Introduction

The choroid is a vascularized, pigmented tissue comprising three vascular layers: Haller’s layer, Sattler’s layer, and the choriocapillaris, which extends from the ora serrata to the optic nerve. Histopathologic studies of normal subjects indicated that the choroid is 0.10 mm to 0.15 mm thick anteriorly and 0.22 mm thick posteriorly. Many ocular diseases are associated with changes in the choroidal thickness (CT) and perfusion. Abnormal choroidal perfusion is implicated in the pathophysiology of many chorioretinal diseases. Grossniklaus and Green postulated that in some patients, decreases in the ability of the choroid to deliver oxygen and other metabolites to the outer retina may lead to growth of neovascular tissue. The choroid also provides nutrients and oxygen to an ischemic retinal pigment epithelium (RPE) and outer retina that express vascular endothelial growth factor and, therefore, a thin choroid may not deliver the necessary nutrients and oxygen.

There are many ancillary imaging examinations that can evaluate the choroid, such as indocyanine green angiography, ultrasonography, and Doppler flowmetry. However, the CT and morphology cannot be evaluated precisely using these technologies. Spectral-domain optical coherence tomography (SD-OCT) overcame this shortcoming and can measure the CT using enhanced-depth imaging (EDI) technology. SD-OCT is a noninvasive imaging technique, the precision of which for measuring the subfoveal CT has been reported widely. This ancillary examination also is considered useful for assessing possible risk factors for some diseases. The use of SD-OCT to evaluate the CT has been used worldwide with high...
reproducibility in different available devices. Although it is possible to measure the CT and analyze the choroidal morphology, there is no evidence that the CT is related to blood flow.

Color Doppler flowmetry (CD) is a noninvasive imaging technique that facilitates measurement of hemodynamic parameters of the optic nerve head, iris, and choroidal circulation. Several studies in which CD was performed reported decreased choroidal circulatory volume in diseases such as age-related macular degeneration (AMD) and diabetic retinopathy.

Several studies have reported changes in the CT in chorioretinal diseases. However, there is no evidence that a thinner choroid is correlated with decreased choroidal blood flow. The object of the current study was to compare the CT in normal subjects of different ages and correlate the values with the peak systolic velocities and the resistance index (RI) of the retrobulbar vessels— for example, the ophthalmic artery (OA), short posterior ciliary artery (SPCA), and central retinal artery (CRA).

**PATIENTS AND METHODS**

The study subjects were interviewed and individuals with any potential systemic (diabetes, systemic hypertension, autoimmune disease, etc.) or ophthalmologic disease and risk factors related to choroidal changes were excluded from the study. No subjects were taking any medication at the time of the study. Subjects from different ages were included in this study to better evaluate the choroid. Since the Brazilian population is essentially miscegenated, no race was distinguished. The research followed the tenets of the Declaration of Helsinki and informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. This investigation was approved by the CEP UNIFESP institutional review board.

**Color Doppler Imaging**

The color Doppler examination was performed with patients in the supine position. Two trained examiners (NA, MSAM) conducted the examinations using MyLab30 (Esaote, Genoa, Italy). A conductive gel was used for contact through the eyelid using a linear transducer (LA 435) with frequencies of 6 MHz to 18 MHz. Initially, a real-time 2-D scan was obtained and color-coding was used to identify the retrobulbar vessels, particularly the OA, CRA, and SPCA. The volume sample cursor was adjusted to the minimal level to avoid interference with other vessels smaller than 2 mm and was positioned on the image of the detected vessel to evaluate the real-time flowmetry. Video cursors were placed along the captured flowmetry data to calculate the peak systolic velocity (PSV), and the resistance indices (RIs) were recorded for the OA, SPCA, and CRA (Figure 1).

![Figure 1](image-url)

**TABLE 1**

<table>
<thead>
<tr>
<th></th>
<th>N1</th>
<th>N0.5</th>
<th>Subfoveal</th>
<th>T0.5</th>
<th>T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>296 ± 78.27</td>
<td>312 ± 80.63</td>
<td>319.9 ± 83.79</td>
<td>319.6 ± 79.76</td>
<td>306.1 ± 84.74</td>
</tr>
</tbody>
</table>

N1 = 1,000 µm nasal to the fovea; N0.5 = 500 µm nasal to the fovea; T0.5 = 500 µm temporal to the fovea; T1 = 1,000 µm temporal to the fovea; CT = choroidal thickness.
The RI is calculated according to the formula (PSV-EDV)/PSV, in which EDV is the end diastolic velocity.\textsuperscript{31}

**Choroidal Thickness Measurement**

After ultrasonography, all patients underwent SD-OCT (Spectralis OCT; Heidelberg Engineering, Heidelberg, Germany), using the one-line scan pattern, a line of 30° consisting of 768 A-scans per frame. All OCT exams were performed from 9 a.m. to 10 a.m., right after CD, to avoid variations on the CT related to circadian changes. The EDI option was used, which places the chorioretinal interface adjacent to the zero delay. The one-line scan averages 90 B-scans with tracking. To be included in this study, the signal-to-noise had to be at least 20 dB and taken as close to the fovea as possible (thinnest macular point), with the understanding that slight differences in positioning could affect the measured thicknesses. Using the Spectralis linear measurement tool, two independent observers measured the CT perpendicularly from the outer edge of the hyperreflective RPE to the inner sclera at 500-mm intervals temporal and nasal to the fovea up to 1,000 mm (Figure 2).

**Statistical Analysis**

The data are expressed as the mean ± standard error. The Pearson correlation coefficient was used to evaluate the correlation between the subfoveal CT and the PSV and RI for each vessel. A 95% confidence interval and a 5% level of significance were adopted. \(P\) values of .05 or greater were considered significant. All analyses were performed using Graph Pad Prism 5.0 software for Mac (GraphPad Software, La Jolla, CA).

**RESULTS**

Twenty-seven eyes of 27 normal subjects (12 men, 15 women; mean age: 40.6 ± 12.4 years; range: 27-68 years) were included in this study. The mean subfoveal CT was 319.9 µm ± 83.79 µm. The subfoveal CT values measured using OCT are shown in Table 1.

The PSV and RI of the OA, CRA, and SPCA measured by Doppler flowmetry are shown in Table 2.

The mean PSV measured by Doppler flowmetry was higher in the OA (32.28 ± 12.11 centimeters/second [cm/sec]) compared to the CRA (11.93 cm/sec ± 4.027 cm/sec) and SPCA (10.87 cm/sec ± 4.251 cm/sec; Table 2). The mean RI measured by CD was lower in the SPCA (0.6117 ± 0.07911) compared with the CRA (0.6893 ± 0.08994) and the OA (0.7019 ± 0.07317) (Table 2). An inverse proportional relationship \( (P = .0496)\) was seen between the RI of the SPCA (mean, 0.6117 ± 0.07911) and the subfoveal CT (319.9 ± 83.79 µm), but not between the RI and the OA (mean, 0.7019 ± 0.07317) or the CRA (mean, 0.68893 ± 0.08994) (Table 3). There was no significant \( (P = .5476)\) difference between the CT values in both eyes (Figure 3).

**DISCUSSION**

We conducted a cross-sectional study to evaluate the correlation between the subfoveal CT measured by SD-OCT and the ciliary artery blood flow in normal subjects. The mean subfoveal CT (319.9 µm ± 83.79 µm), RI, and PSV agreed with those reported previously.\textsuperscript{18,31,32} The current results suggested that there is an inverse proportional relationship \( (P = .0496)\) between the subfoveal CT and RI.
between the resistance in the SPCA and subfoveal CT. The SPCA is responsible for choroidal blood irrigation and, therefore, an increased RI in these arteries that supply nutrition may lead to diminished blood flow to the choriocapillaris site, leading to a thinner choroid.

Many authors have reported that decreased choroidal flow can result in photoreceptor dysfunction, death,\textsuperscript{6} glaucoma,\textsuperscript{33} and increased severity of AMD.\textsuperscript{7-12} However, some authors have speculated about a relationship between abnormal choroidal circulation that leads to increased CT and diseases such as in Vogt-Koyanagi-Harada,\textsuperscript{13} central serous chorioretinopathy,\textsuperscript{2} and others. Using the EDI SD-OCT technique, Vance et al. reported a 12.3% increase in the CT and suggested that this was a possible risk factor for serous chorioretinopathy.\textsuperscript{34} Sogawa et al. assessed the CT in young healthy Japanese patients and correlated the findings with ocular blood flow based on a laser Doppler velocity flowmetry method and pulsatile ocular blood flow using computerized tonometry. The authors concluded that there was no correlation between these two variables.\textsuperscript{35} However, to our knowledge, no information about the correlation of the CT and the RI has been reported.

The ocular vessel tonus is mediated by endothelial-derived relaxing factors, including nitric oxide, endothelial-derived hyperpolarizing factor, prostaglandin I2, and a potent vasoconstrictor peptide endothelin-1.\textsuperscript{36-38} The increase in the RI of the SPCA may be related to peripheral vasoconstriction.\textsuperscript{39} Vance et al. found that the vasodilatory effect of silde-

![Figure 3. The graph shows the difference between the right and left eyes. There is no significant difference between the CT values in both eyes (P = .5476).](image)

### TABLE 2

<table>
<thead>
<tr>
<th></th>
<th>OA (PSV)</th>
<th>CRA (PSV)</th>
<th>SPCA (PSV)</th>
<th>OA (RI)</th>
<th>CRA (RI)</th>
<th>SPCA (RI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV (cm/sec)</td>
<td>32.28 ± 12.11</td>
<td>11.93 ± 4.027</td>
<td>10.87 ± 4.251</td>
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<td></td>
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<tr>
<td>RI</td>
<td>0.7019 ± 0.07317</td>
<td>0.6893 ± 0.08994</td>
<td>0.6117 ± 0.07911</td>
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<td></td>
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</table>

RI = resistance index; PSV = peak systolic velocity; OA = ophthalmic artery; CRA = central retinal artery; SPCA = short posterior ciliary artery; cm/sec: centimeters/second.

### TABLE 3

<table>
<thead>
<tr>
<th></th>
<th>Right Eye</th>
<th>CRA (PSV)</th>
<th>CRA (RI)</th>
<th>SPCA (PSV)</th>
<th>SPCA (RI)</th>
<th>OA (PSV)</th>
<th>OA (RI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spearman r</td>
<td>-0.1904</td>
<td>-0.1309</td>
<td>0.09284</td>
<td>-0.324</td>
<td>0.1312</td>
<td>0.04793</td>
<td></td>
</tr>
<tr>
<td>95% confidence interval</td>
<td>-0.5404 to -0.4958 to</td>
<td>-0.3085 to -0.6340 to</td>
<td>-0.2898 to -0.3648 to</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P value (one-tailed)</td>
<td>0.1707</td>
<td>0.2576</td>
<td>0.3226</td>
<td>0.0496</td>
<td>0.266</td>
<td>0.41</td>
<td></td>
</tr>
</tbody>
</table>

CT = choroidal thickness; CD = color Doppler flowmetry; CRA = central retinal artery; PSV = peak systolic velocity; RI = resistance index; SPCA = short posterior ciliary artery.
related to endothelial vascular mediators. Therefore, endothelial dysfunction can lead to ocular hemodynamic abnormalities and predispose patients to an increased risk for a pathological state. The direct correlation between the CT and the blood flow may play an important role in predicting and preventing a number of diseases, since recent technology can assess the CT rapidly, easily, and noninvasively.

The ability to directly evaluate and monitor the choroidal status can facilitate indirect evaluation of the microvascular beds of interest that may hold preventive, therapeutic, and prognostic potential.

REFERENCES