The Premacular Bursa’s Shape Revealed In Vivo by Swept-Source Optical Coherence Tomography

Karen B. Schaal, MD,1 Claudine E. Pang, MD,1 M. Carolina Pozzoni, MD,2 Michael Engelbert, MD, PhD1

Objective: To resolve the controversy surrounding the shape and relationship of posterior vitreous spaces by characterizing the connections between the premacular bursa, the area of Martegiani, and Cloquet’s canal.

Design: Comprehensive posterior vitreous maps were created using swept-source optical coherence tomography (SS OCT) in a cross-sectional study.

Participants: The posterior vitreous of 102 eyes of 51 volunteers 21 to 54 years of age without ocular pathologic features was imaged using SS OCT.

Methods: The DRI OCT-1 Atlantis 3D SS OCT (Topcon Medical Systems, Oakland, NJ) was used to acquire scans of the posterior vitreous over an 18×18-mm area.

Main Outcome Measures: Posterior vitreous spaces and their relationships were identified.

Results: The premacular bursa was identified in all 102 eyes and was found to extend superiorly beyond our scanning ability at a variable angle. No discernible superior borders could be identified. Instead, a connection of the bursa with the preoptic area of Martegiani or its extension, Cloquet’s canal, was found in 101 of 102 eyes. This connection occurred at a variable distance from the optic nerve, where it formed a flat and broad superior channel. The skyward direction of this channel was found to be gravity dependent in all 14 eyes of the 7 subjects examined in various head positions. Although SS OCT was able to identify vitreous degeneration, the above changes were present in 28 eyes even without any discernible vitreous degeneration.

Conclusions: The premacular bursa, also called the posterior precortical vitreous pocket, was found to continue superiorly beyond the posterior pole without a detectable border. The bursa fused broadly with the extension of the preoptic area of Martegiani, namely Cloquet’s canal, or the hyaloideal tract of Eisner. These findings suggest that there is a direct anteroposterior connection between the retrolental and premacular and preoptic spaces already existent in the eyes of young adults before the occurrence of vitreous degeneration. This observation may have important implications with respect to the movement of intrinsic and extrinsic mediators between the anterior and posterior segments. Ophthalmology 2014;121:1020-1028 © 2014 by the American Academy of Ophthalmology.

Supplemental material is available at www.aaojournal.org.

Considering the importance of the vitreous in retinal disease, surprisingly little is known about its anatomic features. Although the vitreoretinal interface has been relatively well characterized, structures in the center of the vitreous have been comparatively elusive. This is because it is difficult to fixate this delicate organ, which consists primarily of water. Our knowledge of internal vitreous structures therefore has been gleaned from in vivo biomicroscopic observations with the slit lamp and ophthalmoscopy, which are limited by the inability to scan and document larger areas reliably, the resolution provided by visible light, and the transparent nature of the organ itself. B-scan ultrasonography is clinically indispensable in assessing the vitreous, but is similarly limited to visualization of relatively echodense structures, and its resolution is limited.

Recently, optical coherence tomography (OCT) has allowed us to image intraocular structures with ever-increasing resolution, sensitivity, and depth of field. The first attempts at imaging posterior vitreous structures were made using spectral-domain OCT1,2 and, more recently, swept-source (SS) OCT.3 Both spectral-domain and SS OCT allow imaging of the retina with an axial resolution of 8 μm and lateral resolution of 20 μm. However, SS OCT’s depth of field permits visualization of deep structures such as the choroid, sclera, and penetrating vasculature as well as orbital fat, but also the vitreous at the posterior pole and about half way up to the equator with an approximate imaging depth of 2.6 mm. This is superior to spectral-domain OCT’s depth of field of approximately 1.5 mm on an optimal vitreous scan (personal observation of the authors’ [technical data provided by Heidelberg Engineering: scan depth in tissue: 1.9 mm; Spectralis OCT user manual]).

We were interested in identifying vitreous structures commonly found during vitreoretinal surgery aided by triamcinolone staining4 (Fig 1, available at www.aaojournal.org) on in vivo SS OCT images. We were particularly interested in correlating these OCT findings to those based on preparations of postmortem vitreous performed first by Worst5 and later Kishi and Shimizu,6 which led to the identification of the...
premacular bursa and posterior precortical vitreous pocket, respectively.

Knowledge of the internal vitreous anatomic features and refinement of means to study them in vivo are crucial to understanding vitreous aging and its associated complications, such as vitreoretinal interface changes (vitreomacular traction and diabetic and myopic vitreopathy) and vitreous separation with its possible sequelae. It also may allow for exploration of possible intravitreal conduits for intrinsic and extrinsic biological mediators.

Methods

The posterior vitreous of healthy subjects older than 18 years without posterior vitreous separation was imaged using the DRI OCT-1 Atlantis 3D SS OCT device (Topcon Medical Systems, Oakland, NJ). Eyes with posterior vitreous separation, vitreoretinal pathologic features, or ocular or systemic comorbidities known to affect the vitreous, such as diabetes or high myopia (defined as an axial length [AL] of more than 28 mm), were excluded from the study.

To acquire the vitreous images, 5-line cross-scan patterns with a spacing of 1.5 mm between each line of the cross-scan pattern were acquired. A scan width of 12 mm was chosen and 32 A-scans were averaged for each line of the 5-line cross. The OCT was focused on the vitreous and contrast adjusted with the instrument’s viewing software to visualize vitreous structures. Six 5-line cross-scans were acquired for each eye to create composite maps of the vitreous anatomic features at the posterior pole (Fig 2): 1 5-line cross-pattern was centered on the macula (Fig 2A), consisting of 5 horizontal (M1–M5) and 5 vertical (M6–M10) 12-mm line scans, each 1.5 mm apart from one another. Four 5-line cross-patterns in the periphery of the posterior pole were obtained by moving the fixation target 3 mm vertically and 3 mm horizontally into the superotemporal (ST1–ST10), superonasal (SN1–SN10), inferonasal (IN1–IN10), and inferotemporal (IT1–IT10) quadrants, overlaid on a schematic (Fig 2B) corresponding to the infrared image shown in Figure 2A. The sixth scan pattern was obtained with the patient maximally elevating the eye beyond the central fixation target (example shown in Fig 3B). The area of uniformly optically empty scan areas was measured using the instrument’s caliper function after adjusting the B-scan scale to 1:1. This was done to avoid false measurements because of an anteroposterior magnification on the B-scan.

To exclude the possibility that connections between spaces identified with the above protocol were missed with 1.5-mm spaced horizontal and vertical line sampling, 0.25-mm spaced scans over the optic nerve head were obtained in cases where no connection could be identified.

In many cases, connections of the premacular bursa with adjacent optically empty spaces in the context of degenerative cleavage of the vitreous cortex (i.e., vitreous degeneration) were noted. A grading scheme was developed to categorize these changes (Fig 4, available at www.aaojournal.org). Grade 0 describes a premacular bursa with no connections to adjoining spaces. Grade 1 was defined as visible neighboring spaces with speckled hyperreflectivity at the edges without a connection to the premacular bursa. Grade 2 was defined as more advanced vitreous degeneration with coil-like fibrillar structures, prominent localized hyperreflectivity of the borders, and connections of these shallow spaces with the premacular bursa. Grade 3 was defined as a connection between the premacular bursa and a more central, larger lacuna. Axial length was determined using partial coherence laser interferometry (Zeiss IOL Master; Carl Zeiss AG, Oberkochen, Germany).

Institutional review board approval was obtained through Western Institutional Review Board. Informed consent was obtained from all volunteers. This study complied with the Health Insurance Portability and Accountability Act and adhered to the tenets of the Declaration of Helsinki.

Results

Fifty-one subjects (18 men and 33 women) 21 to 54 years of age (mean ± standard deviation [SD], 33±8 years) with ALs ranging from 20.6 to 27.6 mm (mean ± SD, 24.2±1.4 mm; 4 subjects had anisometropia of more than 0.5 but less than 1 mm) were included in this study. All eyes showed an optically empty space overlying

Figure 2. Scan patterns used to map the vitreous over an oval 18x18-mm area over the posterior pole. A, Five-line cross-pattern centered on the macula. B, Four patterns obtained by moving the fixation target 3 mm vertically and horizontally into the superotemporal, superonasal, inferonasal, and inferotemporal quadrants. Yellow star = foveal center; yellow circle = optic disc; red lines = vascular arcades.
Figure 3. Vertical scans demonstrating a superior extension of the premacular bursa far beyond the superior arcade. A, Infrared image of the left eye of a 23-year-old emmetropic individual, with the horizontal scan line (horizontal white arrow) corresponding to the B-scan image (A') and the vertical scan line (vertical white arrow) corresponding to the B-scan image (A''). The horizontal B-scan shown in (A') shows the premacular bursa, an ovoid space (asterisk)
the macula that appeared ovoid and well defined on horizontal optical sections but extended anteriorly and superiorly beyond our scanning ability on vertical scans (Fig 3). In all 102 eyes of 51 healthy individuals, we found an optically empty premacular space similar to the one first described as *premacular bursa* and later as *posterior precentral vitreous pocket* (Fig 3A). It measured 7.0±1.2 mm in width and 0.6±0.3 mm in height in subjects in whom the premacular bursa was measurable in isolation and had not fused with adjacent spaces (41 eyes of 23 subjects; mean age ± SD, 32±8 years; mean AL ± SD, 23.8±1.3 mm). We used an extended scanning protocol that allowed us to map an area of approximately 18×18 mm over the posterior pole and somewhat higher superiorly in extreme upgaze. This allowed us to visualize a variably flattening, but uniformly patent, extension of this space superiorly and anteriorly. This extension went beyond the edge of the most superior scan to more than 9 mm above fixation (Fig 3B).

Angle and depth of the superior extension were quite variable (Fig 3C–E). In most subjects (45/51), the superior extension of the premacular bursa followed the contour of the eye wall with an angle toward the center of the eye of less than 30° (mean age ± SD, 33±8 years; mean AL ± SD, 24.2±1.4 mm). In 4 subjects, the superior extension of the premacular bursa was pointed more steeply toward the center of the globe (mean angle between 30° and 60° ± SD, 31±5°; mean AL ± SD, 24.7±1.9 mm). In 2 of the youngest subjects, the extension was directed almost perpendicularly into the eye (>60°), both 21 years old; mean AL ± SD, 23.5±2.4 mm).

The premacular bursa was found to be variably connected with more central lacunar spaces in the context of vitreous degeneration, but its superior extension was present even in the absence of such connections (Fig 4, available at www.aaojournal.org; Table 1). Figure 4 shows vertical B-scan images through the fovea demonstrating various degrees of vitreous degeneration and illustrates the grading scheme used in this study. In approximately one third of eyes (28/102), no shallow spaces next to the premacular bursa could be detected. In some of these eyes (n = 11), parts of one or several larger ovoid or spherical lacunar spaces could be identified at a variable distance from the premacular bursa (Fig 4A). In approximately one third of eyes, vitreous degeneration changes characterized by the presence of shallow, optically empty planes, often multiple and sometimes with irregular and hyperreflective edges, could be found overlying the premacular bursa (Fig 4B) and fused with it in some (Fig 4C). No such changes were found in another one third of eyes (Fig 4A). In approximately another one third, broad fusion of the premacular bursa and more central lacunar spaces were observed (Fig 4D).

The superior extension of the premacular bursa was apparent in all but one case, even where there were no connections to either shallow peripheral fissure planes or more central lacunar spaces. Although it appeared that the grade of vitreous disorganization reflected by the grading used here correlated with increasing age and AL, we were unable to demonstrate a statistically significant correlation with either (Table 1).

A connection between the premacular bursa and preoptic area of Martegiani could be detected in all but 1 of 102 eyes studied (Table 2). We were able to detect a connection between the premacular bursa and preoptic area of Martegiani in 101 of 102 eyes. This connection was of variable width and depth. In approximately one third of the eyes, a connection was seen on the M3 scan, which bisects the nerve and fovea. In the remainder, most demonstrated a connection between the premacular bursa and area of Martegiani on cuts obtained above M3. In 12 eyes, the connection could be seen below the optic nerve. In 2 eyes of another 2 subjects, the connection was only detectable on dense scans centered over the optic nerve because suboptimal scan quality precluded assessment of the superonasal scans. In 3 eyes of 2 subjects, a connection was suspected but was obvious neither on the 6 5-line scans we routinely obtained nor on the dense scan over the optic nerve. In 2 of those 3 eyes, additional dense scanning with the Heidelberg HRA OCT (5×15°, 60-line averages; Heidelberg Engineering, Heidelberg, Germany) showed a thin connection superior to the optic nerve. In 1 eye with poor image quality, we were unable to demonstrate a connection (Table 2).

These connections were delineated by a variably broad and high ridge on the retinal surface posteriorly and on the roof of the premacular bursa and area of Martegiani anteriorly. In most cases, broad connections were present and sometimes associated with the vitreous degeneration changes described in the previous section. This connection gives rise to a broad fused superior extension of the premacular bursa and the anterior extension of the area of Martegiani, Cloquet’s canal (Fig 5, Table 3). In all but 1 eye, the examination of multiple anterior and superior horizontal and vertical scans revealed a continued connection between the superior extension of the premacular bursa and the superoanterior extension of the area of Martegiani, presumably Cloquet’s canal or Eisner’s hyaloid tract, forming a broad and flat channel.

To evaluate the width of this superior channel, the most superior scans, S6 through S10, were evaluated. If the superior extension of the premacular bursa was still present on S6, S10, or both (horizontal edges of the 2 most superior scans), the adjacent temporal or nasal scans also were evaluated (ST and SN scans) to

<table>
<thead>
<tr>
<th>No. of</th>
<th>Axial Length (mm), Mean (Standard Deviation)</th>
<th>Age (yrs), Mean (Standard Deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes</td>
<td>Subjects</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>31</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
<td>21</td>
</tr>
</tbody>
</table>
estimate the width of this superior channel as accurately as possible within the limits of current SS technology. In a minority of eyes (18 eyes of 11 subjects), the S scan quality was inadequate to accurately measure width, and therefore the vertical M scans (M6—M10) were examined. In individuals with vitreous degeneration connections between the premacular and adjacent spaces, the superior channel usually had an irregular outline and variable depth. In some cases (14 eyes of 11 subjects), the pre-macular bursa had fused with a more central, larger lacuna. These were excluded from the assessment. In 1 eye of 1 subject, scan

<table>
<thead>
<tr>
<th>Lowest Scan Position with Detectable Connection</th>
<th>No. of Eyes</th>
<th>No. of Subjects</th>
<th>Axial Length (mm), Mean (Standard Deviation)</th>
<th>Age (yrs), Mean (Standard Deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above M1</td>
<td>1</td>
<td>1</td>
<td>23.1</td>
<td>31</td>
</tr>
<tr>
<td>M1</td>
<td>9</td>
<td>9</td>
<td>23.7 (2.0)</td>
<td>29 (8)</td>
</tr>
<tr>
<td>M2</td>
<td>37</td>
<td>27</td>
<td>24.3 (1.2)</td>
<td>33 (8)</td>
</tr>
<tr>
<td>M3</td>
<td>38</td>
<td>26</td>
<td>24.2 (1.6)</td>
<td>34 (9)</td>
</tr>
<tr>
<td>M4</td>
<td>10</td>
<td>9</td>
<td>24.3 (1.3)</td>
<td>36 (6)</td>
</tr>
<tr>
<td>M5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Below M5</td>
<td>2</td>
<td>2</td>
<td>25.2 (2.9)</td>
<td>31 (8)</td>
</tr>
<tr>
<td>Not on any M horizontal scans</td>
<td>2</td>
<td>2</td>
<td>22.2 (0.5)</td>
<td>21 (0)</td>
</tr>
<tr>
<td>Not seen on SS OCT</td>
<td>2</td>
<td>2</td>
<td>23.6 (0.7)</td>
<td>27 (1)</td>
</tr>
<tr>
<td>Not found</td>
<td>1</td>
<td>1</td>
<td>23.9</td>
<td>26</td>
</tr>
</tbody>
</table>

— = no subject (eye) met this category; SS OCT = swept-source optical coherence tomography.

Figure 5. The extension of the premacular bursa fuses superiorly with Cloquet’s canal, regardless of the degree of vitreous degeneration. Serial horizontal cuts (stacked from superior to inferior and corresponding to superonasal scans SN1—SN5 on the infrared images) demonstrate a fusion between the premacular bursa (asterisk) and the area of Martegiani and Cloquet’s canal (triangle) in a 21-year-old emmetrope with no apparent vitreous degeneration. (B) Grade 2 vitreous degeneration in a 32-year-old emmetrope, and (C) grade 3 vitreous degeneration in a 46-year-old. Empty circles indicate optically empty cleavage planes in (B) and (C).
quality did not allow for width or depth measurements. In 1 eye of another subject, we were unable to identify a superior extension of the premacular bursa; rather, it appeared to be an isolated space where only Cloquet’s canal was oriented anteriorly and superiorly.

In 16 eyes of 12 subjects, the borders of the superior channel could be detected on both sides and a precise measurement of width could be performed. In 59 eyes of 40 subjects, only the temporal border was detectable, but the nasal border extended beyond our scanning ability. In 18 eyes of 13 subjects, the superior channel was so broad that both the nasal and temporal borders extended beyond our scanning ability. For these eyes, minimum width is reported in Table 3. In one patient, one eye did not show a superior extension, and in the fellow eye, the superior channel tilted anteriorly into the vitreous. It therefore was not visible on the S scans.

Given the mean width of the premacular bursa in the central macula (7.0 mm) and the mean minimal width of the superior extension of the premacular bursa (>5.8 mm) more than 9 mm above fixation, the superior extension of the premacular bursa appears as a flattened ovoid tunnel that is closed inferiorly but extends superiorly, anteriorly, and often nasally beyond our scanning ability. In many eyes (59 eyes), because the nasal border and, in some cases (18 eyes), neither border, was present, this tunnel appears to become wider. We also analyzed 41 eyes of 23 subjects (mean age ± SD, 32±8 years; mean AL ± SD, 23.8±1.3 mm) in whom the premacular bursa could be measured in isolation because it had not fused with the area of Martegiani. We found that, in 13 eyes, the width at fixation was smaller than the most superior width; in 3 eyes, it was identical; and in 25 eyes, it was smaller than at fixation. However, in 11 of the latter 25 eyes, only 1 border of the superior channel was detectable, and therefore only 14 of 41 eyes had a superior extension that was demonstrably narrower than the width at the fovea.

As has been described previously, the premacular bursa has an inferior border, usually within an area delineated by the vascular arcades. In 5 eyes of 5 subjects (mean age ± SD, 28±5 years; mean AL ± SD, 25±1.8 mm), the premacular bursa ended less than 1.5 mm below fixation. In 62 eyes of 39 individuals (mean age ± SD, 32±7 years; mean AL ± SD, 24.1±1.5 mm), the premacular bursa terminated more than 1.5 mm but less than 3 mm below fixation. In 31 eyes of 22 subjects (mean age ± SD, 35±9 years; mean AL ± SD, 24.2±1.3 mm), the premacular bursa ended more than 3 mm but below 4.5 mm below fixation, and in 4 eyes of 4 subjects (mean age ± SD, 35±6 years; mean AL ± SD, 24.2±0.8 mm), the premacular bursa extended beyond the lowest horizontal scan (more than 4.5 mm below fixation). However, the vertical M8 scan always demonstrated an inferior border of the premacular bursa within the arcades.

Table 3. Width and Depth of Superior Channel (Fused Extension of Worst’s Premacular Space and Cloquet’s Canal)

<table>
<thead>
<tr>
<th>Minimum Channel Width (mm), Mean (Standard Deviation)</th>
<th>Depth of Superior Channel (mm), Mean (Standard Deviation)</th>
<th>Borders of Superior Channel</th>
<th>No. of Eyes</th>
<th>No. of Patients</th>
<th>Axial Length (mm), Mean (Standard Deviation)</th>
<th>Age (yrs), Mean (Standard Deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 (1.7)</td>
<td>0.6 (0.3)</td>
<td>Detectable on both sides</td>
<td>16</td>
<td>12</td>
<td>23.6 (1.3)</td>
<td>31 (8)</td>
</tr>
<tr>
<td>6.8 (1.9)</td>
<td>0.7 (0.4)</td>
<td>Not detectable nasally</td>
<td>59</td>
<td>24.2 (1.6)</td>
<td>33 (8)</td>
<td></td>
</tr>
<tr>
<td>&gt;10.5</td>
<td>0.6 (0.2)</td>
<td>Detectable neither nasally</td>
<td>18</td>
<td>13</td>
<td>24.2 (1.4)</td>
<td>37 (9)</td>
</tr>
<tr>
<td>7.5 (2.6)</td>
<td>0.5 (0.3)</td>
<td>Not detectable temporally</td>
<td>3</td>
<td>22.9 (0.3)</td>
<td>28 (7)</td>
<td></td>
</tr>
<tr>
<td>6.4 (1.9)</td>
<td>0.5 (0.4)</td>
<td>Unclear borders (poor scan quality)</td>
<td>4 3</td>
<td>24.6 (1.1)</td>
<td>34 (2)</td>
<td></td>
</tr>
<tr>
<td>Channel not detectable</td>
<td></td>
<td>No bursal channel detectable</td>
<td>1 1</td>
<td>21.8</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Channel not detectable</td>
<td></td>
<td>Not measurable (anterior tilt)</td>
<td>1 1</td>
<td>21.9</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

Data are mean (standard deviation) unless otherwise indicated.

The skyward extension of the premacular bursa and its fusion with Cloquet’s canal is a gravity-dependent phenomenon (Fig 6). To determine whether the extension of the premacular bursa obeyed its skyward course to an anatomic tether at the 12-o’clock position or gravitational forces exerted on this liquid-filled space of lower specific weight than the surrounding formed vitreous, 7 of the 51 subjects were scanned in the supine position with their heads maximally extended backward to rotate the eye 180° and on their right and left sides to rotate the eye 90° clockwise or counterclockwise, respectively. In both eyes of all 7 subjects, a vertical scan through the fovea (M8) demonstrated an inferiorly closed premacular bursa without a superior border, regardless of eye position (representative example shown in Fig 6). Overall shape and dimensions did not change significantly from one position to the other.

Discussion

The anatomic features of the posterior vitreous have eluded surgeons and anatomists. Universal agreement seems to exist only on the fact that there is a liquid space in front of the macula, which was first described by Worst in 1976. Controversy still exists as to whether this space is confined, a view that is held by Kishi and Shimizu, who connects to other spaces in the vitreous, as initially described by Jongebloed and Worst, and if so, to which, and whether those connections are present early in life or are degenerative in nature.

The results of our study are based on in vivo observations obtained with SS OCT and may resolve some of these issues. They may help to provide a more complete understanding about vitreous anatomic features when put into context with the observations of others. We have produced extensive maps of the posterior vitreous over an area of approximately 18×18 mm, corresponding to the area delineated by the vascular arcades and approximately 4 mm beyond (representative scan map is shown in Fig 2; actual scans illustrating the most superior vertical scans are shown in Fig 3), reaching approximately halfway between the fovea and the equator, which is approximately 18 mm from the optic nerve in the emmetropic eye with an average diameter of 72 mm.

Several optically empty spaces could be identified consistently in 102 eyes of 51 healthy individuals. The first is an optically empty space, the bulk of which could be
found overlying the macular area. Although this space terminated within the arcades inferiorly, it continued far superiorly and turned toward the center of the eye at a variable angle with increasing distance from the posterior pole. This premacular space corresponds to what Worst first identified in the 1970s and called premacular bursa, which Kishi and Shimizu later described as the posterior precortical vitreous pocket, but observed important differences. Kishi and Shimizu interpreted his findings obtained with fluorescein staining of postmortem vitreous specimens as a confined space that only opens up later to other lacunar vitreous spaces in the context of vitreous degeneration, a view that was supported by Sebag and contested by Worst. Itakura et al recently described SS OCT findings obtained on the same platform we used and found a “boat-shaped lacunae in the macular area.” This description again implies a confined space that is displaced superiorly, presumably by the heavier vitreous, which gravitates inferiorly. In contrast to our study, Kishi’s group used only 2 vertical 12-mm line scans: 1 through the fovea and 1 through the optic nerve. We scanned a significantly wider macular area covering approximately 18×18 mm with 9 vertical and 9 horizontal scan pairs and multiple, more tightly spaced scans if necessary. In all of our subjects, the premacular bursa extended beyond the central vertical 12-mm scan used by Kishi’s group, and appeared to continue beyond the area that can be scanned with the SS OCT. Only in 1 of 102 eyes were we unable to demonstrate a superior extension of the premacular bursa.

Figure 6. The shape of the premacular bursa is independent of head position. Vertical scans through the fovea with corresponding infrared images and sketches indicating head position (schematic arcades of the imaged left eye in red): (A) upright, (B) upside down position, (C) on the right side, and (D) left side. Arrows indicate direction of the extension of the premacular bursa.

Figure 7. Schematic showing the relationship between the premacular bursa and other vitreous structures. The superior extension of the premacular bursa (asterisk) fuses with Cloquet’s canal (triangle) at a variable distance from the optic nerve and continues its course through the eye as the hyaloid tract (arrow) to terminate behind the lens in space of Erggelet (open circle). Light blue halo at the posterior pole outlines the approximate scan area 18 mm in diameter centered around fixation (anterior portion of schematic adapted from Eisner).
bursa with our extended scanning protocol, possibly because of the poor vitreous representation on this scan. This finding is more consistent with Worst’s description of a premacular bursa that connects anteriorly. However, Worst’s ciliobursal canal originates from the anterior aspect of the premacular bursa, rather than being an extension of its superior aspect, as evident on SS OCT. A possible explanation for this is given by Worst himself, who cautioned against “selective overfilling” with the inks he used on postmortem specimens. It is conceivable that the necessary addition of volume containing the ink to the premacular bursa straightens the canal and gives the artifactual appearance of an anterior rather than superior connection. Furthermore, Worst’s observations were made in vitro on laboriously prepared postmortem specimens, possibly inducing further artifact. It is interesting to note that in some of our younger subjects, a more acutely angled connection toward anterior was found, implying that the course more parallel with the wall found in most of our subjects may be an age-related change. This is also in line with Eisner’s observation of a predominantly straight anteroposterior orientation of vitreous fibers that becomes more undulating later in life. Unfortunately, Worst did not provide information on the age, AL, or number of the subjects from whom his preparations were obtained.

The second is another more cone-like empty space overlying the optic nerve, which was found to have connections to the premacular bursa in 101 of the 102 eyes examined in this study and corresponds to the well-characterized area of Martegiani. In some cases, dense scans spaced 0.25 mm apart had to be obtained to identify thin connections in the relatively homogenous cortical vitreous separating the premacular and epipapillary space, which had been termed septum interpapillomaculare by Worst. Because our youngest subject was 21 years old, we cannot exclude that the tenuous connections we observed in our youngest subjects may be degenerative in nature, as suggested by Yokoi et al.

The area of Martegiani also could be identified by Jongbloed and Worst in their postmortem specimens with ink. They termed it the cisterna preoptica and found it to be connected to the ciliobursal canal through a “funnel-like extension...which runs through the septum interpapillomaculare.” Similarly, Itakura et al found connections in most of their subjects using a protocol, 2 scans of which incorporated the optic nerve—the horizontal and 1 vertical. In 4 subjects, no connecting channel could be detected. However, connections can be missed with cursory scanning protocols. With our scan protocol, we were able to demonstrate connections between the premacular bursa and the area of Martegiani, or its extension, in 101 of 102 eyes by examining adjacent horizontal and vertical scans or using a denser scan pattern if necessary.

Third and most surprising to us, however, was the discovery that the anterior and superior extension of the premacular bursa remained united with Cloquet’s canal after fusing with it at a variable distance from the nerve, giving rise to a broad flat channel in most cases (schematic Fig 7). Although Worst had already observed a “superior branching channel that arose from the roof of the bursa and merged into Cloquet’s canal,” he maintained that the premacular bursa connects to an anterior system of retrociliary cisterns by a “canalis cilio-bursalis” separate from the “canalis centralis Cloquet.” We did not find evidence of such a separate connection, although it is theoretically possible that the channels could separate again at increasing distance from the posterior pole. However, careful examination of one of Worst’s dissection videos (minute 5, available at: http://www.youtube.com/watch?v=hBD8FiBcq90; accessed September 25, 2013) seems to validate our findings in that the area of Martegiani and premacular bursa are distinct posteriorly but merge a short distance from the posterior pole. They then continue into what appears to be the hyaloidal tract of Eisner because it is more voluminous than one would expect Cloquet’s canal—a so-called hyaloidal artery basement membrane ghost—to be. It then terminates behind the lens in what appears to be space of Erggelet.

Finally, we discovered that the direction of the premacular bursa’s superior extension is gravity dependent, whereas the overall shape and dimensions of the premacular bursa are relatively constant. Regardless of the eye’s position in space, the extension will always point superiorly, whereas the inferior border will always be dependent (schematic in Fig 8, available at www.aaojournal.org). Itakura and Kishi recently reported similar observations, and Kishi had already suggested that the peculiar shape of the premacular bursa, which appears to be slightly decentered superiorly, is rounded and deeper inferiorly, and tapers superiorly, is the result of displacement of this fluid-filled cavity by the adjacent heavier formed vitreous. This was the reason brought forth by Kishi’s group as to why, on several vertical scans, no superior border of the presumably closed premacular bursa could be seen. We observed that the overall shape and dimensions of the premacular bursa did not change significantly from one position to the other, giving the impression of a space tethered only posteriorly at the nerve and macula and anteriorly with Cloquet’s canal and the hyaloidal tract at Wiëger’s ligament with rotational freedom in the coronal plane. Additional, limited freedom along the sagittal and transverse axes is probably conferred by the increasing redundancy of Cloquet’s canal and the hyaloidal tract with increasing age, as demonstrated by Eisner. In fact, the S-shaped course of the hyaloidal tract, which can be observed routinely in vivo using a slit lamp, may relate to the upward displacement of its posterior portion by the superior extension of the premacular bursa.

In summary, that (1) a superior border of the premacular bursa could not be detected in the vast majority of our subjects using an extended scanning protocol and (2) the premacular bursa was found to fuse broadly with the extension of the area of Martegiani, namely Cloquet’s canal or the hyaloidal tract of Eisner, strongly suggest that, from young adulthood on, a direct anteroposterior connection between the retrolental and premacular and preoptic spaces exists. In contrast to the preliminary report by Yokoi et al, this connection can be found superior to the optic nerve, rather than at the previous origin of the hyaloidal artery on the disc (Figs 3A and 5A are good examples) in almost half of the eyes (47/102) and has the distinct appearance of 2 independent channels fusing, rather than representing merely a vitreous degeneration.
fissure plane that is extending with age. This suggests that this connection eventually reaches the nerve in the context of vitreous degeneration but does not necessarily originate there. We used a more comprehensive scanning protocol than Yokoi et al\textsuperscript{12} in a larger group of subjects, and it is conceivable that some of our observations could be missed with a more cursory protocol. Because SS OCT is not yet approved by the Food and Drug Administration in the United States, we were unable to include subjects younger than 18 years old in our study.

Our observations may have important implications in the pathogenesis of a variety of conditions. It may provide a conduit for inflammatory mediators released in the anterior portion of the eye, for example, in the context of cataract surgery or uveitis, and may facilitate diffusion over the macula, resulting in macular edema. The presence of a larger communicating vitreous degeneration network for these mediators to diffuse in or a posterior vitreous separation may be a negative predictor in this context and deserves further study because nonsteroidal anti-inflammatory agents are dispensed almost routinely to patients after cataract surgery in the developed world—a costly, and potentially unnecessary, practice. Conversely, iatrogenic induction of a posterior vitreous separation could be helpful in conditions in which the presence of this conduit may turn out to play a role. Likewise, the pharmacokinetics of iatrogenically induced substances are likely affected by the state of these vitreous spaces, and a more targeted delivery that takes these structures into account may well influence efficacy.

Acknowledgments. The authors thank the photographic staff at VRMNY, particularly Eugene Agresta, Danielle Schweitzer, Erasmo Gomez, and Ivette de LaRosa, for lending their time and expertise to this project; Dennis Bellone and Vishnu Hoff for their assistance in assembling publication-quality figures; Ana Camila Engelbert for creating Figures 7 and 8; and Stanley Chang, K. Bailey Freund, Taku Sato, Hermann D. Schubert, and Richard F. Spaide for their comments on the final manuscript.

References


Footnotes and Financial Disclosures

Originally received: July 3, 2013.
Final revision: September 27, 2013.
Accepted: November 14, 2013.

1 Vitreous Retina Macula Consultants of New York, New York, New York.
2 Department of Ophthalmology, Hospital Italiano de Buenos Aires, Buenos Aires, Argentina.

Financial Disclosure(s):
The author(s) have no proprietary or commercial interest in any materials discussed in this article.

Supported by The Macula Foundation, Inc., New York, New York. The funding organization had no role in the design or conduct of this research.

Correspondence:
Michael Engelbert, MD, PhD, Vitreous Retina Macula Consultants of New York, 460 Park Avenue, New York, NY 10022. E-mail: Michael.Engelbert@gmail.com.