256.94 ± 67.65</td>
<td>212.82 ± 67.09</td>
<td>178.46 ± 57.81</td>
<td>3.15</td>
<td>0.002</td>
</tr>
<tr>
<td>2 mm temporal</td>
<td>279.84 ± 77.12</td>
<td>298.90 ± 66.96</td>
<td>266.42 ± 61.83</td>
<td>0.97</td>
<td>0.333</td>
</tr>
</tbody>
</table>
and 2 mm measurements in superior, inferior, and nasal directions. In amblyopic eyes, CT at the fovea was the thinnest. Choroidal thickness at 1 mm from fovea was larger than CT at 2 mm from fovea in superior, inferior, nasal, and temporal directions (P = 0.011, P < 0.001, P < 0.001, P < 0.001, respectively). In fellow eyes, CT at the fovea was larger than in inferior and nasal measurements 1 and 2 mm from the fovea. CT at inferior, nasal, and temporal points 1 mm from the fovea was larger than at 2 mm. In control eyes, CT was larger at the fovea than 1 mm inferior or nasal and 2 mm superior or nasal. There was no significant difference between 1 and 2 mm measurements in superior, inferior, and temporal (P = 0.054, P = 0.324, P = 0.813, respectively). The error bars in both figures represent ±1 standard deviation.

including movement of Henle’s fibers away from the fovea and a decrease in foveal cone diameter. This would result in increased foveal thickness. The primary role of the choroid is to nourish and thermo-regulate the retina. In amblyopic eyes, there are more Henle’s fibers in the fovea and the foveal cone diameter is larger than in normal eyes. A thicker retina may need more blood to nourish it. Thus, the choroid may thicken to supply more blood to the retina.

These researchers found that, in patients with amblyopia, both in the amblyopic eyes and in fellow eyes, subfoveal CT measurements were larger than in eyes of children with normal vision. There are some studies that found deviations in both amblyopic eyes and fellow eyes in children with unilateral amblyopia compared with individuals with normal vision. Huang reported that in anisometropic amblyopia, the functional imbalance between the two eyes may lead to permanent changes that affect not only the visual pathway associated with the amblyopic eye, but also the pathway associated with the fellow eye. Bruce found differences in the foveal structure in both eyes of 85 subjects with amblyopia compared with 110 subjects with normal vision, including increased foveal thickness, reduced pit depth, and flattening of the nasal and temporal sides of the foveal pit. Other investigators observed bilateral structural defects of the retina in animal models of unilateral amblyopia, both in lid suture and optical defocus, even in the nondefocused eyes of animals that have been unilaterally blurred. In the study by Sloper, the parvocellular cells associated with both the deprived and undeprived eyes shrank almost equally by 25% to 30% after a period of monocular deprivation. These parvocellular lateral geniculate nucleus (LGN) cells are the target cells for the retinal ganglion cells, and this may further support a retrograde effect on the retina. From this, the present authors purport that amblyopia is a complex disease that affects both eyes on various levels of the eyes and visual pathway, including the visual cortex, the lateral geniculate nucleus, and the structure of the retina and choroid.

Besides providing metabolic support to the RPE and the outer retina, the choroid has been shown to regulate ocular growth and may play a role in the development of refractive error. In animal models, hyperopic defocus has been shown to rapidly result in thinning of the choroid while myopic defocus can result in thickening of the choroid. Nishi hypothesized that in patients with amblyopia, young children’s hyperopic defocus causes choroidal thinning in fellow eyes and control eyes; however, in amblyopic eyes, this choroidal compensation does not occur, thus, the subfoveal CT was larger and the ocular growth was limited. Troilo et al. reports that in monkeys, monocular lid suture early in life initially results in short, hyperopic eyes and a thicker choroid than in fellow eyes and in control eyes. Furthermore, the last 2 or 4 weeks of monocular lid suture at age 10 to 17 days may also lead to deprivation amblyopia in these monkeys. While this can explain the thicker choroid in anisometropic amblyopic subjects, it fails to explain the findings that the thicker choroid in strabismic amblyopic eyes, even though there was no difference in refractive error between the two eyes. Therefore, the present authors speculate that the hypothesis is insufficient in explaining the larger CT in amblyopic eyes in both anisometropic amblyopia and strabismic amblyopia.

Some studies investigated the correlation of retinal thickness and logMAR VA in eyes with amblyopia and found that the logMAR VA is not correlated with either retinal thickness or structure. Dickmann et al. found that macular thickness (MT) both in strabismic amblyopia and anisometropic amblyopia had no relationship to logMAR VA, and macular sensitivity was not correlated with logMAR VA. Pang et al. also failed to find a correlation between interocular difference in MT and logMAR VA in high myopia. Chen et al. also found that during the recovery of the VA after treatment, thinning of the fovea was not associated with VA improvement. Similarly, in the present study, subfoveal CT was not correlated with logMAR VA. To the best of our knowledge, there was no other report of the correlation between the CT and logMAR VA in eyes with amblyopia. Studies above and ours indicate that a greater MT or CT may be correlated with amblyopia but are unrelated to the degree of amblyopia.

There are some limitations to our study. The sample size of amblyopic eyes was small. Although the use of EDI OCT allowed for the CT to be evaluated with a lesser number of images than previously reported, the OCT used in this study did not combine the eye tracking system, and thus may present a weakness in obtaining images from the patients with poorer fixation. In addition, the measurements of the CT were manually performed in a retrospective manner, and automated
software will be required for a more objective evaluation. Lastly, as noted by Wagner-Schuman et al., the shorter axial length in hyperopia affects the lateral scale of OCT data sets for peripheral measurements. The presence of significant hyperopia (or shorter axial length) means that measurements of thickness taken nominally at 1 and 2 mm are actually taken at a slightly less peripheral location than for an emmetropic control eye. The peripheral locations may appear to have greater choroidal thickness in children with hyperopic amblyopia than their nominal locations despite this difference being minimal. Future studies are anticipated where researchers will correct for axial length in measuring CT at peripheral locations.

In the future, the researchers plan to follow children with amblyopia to evaluate changes in the choroid during treatment to determine further relationships between the choroid and amblyopia.

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