Choroidal Thickness In and Outside of Vascular Arcade in Healthy Eyes Using Spectral-Domain Optical Coherence Tomography

Jae Yong Park, Bum Gi Kim, Je Hyung Hwang, and Jae Suk Kim

Department of Ophthalmology, Sanggye Paik Hospital, Inje University College of Medicine, Seoul, Korea

PURPOSE. To study the distribution of choroidal thickness (CT) in and outside of the vascular arcade, as well as at the fovea in healthy eyes using spectral-domain optical coherence tomography (OCT).

METHODS. Seventy healthy eyes were examined with OCT to obtain nine horizontal lines in and outside of the vascular arcade. Nine points including the central point of the line were chosen in 0.5-mm intervals to calculate CT. CT was measured at a total of 81 points in each patient to construct a map of CT distribution.

RESULTS. Average subfoveal CT showed a significant relationship with age ($P < 0.001$) and axial length ($P = 0.001$). In all nine horizontal lines, CT showed a rough trend of being thickest at a particular point and decreasing thereafter. The aspect of CT distribution was different among the nine horizontal lines ($P < 0.001$), and the near superotemporal line displayed the thickest choroid among the lines. The difference of the trend between temporal vertical lines was significant as well ($P < 0.001$).

CONCLUSIONS. The CT generally decreased with age, but it decreased much faster in old age than in relatively younger people. CT displayed large variations among different points in and outside of the vascular arcade. The thickest choroid was located at the point superior to the fovea, not the fovea itself. Such physiological variations should be considered when interpreting pathologic changes of the choroid.

Keywords: choroidal thickness, healthy eyes, optical coherence tomography, outside vascular arcade

The choroid is a connective tissue–containing vascular meshwork between the retina and sclera. It plays an important role in normal eyes, and a structurally and functionally healthy choroid is essential for adequate retinal function. The choroid supports the retina by supplying nutrients and oxygen to retinal pigment epithelial cells and photoreceptors.$^1$

Adequate visualization of the choroid has not been possible until recently, owing to its rearward location and the presence of retinal pigment epithelium that attenuates the incident light and the dense vascular structure of the choroid.$^2$ The imaging of the choroid has been gradually developing since the introduction of spectral-domain optical coherence tomography (SD-OCT). Moreover, emergence of SD-OCT enhanced depth imaging (EDI) has enabled a better visualization and clearer imaging of the choroid.$^3$

Quantitative assessment of choroidal characteristics such as choroidal thickness (CT) using SD-OCT has been proposed as an important factor in understanding the physiological mechanisms of the choroid.$^4$ Recent studies in a healthy population reported CT from 270 to 350 $\mu$m.$^5$–$^8$ Further studies proved that CT is associated with age, refractive error, and axial length.$^9$–$^{11}$

However, most OCT-derived studies have focused on the assessment of CT in the macular region alone, examining the correlation between macular CT changes and disease expression. Further studies involved research confined to the posterior pole. Shin et al.$^5$ acquired single-line horizontal and vertical scans from healthy subjects using the SD-OCT to report that the CT was thickest at the fovea and decreased thereafter. Ouyang et al.$^7$ conducted macular volume scan and calculated the average CT using the Early Treatment Diabetic Retinopathy Study (ETDRS) grid. They found a symmetric distribution of the CT around the optic disc, and suggested that the optic nerve head may serve as a better reference point for the choroid. More recent researchers set the optic disc as a reference and conducted SD-OCT studies about peripapillary CT.$^{12}$–$^{14}$ But the limitation of the mentioned research was that the measurement of the CT was limited only to the posterior pole. This information is not sufficient to fully understand the wide distribution of the choroid.

Also, although the relationship between subfoveal CT and age is well known, the variations of the CT outside of the vascular arcade with respect to age have not yet been studied. Many studies reported that the subfoveal CT decreases in proportion to age. But the choroid is a much wider tissue, and senile changes of other portions of the choroid may not be the same as for the subfoveal choroid.

Unlike the neurosensory retina, the choroid is a vascular layer with a potentially different topography. Pathologic changes of the choroid outside the vascular arcade need to be studied in order to fully understand disease of the retina and...
the choroid. Therefore, quantitative assessment of the normal peripheral choroid should be made in advance. In this study, we aimed to report the distribution of CT in and outside of vascular arcade in healthy eyes and its variations with respect to age.

METHODS

Subjects

This retrospective records review was performed in the Department of Ophthalmology of Sanggye Paik Hospital with the data collected from June 2012 to December 2012. Approval for data collection and analysis was obtained from the institutional review board at Inje University. The institutional review board waived informed consent, since this study involved a reevaluation of the images collected in a previously approved study and the previously collected data were de-identified. This research adhered to the tenets set forth in the Declaration of Helsinki.

The patients were divided into three groups by age: 20s to 30s, 40s to 50s, and 60s to 80s. Each group was further used for statistical analysis.

The inclusion criteria were (1) healthy subjects with no history of any medical disease, such as diabetes mellitus or hypertension; (2) subjects without any ocular pathologies, except cataract with Lens Opacities Classification System III (LOCS III) scale of less than 2 units, proven under routine ophthalmic examinations such as slit-lamp examination, Goldmann applanation tonometry, and fundus examination.

The exclusion criteria were (1) any history of previous maculopathy; (2) any history of vascular diseases, including diabetic retinopathy or retinal vein occlusion; (3) any history of optic neuropathy, including glaucoma, or any condition increasing the risk of secondary glaucoma; (4) any previous ocular surgery other than cataract surgery; (5) any history of neurodegenerative diseases known to influence retinal nerve fiber layer thickness; and (6) significant media opacities that prevent examination of the retina and OCT imaging.

Materials

Information about age and sex was gathered before clinical ophthalmic examination. All patients underwent a detailed ophthalmic examination, including slit-lamp examination and fundus examination. Spectral-domain OCT (Heidelberg Engineering, Heidelberg, Germany) with EDI mode and eye-tracking system was used to image the different areas of the choroid. Therefore, quantitative assessment of the normal peripheral choroid should be made in advance. In this study, we aimed to report the distribution of CT in and outside of vascular arcade in healthy eyes and its variations with respect to age.

OCT Protocols

The fixation point system embedded in SD-OCT was used to fixate the subject’s gaze on superior, middle, inferior, superonasal, and inferonasal spots. A 25–horizontal line posterior pole scan (30° × 20°, 240-μm intervals) was conducted in each of the superior, middle, and inferior gazing spots. The 1st and 13th lines from the superior gazing spot, the 13th line from the middle gazing spot, and the 13th and 25th lines from the inferior gazing spot were chosen for analysis, and the lines were designated far superotemporal line (STf), near superotemporal line (STn), center line (Cf), near inferotemporal line (TIn), and far inferotemporal line (TIf), in order. The patient was asked to fixate on the superonasal gazing spot, and a 25–horizontal line posterior pole scan (20° × 20°, 240-μm intervals) was carried out after manually shifting the scan area to orient the temporal end of the lines to the temporal margin of the optic disc and the 25th line of the scan to the inferior margin of the optic disc. The same procedure was done on the inferonasal gazing spot after manually shifting the scan area to orient the temporal end of the lines to the temporal margin of the optic disc.

RESULTS

A total of 70 healthy patients participated in the study, which consisted of 36 males and 34 females. The mean age was 50.49 ± 16.61 years. Mean subfoveal CT of total subjects was 309.57 ± 56.44 μm. Specific demographics of the study including sex, age, axial length, and subfoveal CT among different age groups are summarized in Table 1. Intra-class correlation coefficient between the two independent observers was 0.876 (P < 0.05).

Pearson correlation analysis showed a significant relationship between age and average CT of each horizontal line (P < 0.05). Average CT of all nine horizontal lines showed a negative correlation with age. In addition, axial length exhibited a significant negative correlation in horizontal lines except for the INn (P < 0.05). However, sex did not seem to have a correlation with horizontal lines except for the STn (Table 2).

Simple regression analysis for subfoveal CT displayed significance with regard to age (Fig. 3) and axial length (Fig. 4). Subfoveal CT decreased 1.683 μm for each year of age (P <
0.001) and 13.756 μm for each millimeter of axial length ($P = 0.001$).

Paired $t$-test was done to discriminate the difference between the average CT of each horizontal line. For the most part, the average CT of each horizontal line differed significantly (Table 3). However, this was not evident between STf and Cf ($P = 1.000$), between ITf and SNn ($P = 1.000$), between ITn and STf ($P = 0.072$), and between SNf and ITf ($P = 0.648$).

Figure 5 displays the trend of the horizontal lines and the average CT at nine locations within nine lines of healthy patients. The specific point with the thickest CT was N0.5 in STf, N0.5 in STn, C in Cf, N0.5 in ITn, N1.0 in ITf, C in SNf, N0.5 in SNn, N1.0 in INn, and C in INf. The majority of the horizontal lines exhibited peak CT at a particular point and the CT decreased thereafter. Repeated-measures ANOVA for comparison of the trend of horizontal lines showed a significant difference between the nine lines in general ($P < 0.001$). Results from Tukey post hoc analysis of repeated-measures ANOVA are shown in Table 4.

The trend of the horizontal lines and the average CT at nine locations within nine lines stratified by the three age groups (20s to 30s, 40s to 50s, 60s to 80s) is plotted in Figure 6. In general, the specific point with the thickest CT was identical among three age groups, except for STn and ITf. In STn, the point with the thickest CT was C in the 20s to 30s groups and N0.5 in the 40s to 50s and 60s to 80s groups. In ITf, the 20s to 30s group showed the peak point at N0.5 and the 40s to 50s and 60s to 80s groups at N1.0. Repeated-measures ANOVA showed that in all nine lines, the average CT was significantly different between the 20s to 30s group and the 60s to 80s group. The lines with significantly different average CT between the 40s to 50s group and the 60s to 80s group were STf, STn, Cf, ITn, and ITf.

Figure 7A shows the trend of the temporal vertical lines and the average CT at five lines within nine locations of healthy patients. STn was the location with the thickest CT in all of the nine vertical lines. Repeated-measures ANOVA revealed that the difference of trend between temporal vertical lines was significant ($P < 0.001$). Tukey post hoc analysis is presented in Table 5. The trend was significantly different between T2.0 and C, T2.0 and N0.5, C and N2.0, N0.5 and N 2.0.

Figure 7B displays the trend of the nasal vertical lines and the average thickness at five lines within nine locations of healthy patients. The vertical lines showed an increasing trend from the INf to the SNf, with SNf their thickest location. Repeated-measures ANOVA was done as well, but no significant trend difference was found ($P = 0.084$). Results from Tukey post hoc analysis are shown in Table 6.
Axial length
Sex

Ikuno et al.,11 261.9
l
relationship was verified with SD-OCT as well, as a decrease
et al.10 The values differ to varying degrees, but they seem to
subfoveal CT was 287
6
healthy eyes using SD-OCT, in order to discover the normal
measuring the CT in and outside of the vascular arcade in
choroid outside the vascular arcade is yet beyond our
clinical importance, information about the distribution of the
inside the vascular arcade. Hence, despite its anatomic and
mechanism underlying it is still beyond our knowledge.
However, most of these studies focused only on the CT of
the posterior pole or around the optic disc, which is restricted
inside the vascular arcade. Hence, despite its anatomic and
clinical importance, information about the distribution of the
choroid outside the vascular arcade is yet beyond our
knowledge. In the present study, we addressed this issue by
measuring the CT in and outside of the vascular arcade in
healthy eyes using SD-OCT, in order to discover the normal
topographic configuration of the peripheral choroid.
The mean subfoveal CT in the healthy population of our
study was 309.57 ± 56.44 μm. Previously reported mean
subfoveal CT was 287 μm for Margolis and Spaide,23 354 μm for
Ikuno et al.,11 261.9 μm for Ding et al.,24 and 307.3 μm for Kim
et al.10 The values differ to varying degrees, but they seem to
lie around 300 μm, which is consistent with our findings. Many
factors including age, axial length, race, and measurement
tools are known to influence the CT, and the difference in
mean subfoveal CT of these reports may be due to these
causes.25
Aging is a traditionally well-known factor influencing the
CT. Previous histologic studies have shown that as the aging
process proceeds, choriocapillary density and diameter
decrease, which results in the decline of the CT.26 This
relationship was verified with SD-OCT as well, as a decrease
in subfoveal CT of 1.4 μm per year by Ikuno et al.,11 1.56 μm per
year by Margolis et al.,23 and 2.67 μm per year by Shin et
al.5 Simple regression analysis in our study has shown that CT
decreases 1.68 μm per year, which is similar to the values
described above.
We stratified our subjects by three age groups, concluding
that in all of the nine horizontal lines, the 20s to 30s group had
significantly thicker CT than the 50s to 80s group. The CT of
the 20s to 30s group, however, was not significantly different
from the CT of the 40s to 50s group. This analysis suggests a
possibility that the relationship between CT and age may not
be linear. It was previously clear that the CT generally
decreases with age, but it seems that the CT decreases much
faster in old age than in relatively younger people. Such a
phenomenon is more prominent in the five horizontal lines of
the temporal side, since the 40s to 50s group had significantly
thicker CT than the 50s to 80s group. However, of the four
horizontal lines of the nasal side, all of the 40s to 50s group
showed no significant difference with the 60s to 80s group.
These results suggest that the temporal side of the choroid is
more easily affected by age.
Although a clear explanation of this phenomenon cannot
yet be made, we consider the senile change of the diameter of
the vessel a cause. Previous histopathologic studies have
proved that a decrease in choriocapillaris diameter with aging
automatically results in a decrease in choriocapillaris density
and a resultant CT decline.26 In older patients with smaller
vascular diameter, the same amount of decrease of the vascular
diameter would result in a larger proportional decrease of
vascular area. These changes may influence the amplitude of
CT decrease among different age groups.
Axial length is another important factor affecting the CT.
Highly myopic patients tend to have thin choroids, which
results in many pathologic conditions. Jirarattanasopa et al.6
found that subfoveal CT decreased 14.59 μm for every 1 mm of
axial length, and Wang et al.20 reported a 25.02 μm decrease in
CT for 1 mm of increased axial length. We report a value close
to that of Jirarattanasopa et al.,6 and this result seems to be
derived from similar demographics, such as average age and
axial length.
The first critical finding about the CT in and outside of
vascular arcade is that the horizontal lines display the peak CT
at a specific point, and the CT gradually decreases temporally
and nasally (Fig. 8). This finding was generally identical even

### Table 1. Demographics of Healthy Eyes

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total</th>
<th>20s to 30s</th>
<th>40s to 50s</th>
<th>60s to 80s</th>
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<tr>
<td>Number of subjects</td>
<td>70</td>
<td>21</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Sex, M/F</td>
<td>56/34</td>
<td>10/11</td>
<td>15/9</td>
<td>11/14</td>
</tr>
<tr>
<td>Age, y (mean ± SD, range)</td>
<td>50.49 ± 16.61 (21–84)</td>
<td>29.05 ± 4.56 (21–37)</td>
<td>51.57 ± 5.75 (40–58)</td>
<td>67.64 ± 5.74 (60–84)</td>
</tr>
<tr>
<td>Subfoveal choroidal thickness, μm (mean, range)</td>
<td>56.44 (172–435)</td>
<td>48.73 (185–378)</td>
<td>39.80 (235–386)</td>
<td>65.44 (172–435)</td>
</tr>
</tbody>
</table>

### Table 2. Pearson Correlation Coefficient Between Age, Sex, Axial Length, and Average Choroidal Thickness of Each Horizontal Line

<table>
<thead>
<tr>
<th>Factor</th>
<th>STf</th>
<th>STn</th>
<th>CF</th>
<th>ITn</th>
<th>ITf</th>
<th>SNf</th>
<th>SNn</th>
<th>INf</th>
<th>INn</th>
</tr>
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<tbody>
<tr>
<td>Age</td>
<td>r</td>
<td>0.483</td>
<td>0.572</td>
<td>0.541</td>
<td>0.495</td>
<td>0.495</td>
<td>0.355</td>
<td>0.445</td>
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<td>P</td>
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<td>0.000</td>
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<td>0.000</td>
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<tr>
<td>Sex</td>
<td>r</td>
<td>0.101</td>
<td>0.240</td>
<td>0.207</td>
<td>0.205</td>
<td>0.125</td>
<td>0.081</td>
<td>0.131</td>
<td>0.115</td>
</tr>
<tr>
<td>P</td>
<td></td>
<td>0.405</td>
<td>0.045</td>
<td>0.085</td>
<td>0.089</td>
<td>0.303</td>
<td>0.504</td>
<td>0.281</td>
<td>0.341</td>
</tr>
<tr>
<td>Axial length</td>
<td>r</td>
<td>0.341</td>
<td>0.413</td>
<td>0.373</td>
<td>0.368</td>
<td>0.277</td>
<td>0.289</td>
<td>0.374</td>
<td>0.234</td>
</tr>
<tr>
<td>P</td>
<td></td>
<td>0.004</td>
<td>0.000</td>
<td>0.001</td>
<td>0.002</td>
<td>0.015</td>
<td>0.001</td>
<td>0.051</td>
<td>0.024</td>
</tr>
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</table>
after stratifying the patients by three age groups. In advance, connecting the peak points of the nine horizontal lines results in a circular configuration, with the optic nerve head in its center (Fig. 5). Ouyang et al.\textsuperscript{7} researched the spatial distribution of posterior pole CT to find that each quadrant of the inferior nasal, inferior temporal, superior nasal, and superior temporal area presented peaking at an approximate distance of 5 to 6 mm from the center of the optic nerve head, and claimed that the optic nerve head should serve as a reference point in the distribution of the choroid. Considering the difference in measurement method of CT, as Ouyang et al. measured the CT in a diagonal manner with the center of the optic nerve head as reference, such results seem consistent with ours. We did not measure the CT consecutively with the

![Figure 3](http://tvst.arvojournals.org/)

**Figure 3.** Simple regression analysis for subfoveal choroidal thickness with respect to age ($P < 0.001$, $y = -1.68x + 394.519$, $R^2 = 0.245$).

![Figure 4](http://tvst.arvojournals.org/)

**Figure 4.** Simple regression analysis for subfoveal choroidal thickness with respect to axial length ($P = 0.001$, $y = -13.756x + 634.615$, $R^2 = 0.148$).
optic nerve head in the center, but it seems obvious that the CT peaks at a certain distance from the optic nerve.

Secondly, the vertical lines display the peak CT at a specific point as well. We found that the vertical lines temporal to the optic nerve form their peak at STn, and those nasal to the optic nerve at SNf. These findings suggest that the choroid is thickest at some point above the optic nerve and becomes thin again superiorly. In fact, it is already known that the inferior choroid is thinner than other areas. Rhodes et al. 13 studied the peripapillary CT to verify that the CT was lowest in the inferior quadrant. Ouyang et al. 7 also observed that the choroid inferior to the optic nerve is relatively thinner. They believed the theories suggested by Ikuno et al. 11 as a cause of this distribution, that both a vascular watershed zone and the embryonic location of optic fissure closure may be responsible.

However, as Tanabe et al. 27 argued, choroidal development occurs much later than the closure of the choroidal fissure across the inferior part of the eye. Therefore, the thinner choroid inferior to the optic disc cannot be explained by the current embryologic theory. We explain the geographic configuration of the choroid we discovered with the anatomy of the ocular vasculatures. The choroid is a vascularized and pigmented tissue that consists of four layers, the suprachoroid, stroma, choriocapillaris, and Bruch’s membrane. The suprachoroid and Bruch’s membrane are relatively stable and thin structures, with thicknesses of 30 and 2 μm each. On the other hand, stroma and choriocapillaris are more dynamic and consist of blood vessels derived from a variable number of short posterior ciliary arteries (SPCAs). SPCAs enter the choroid through the sclera slightly nearer to the optic nerve than the long posterior ciliary arteries (LPCAs), 28 which enter the sclera approximately 3 to 4 mm from the optic nerve margin. 29 Furthermore, SPCAs enter the sclera medially, laterally, or superiorly in a circumferential manner with the optic nerve head on their center. 28 A spot of the choroid would become thicker as it gains more blood supply, and points around SPCAs are speculated to be the thickest. Such characteristics of the SPCAs are expected to explain our findings about the choroidal distribution, with the peak CT at specific points around the optic nerve, along with the thinner CT inferior to the optic nerve.

In fact, other studies have attempted to image the peripheral choroid with other instruments, such as ultrasound and magnetic resonance imaging (MRI). Ultrasound was an important tool to detect pathologic changes of the choroid
before the advent of OCT. It was suitable for extensive visualization of the choroid from the ora serrata anteriorly to the optic nerve posteriorly. But the image resolution is relatively low, which made the detection of small changes in the choroid difficult, including its thickness. With regard to MRI, the measurement of CT was still difficult despite its high resolution, but there is an impressive study that coincides with our research. Emeterio Nateras et al. calculated the choroidal...
blood flow using MRI scans of healthy eyeballs. It was calculated on the axial MRI scan of the eyeball, 12 mm nasally and temporally from the fovea. As a result, the choroidal blood flow displayed two peaks, one at the fovea with the highest blood flow, and the other at a distance 2 to 3 mm nasal to the optic nerve head. Such findings are consistent with our study on CT, and there is a reasonable possibility that the choroid thickens proportionally to its blood flow.

Physiological alterations of the choroid among different locations need to be applied when interpreting the CT of the posterior pole in pathologic conditions. As mentioned above, the normal range of CT is different at each point in and outside of the vascular arcade. Therefore, direct comparison of CT between different areas in diseased conditions needs to be contemplated. Such variations of the topographic distribution of the CT should be considered.

There was a similar attempt to investigate the CT outside the macula in diabetic and nondiabetic patients undergoing hemodialysis by Chang et al.\textsuperscript{16} They measured the CT at the foveal center, at a point 1.5 mm temporal to the foveal center,
TABLE 5. Tukey Post Hoc Analysis From Repeated-Measures ANOVA Between Choroidal Thickness of Each Vertical Line in the Temporal Area

<table>
<thead>
<tr>
<th>P</th>
<th>T2.0</th>
<th>T1.5</th>
<th>T1.0</th>
<th>T0.5</th>
<th>C</th>
<th>N0.5</th>
<th>N1.0</th>
<th>N1.5</th>
<th>N2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2.0</td>
<td>0.952</td>
<td>0.409</td>
<td>0.056</td>
<td>0.002</td>
<td>0.002</td>
<td>0.032</td>
<td>0.650</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>T1.5</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>T1.0</td>
<td>0.056</td>
<td>0.664</td>
<td>0.094</td>
<td>0.056</td>
<td>0.002</td>
<td>0.032</td>
<td>0.650</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>T0.5</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>N0.5</td>
<td>0.032</td>
<td>0.517</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
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<tr>
<td>N1.0</td>
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<td>0.671</td>
<td>0.002</td>
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<tr>
<td>N1.5</td>
<td>0.056</td>
<td>0.664</td>
<td>0.094</td>
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<td>0.002</td>
<td>0.032</td>
<td>0.650</td>
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<td></td>
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<tr>
<td>N2.0</td>
<td>1.000</td>
<td>0.964</td>
<td>0.449</td>
<td>0.067</td>
<td>0.003</td>
<td>0.002</td>
<td>0.039</td>
<td>0.690</td>
<td></td>
</tr>
</tbody>
</table>

T2.0: Point 2.0 mm temporal to the central point of the horizontal line.
T1.5: Point 1.5 mm temporal to the central point of the horizontal line.
T1.0: Point 1.0 mm temporal to the central point of the horizontal line.
T0.5: Point 0.5 mm temporal to the central point of the horizontal line.
C: Central point of the horizontal line.
N0.5: Point 0.5 mm nasal to the central point of the horizontal line.
N1.0: Point 1.0 mm nasal to the central point of the horizontal line.
N1.5: Point 1.5 mm nasal to the central point of the horizontal line.
N2.0: Point 2.0 mm nasal to the central point of the horizontal line.

and at points 3.5 mm superior, inferior, and nasal to the optic disc margin to discover that the CT decreased more after hemodialysis in diabetic patients than in nondiabetic patients. The thickness of the choroid 1.5 mm temporal to the foveal center before hemodialysis was 211.1 ± 42.7 μm in the study, which is comparable to the T1.5 of Cf in our research due to the similar study designs. It is much lower than what is measured from healthy subjects in our study, and the difference may have come from the vascular changes derived from end-stage renal disease. More studies need to be accomplished regarding the peripheral choroid in pathologic conditions, and we expect our outcomes to shed light on further studies about CT changes in pathologic conditions.

There are some limitations to our study. First, the sample size was relatively small. Our subjects may not be numerous enough to represent the healthy CT of the much larger general population. Second, variations of the choroid with respect to age were not fully explored. The CT is largely affected by age, and there is a possibility that the normal distribution of the choroid may differ in different age groups. Studies with larger sample size and diverse age groups may reflect more various aspects of the choroid with respect to age. Third, the study design was not appropriate to explore CT with the optic nerve as a reference, since the primary goal of the research was to investigate CT outside the macula. It seems evident that the optic disc serves as an important reference in the geographic distribution of the choroid, and further studies about the peripheral choroid need to focus on it. Fourth, visualization of the nasal choroid was not wide enough due to the technical problems. The 25–horizontal line posterior pole scans were easily attainable at superior, middle, and inferior gazing spots, and we could measure CT at sufficient distance from the optic disc. However, when the patient fixated at a superonasal and inferonasal gazing spot, visualization of the nasal retina on OCT was not sufficient to perform a 30° × 20° 25–horizontal line posterior pole scan. This problem arose because the palpebral fissure was narrower on the nasal side, and sufficient pupil area could not be secured to fully visualize the nasal retina on OCT. We therefore had to perform 20° × 20° 25–horizontal line posterior pole scans on superonasal and inferonasal gazing spots, and the distance to the nasally furthest point was shorter than we first expected. We anticipate this problem to be settled in the future with technical development of OCT.

TABLE 6. Tukey Post Hoc Analysis From Repeated-Measures ANOVA Between Choroidal Thickness of Each Vertical Line in the Nasal Area

<table>
<thead>
<tr>
<th>P</th>
<th>T2.0</th>
<th>T1.5</th>
<th>T1.0</th>
<th>T0.5</th>
<th>C</th>
<th>N0.5</th>
<th>N1.0</th>
<th>N1.5</th>
<th>N2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2.0</td>
<td>0.995</td>
<td>0.873</td>
<td>0.507</td>
<td>0.629</td>
<td>0.163</td>
<td>0.316</td>
<td>0.951</td>
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<tr>
<td>T1.5</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
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<td>0.002</td>
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<td>0.002</td>
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<tr>
<td>T1.0</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>T0.5</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
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<td>0.002</td>
<td></td>
</tr>
<tr>
<td>N0.5</td>
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<tr>
<td>N1.0</td>
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<td>0.126</td>
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<tr>
<td>N1.5</td>
<td>0.002</td>
<td>0.126</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
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<td></td>
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<tr>
<td>N2.0</td>
<td>1.000</td>
<td>0.964</td>
<td>0.449</td>
<td>0.067</td>
<td>0.003</td>
<td>0.002</td>
<td>0.039</td>
<td>0.690</td>
<td></td>
</tr>
</tbody>
</table>

T2.0: Point 2.0 mm temporal to the central point of the horizontal line.
T1.5: Point 1.5 mm temporal to the central point of the horizontal line.
T1.0: Point 1.0 mm temporal to the central point of the horizontal line.
T0.5: Point 0.5 mm temporal to the central point of the horizontal line.
C: Central point of the horizontal line.
N0.5: Point 0.5 mm nasal to the central point of the horizontal line.
N1.0: Point 1.0 mm nasal to the central point of the horizontal line.
N1.5: Point 1.5 mm nasal to the central point of the horizontal line.
N2.0: Point 2.0 mm nasal to the central point of the horizontal line.
In summary, we designed this study to evaluate CT in healthy eyes measured in and outside of the vascular arcade, as well as at the fovea, since the distribution of CT outside the vascular arcade has not been described before. We found that CT peaks at specific points around the optic nerve, and CT inferior to the optic nerve becomes thinner. Such physiological variations should be considered when interpreting pathologic changes of the choroid. We anticipate that our findings about the distribution of the CT may serve as a blueprint for future research on choroidal changes in many ocular diseases.

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References