Optical Coherence Tomographic Imaging of Posterior Episclera and Tenon’s Capsule

Kyoko Ohno-Matsui,1 Yuxin Fang,1 Kei Morohoshi,1 and Jost B. Jonas2

1Department of Ophthalmology and Visual Science, Tokyo Medical and Dental University, Tokyo, Japan
2Department of Ophthalmology, Medical Faculty Mannheim of the Ruprecht-Karls-University of Heidelberg, Heidelberg, Germany

Purpose. To investigate structural features of the posterior episclera and Tenon’s capsule in patients with high myopia.

Methods. This hospital-based observational study included highly myopic eyes (myopic refractive error > -8 diopters or axial length ≥26.5 mm) in which the posterior sclera in its full thickness could be visualized on swept-source optical coherence tomography (OCT) images in all 12 radial scans centered on the fovea. We assessed the posterior episclera and Tenon’s capsule.

Results. The study included 278 eyes of 175 patients (mean age, 60.9 ± 11.4 years; range, 32–89 years; axial length, 30.7 ± 1.9 mm; range, 26.5–36.6 mm). The episclera was detected outside of the sclera in 164 eyes (59.0%) and appeared as a relatively uniform structure with a reflectivity slightly lower than scleral reflectivity. In these eyes, mean scleral thickness was 197 ± 73 μm in the foveal region and 164 ± 64 μm and 146 ± 59 μm at 1000 and 2500 μm temporal to the fovea, respectively. The posterior episclera was visualized in the region temporal to the fovea. Mean episcleral thickness detected in 77 eyes was 80 ± 27 μm and 82 ± 30 μm at 1000 μm and 2500 μm temporal to the fovea, respectively. Tenon’s capsule was detected in 11 of the 278 eyes (4.0%) as structurally, loosely connected tissue with a meshwork-like appearance. The measured thickness in four eyes was 60 ± 32 μm. In 25 eyes with extremely thin sclera (<100 μm at 1000 μm temporal to the foveola), the mean thickness of the sclera and episclera were 87 ± 11 μm and 65 ± 15 μm, respectively.

Conclusions. Swept-source OCT applied to a subset of highly myopic eyes with significant thinning of the retina and choroid allowed visualization of the posterior sclera and episclera, and in some cases, also Tenon’s capsule.

Keywords: posterior episclera, Tenon’s capsule, optical coherence tomography, swept-source optical coherence tomography, pathologic myopia, high myopia
approved the investigation and confirmed that the methods used in our study conformed to the tenets of the Declaration of Helsinki. The ethics committee waived informed consent, since this study involved a reevaluation of images collected in our previously approved study, and since the previously collected data were deidentified. High myopia was defined as a myopic refractive error (spherical equivalent) of $>-8\,$ diopters or an axial length $\geq 26.5\,$ mm. Exclusion criteria were a lack of clear OCT images, and a history of previous vitreoretinal surgery, since it could have affected the scleral curvature.

All patients underwent a comprehensive ophthalmologic examination including refraction, ocular biometry for measurement of axial length (IOLMaster; Carl Zeiss Meditec Co., Jena, Germany); color fundus photography; fundus autofluorescence; and swept-source OCT. The optical coherence tomography examination was carried out using a prototype of a swept-source OCT device (Topcon Corp.). This device had an A-scan repetition rate of 100,000 Hz. The light source used was a wavelength-sweeping laser centered at 1050 nm with a bandwidth of approximately 100 nm. The effective bandwidth was roughly 60 nm due to water absorption. The axial resolution in the tissue was estimated to be 8 $\mu$m while the lateral resolution was estimated as 20 $\mu$m. The imaging depth in the tissue was 2.6 mm, and the lateral scan length was adjustable. Our scanning protocol included a pattern of 12-mm long radial scans along 12 meridians centered on the fovea. A single image was made up of 1024 A-line scans acquired in 10 ms. Each scan consisted of 52 B-scan images which were recorded and averaged by postprocessing to yield a despeckled, high-quality B-scan image. The thickness of the sclera, episclera, and Tenon’s capsule were measured with the “caliper function” of the built-in software of the OCT. The scleral thickness was determined in the foveal region and at eight locations at 1000 $\mu$m and at 2500 $\mu$m superior, inferior, temporal, and nasal to the fovea, respectively. Since the scleral shape was bent, the scleral thickness was measured along an axis orientated perpendicularly to the eye surface (Fig. 1).

The statistical analysis was carried out using a commercially available statistical software program (SPSS version 22.0; IBM-SPSS, Chicago, IL, USA). The measured values of the outcome parameters were presented as mean $\pm$ standard deviations. Since the parameters were not normally distributed, as shown by the Kolmogorov-Smirnov test, the statistical significance of the differences between the two groups of eyes was assessed by the Mann-Whitney $U$ test for unpaired samples. The differences in measurements between two locations within the same eye were examined by the Wilcoxon-test for paired samples. Associations between two linear parameters were assessed by a linear regression analysis with calculation of the standardized regression coefficient $\beta$, the nonstandardized regression coefficient $\hat{\beta}$ and its 95% confidence intervals (CI). Additionally, we carried out a 1-way ANOVA to compare the measurements obtained at different locations in the same eye. All $P$-values were two-sided and considered to be statistically significant if their value was lower than 0.05.

**Results**

Out of 488 highly myopic eyes, which had undergone swept-source OCT examination in the study period, the entire sclera was visualized in all 12 radial foveal scans in 278 eyes (57.0%) of 175 patients. The mean age of these 175 patients was 60.9 $\pm$ 11.4 years (32–89 years) and the mean axial length of the 278 eyes was 30.7 $\pm$ 1.9 mm (26.5–36.6 mm). Among the 278 eyes, the episclera and/or Tenon’s capsule were detected in 164 eyes (59.0%; or 33.6% of the original 488 eyes) of 117 patients (mean age: 59 $\pm$ 11.4 years; mean axial length: 30.9 $\pm$ 1.8 mm). The episclera appeared as a relatively uniform structure with a reflectivity that was slightly lower than the scleral reflectivity (Fig. 2). The episclera was closely attached to the outer surface of the sclera in most areas; although in some regions, especially in the macular area, the episclera was clearly separated from the outer surface of the sclera (Figs. 3, 4). The latter finding suggested that the episclera represented a different tissue, distinct from the sclera proper. The border between the sclera and episclera was relatively clear in most eyes due to differences in reflectivity between these tissues. Eyes with detectable episclera compared to eyes in which the episclera was not visible had a significantly longer axial length ($P = 0.003$); thinner central retinal thickness ($P = 0.01$); and thinner subfoveal scleral thickness ($P < 0.001$). There were no significant differences in age between these groups ($P = 0.66$). Because the subfoveal chorioid was too thin to be measured in most eyes included in our study, chorioidal thickness was not included in the list of outcome parameters.

Overlying the episclera, the tissue considered to be Tenon’s capsule was detected in 11 of the 278 eyes (4.0%). Tenon’s capsule appeared as loosely arranged tissue. In some eyes, a thin space was observed between the episclera and Tenon’s capsule (similar to the slit shown in Fig. 2A, although slightly wider than that shown in Fig. 2C).

Blood vessels located in the sclera were surrounded by fibrous tissue within a rhomboid space (Fig. 2C). A cluster of blood vessels was observed in the subfoveal area between the sclera and episclera (Fig. 2E). In contrast to the intrascleral blood vessels, the blood vessels between the sclera and episclera did not appear to be ensheathed. Due to the presence of these blood vessels between the episclera and sclera, the outer border of the episclera was located outside of the imaging range of the OCT in these eyes. The region with the posterior episclera visible on the horizontal OCT images was located in these eyes temporal to the fovea. In three eyes, the outer surface of the sclera was folded inwardly and a cluster of blood vessels was located between the inwardly folded sclera and the episclera (Fig. 4).

In the 164 eyes in which the episclera could be visualized in the OCT images, the mean scleral thickness in the foveal region was $197 \pm 73\,$ $\mu$m (range, 64–482 $\mu$m; Table 1). In univariate analysis, scleral thickness decreased in conjunction with the longer axial length in the subfoveal region ($P = 0.008$; $\beta = -0.22$) and at 1000 $\mu$m ($P = 0.02$; $\beta = -0.20$) and at 2500 $\mu$m ($P = 0.01$; $\beta = -0.21$) temporal to the fovea. The scleral thickness was significantly ($P < 0.0001$) thicker in the foveal region than at the region that was located 1000 $\mu$m temporal to the fovea. The scleral thickness at this point was thicker ($P < 0.0001$) than that found at 2500 $\mu$m temporal to the fovea (Table 2).
The same results were found when all of the measurements for all of the locations were included in the statistical analysis and subsequent ANOVA.

In the horizontal OCT sections of the 164 eyes with detectable episclera, the mean thickness of the sclera at 1000 μm temporal to the fovea was 164 ± 64 μm (range, 54–412 μm). The full thickness of the episclera was detectable in 77 eyes with a mean thickness of 80 ± 27 μm (range, 30–135 μm). The thickness of Tenon’s capsule was measurable in 4 eyes at this location. However, the outer surface of Tenon's capsule could not be detected in any of the other eyes. The mean thickness of Tenon’s capsule in these four eyes was 60 ± 32 μm (range, 19–93 μm). At a location of 2500 μm temporal to the fovea, the mean scleral thickness was 146 ± 59 μm (range, 58–561 μm) in the 164 eyes that underwent episcleral imaging. At this location, the thickness of the posterior episclera that

Figure 2. Swept-source OCT images of the posterior sclera, episclera, and Tenon’s capsule. (A, C, E) A horizontal OCT section across the fovea. (B, D, F) Schematic illustration of corresponding OCT images. Sclera is observed as uniform hyperfluorescent tissue. The episclera appears as a relatively uniform structure with a reflectivity slightly lower than the scleral reflectivity. Tenon’s capsule appears as a structurally loosely connected tissue with meshwork appearance and splitting fibers. Red circle shows a cross-section of blood vessels; intrascleral blood vessel in Figure 1D and orbital vessels in Figure 1F. The intrascleral blood vessel is surrounded by relatively hyporeflective tissue (shown in pink, Fig. 1D). In Figure 1E, although the choroid is observed temporal to the fovea, the choroid is extremely thin and barely visible in Figures 1A or 1C.

Figure 3. Swept-source OCT image of the posterior fundus of an eye with dome-shaped macula. Note: cluster of blood vessels (shown in red ovals) between the sclera and episclera.
was measured in 112 eyes was $82 \pm 30$ μm (range, 29–174 μm). The thickness of Tenon’s capsule that was measurable in seven eyes at this location was $55 \pm 13$ μm (range, 30–70 μm).

Among the 77 eyes in which the full thickness of the episclera was observed, 25 eyes exhibited an extremely thin posterior sclera with a thickness of less than 100 μm at 1000 μm temporal to the fovea (mean, 87 ± 11 μm; range, 65–98 μm; Fig. 5). In a subset of 15 eyes that had a detectable outer border of the episclera at this location, the mean episcleral thickness was $65 \pm 15$ μm (range, 39–94 μm). In the entire group of eyes in which the full thickness of the episclera was visible, the episcleral thickness measured at 1000 μm temporal to the fovea was significantly correlated (univariate analysis) with scleral thickness at the same location ($P = 0.03$; regression coefficient $r = 0.25$), but not with the axial length ($P = 0.12$). In multivariate analysis that used episcleral thickness as the dependent variable, episcleral thickness was marginally associated with scleral thickness ($P = 0.06$; $\beta = 0.24$; B: 0.11; 95% CI: –0.01, 0.22), but not with the axial length ($P = 0.27$). Episcleral thickness measured at 2500 μm temporal to the fovea was significantly correlated (univariate analysis) with axial length ($P = 0.02$), but not with scleral thickness at the same location ($P = 0.55$). Similar results were obtained for the multivariate analysis.

**DISCUSSION**

In the present study, swept-source OCT applied to a subset of highly myopic eyes with significant thinning of the retinal and choroidal layers allowed visualization of the posterior sclera and episclera, and in some cases, also Tenon’s capsule. Eyes with detectable episclera compared to eyes without detectable episclera had significantly longer axial length and thinner central retinal thickness.

In the optical coherence tomography images analyzed in the current study, although Tenon’s capsule and the episclera showed similar reflectances, the fibers appeared to be more loosely arranged and to be more split up in Tenon’s capsule (Fig. 2). The border between the episclera and Tenon’s capsule appeared as a cleft in some eyes (Figs. 2A, 2C, 2E). Using high-speed anterior segment OCT, Kumar et al.5 examined the anterior Tenon’s capsule in 12 eyes which received a drug injection into the posterior sub-Tenon space for the therapy of uveitis. The mean thickness of the anterior Tenon’s capsule in this previous study was $0.21 \pm 0.07$ mm. In Figure 2 of the Kumar et al.5 study, Tenon’s capsule showed a similar reflectance with splitting fibers similar to the findings for the Tenon’s capsule in the posterior segment in our current study.

We observed vessels at the interface between the episclera and Tenon’s capsule (Figs. 2E, 3A). According to anatomic studies, branches of the short posterior ciliary arteries perforate the sclera in the peripapillary region.1 Previous studies suggested that some of these branches run in the sclera toward the equator and Anastomose with branches of the long posterior ciliary arteries to supply the posterior episclera in the form of a thin episcleral vessel plexus.5 Furthermore, we detected a cluster of blood vessels between the posterior sclera and the episclera, but not within the episclera. These vessels either might have been part of the so-called “posterior episcleral plexus” or might have been the long posterior ciliary arteries.

The relatively large blood vessels between the posterior sclera and episclera may give rise to an inward bulging of the sclera in the macular region, similar to that observed in three of the eyes in our study population (Fig. 4). One might hypothesize that these types of vessels running along the outer surface of the posterior sclera may partially resist an expansion of the sclera in eyes with pathologic myopia, and may cause a local indentation of the posterior sclera.

**TABLE 1.** Comparison of Clinical Characteristics (mean ± SD; range) Between Highly Myopic Eyes With Visible Episclera or Without Visible Episclera

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Visible Episclera</th>
<th>Episclera Not Visible</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eyes (No. of persons)</td>
<td>164 (117)</td>
<td>17 (12)</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>59.1 ± 12.5 (32–89)</td>
<td>58.3 ± 8.6 (40–74)</td>
<td>0.66*</td>
</tr>
<tr>
<td>Axial length, mm</td>
<td>30.9 ± 1.9 (25.5–36.2)</td>
<td>29.9 ± 1.8 (25.5–33.4)</td>
<td>0.03*</td>
</tr>
<tr>
<td>Subfoveal sclera thickness, μm</td>
<td>197 ± 73 (64–482)</td>
<td>310 ± 83 (168–477)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Central retinal thickness, μm</td>
<td>134 ± 33 (62–216)</td>
<td>160 ± 35 (98–216)</td>
<td>0.02*</td>
</tr>
</tbody>
</table>

* Mann-Whitney U tests.
The thickness of the posterior sclera in the eyes included in our study was significantly thinner at the locations 1000 μm and 2500 μm temporal to the fovea compared to that observed in the foveal region (Table 1). The thinning of the sclera preferentially in the parafoveal versus the foveal region may be of importance, as this could explain the development of parafoveal staphylomas as local backward outpouchings of the sclera. Also of potential interest is the development and progression of a dome-shaped macula, which consists of a local thickening and inward folding of the foveal sclera.3-6-9

Unfortunately, since the measurement of the thickness of the posterior episclera could only be obtained in a few eyes, it was not possible to perform a comparison of the posterior episcleral thickness between the various regions.

At 1000 μm temporal to the fovea, the sclera was thinner than at 100 μm in 25 eyes of our study population. In 15 of these 25 eyes, the mean episcleral thickness could be measured and was shown to be 65 μm. Thus, in eyes with an extremely thin posterior sclera, the episclera appears to be a major part of the outer wall of the globe (Fig. 3A). The coverage of the posterior thinned sclera by the posterior episclera in highly myopic eyes may explain why none of approximately 4000 highly myopic patients in the High Myopia Clinic at the Tokyo Medical and Dental University showed a spontaneous rupture of the posterior globe despite the extremely thinned sclera (and episclera). However, this thinning did allow ophthalmoscopic visualization of the orbital fat tissue in some of these eyes.

Potential limitations of our study should be discussed. First, as the study participants were recruited by a specialized tertiary center for high myopia, it is unclear whether our findings will also apply to highly myopic eyes within the general population. In particular, the study population may have consisted of a disproportionately large number of patients with pathologic myopia. Thus, our current findings may be more typical for eyes with pathologic myopia than for highly myopic eyes in general. Second, the number of eyes with detectable episclera or detectable Tenon’s capsule was relatively small. Third, the study population was composed of Japanese patients, and therefore it is unclear whether these results are applicable to other ethnic groups. Fourth, the observation of the episclera and Tenon’s capsule was possible only in eyes with high myopia. Thus, the mean scleral and episcleral thickness values do not appear to represent the thickness of these tissues in general population. Fifth, a posterior scleral thickness of approximately 100 μm appears to be very low, thereby leading to doubts about the validity of such data. However, histomorphometric examinations of markedly elongated eyes revealed similar thickness values as low as 0.1 mm for the posterior sclera.10,11 Furthermore, it needs to be taken into consideration that histologic specimens under postmortem tissue swelling and tissue shrinkage due to the histologic processing. Sixth, if both eyes fulfilled the inclusion criteria, both eyes of the participant were included into our analysis. In general, studies performed on a paired, normally and mostly symmetrical organ such as the eyes should include only one randomly chosen eye for the statistical analysis. This is particularly true if there are associations between these symmetrical organs and systemic parameters that are quantitatively examined, such as the blood pressure. However, in our study of highly myopic individuals, both eyes of the same individual were relatively asymmetrical, as out of the 164 eyes of 117 individuals, only 47 individuals had both eyes included, while 70 individuals had only one eye included.

The present study showed that in highly myopic eyes, swept-source OCT allowed the visualization of the posterior episclera and Tenon’s capsule. An increase in the tissue depth penetration of the OCT technology may further increase the number of eyes with detectable episclera or Tenon’s capsule upon OCT. Additional studies with OCT will allow further investigation of the changes in the episclera and Tenon’s capsule in pathologic myopia and their role in related pathology.

Acknowledgments

Supported by grants from the Japanese Society for Promotion of Science (no. 15H04993, 15K15629).

Disclosure: K. Ohno-Matsui, None; Y. Fang, None; K. Morohoshi, None; J.B. Jonas, Mundipharma Co. (C), P

Table 2. Thickness of the Sclera, Episclera, and Tenon’s Capsule at Different Locations in the Posterior Fundus

<table>
<thead>
<tr>
<th>Location</th>
<th>Thickness of Sclera</th>
<th>Thickness of Episclera</th>
<th>Thickness of Tenon’s Capsule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subfovea</td>
<td>197 ± 73 (64–482; 164 eyes)</td>
<td>80 ± 27 μm (77 eyes)</td>
<td>60 ± 32 μm (4 eyes)</td>
</tr>
<tr>
<td>1000 μm temporal to the fovea</td>
<td>164 ± 64 μm (164 eyes)</td>
<td>82 ± 30 μm (112 eyes)</td>
<td>55 ± 13 μm (7 eyes)</td>
</tr>
<tr>
<td>2500 μm temporal to the fovea</td>
<td>146 ± 59 μm (164 eyes)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Swept-source OCT image of the posterior fundus of an eye (72-year-old patient; axial length: 31.0 mm) with very thin sclera (84 μm at 2500 μm temporal to the fovea) and an episcleral thickness of 74 μm. The choroid is not visible on either sides of the fovea. A cross-section of an orbital vessel that is located between the sclera and episclera (shown in red oval in Fig. 5B).
References