Visualization of the Posterior Vitreous With Dynamic Focusing and Windowed Averaging Swept Source Optical Coherence Tomography

RICHARD F. SPAIDE

• PURPOSE: **To survey the anatomic structures seen in the posterior vitreous using a newly developed technique, dynamic focusing and windowed averaging swept source optical coherence tomography.**

• DESIGN: **A cross-sectional study of subjects without a history of eye disease or posterior vitreous detachment.**

• METHODS: **A focused illumination beam was swept through the scan depth during 96 successive B-scans and the corresponding most highly resolved portion of each scan was used to make an averaged composite image. The main outcome measures were the frequency and interconnectedness of anatomic features visualized.**

• RESULTS: **There were 44 eyes of 25 subjects, who ranged in age from 23 to 62. An optically empty space was seen above the macula in all eyes, and corresponded to the premacular bursa. Above the optic nerve head was a conical space corresponding to the area of Martegiani. The 2 areas were interconnected in 25 cases (56.8%). Anterior to the premacular bursa was another lacuna, named the supramacular bursa, that was separate from the premacular bursa in horizontal scans centered on the fovea and was found in 38 eyes (86.4%). Both the supramacular and premacular bursae coursed anteriorly and in 21 of the 38 eyes (55.3%) were seen to interconnect.**

• CONCLUSIONS: **The anatomic arrangement of the vitreous is consistent in living eyes with no posterior vitreous detachment, and does not correspond precisely to that described from dissection studies of autopsy specimens. The constancy of the specific findings suggests there may be some beneficial effect from the architectural structure of the vitreous that enhances evolutionary fitness. (Am J Ophthalmol 2014;158:1267–1274. © 2014 by Elsevier Inc. All rights reserved.)**

THE VITREOUS IS THE LARGEST STRUCTURE INSIDE OF the eye and fills a space between the lens and the retina. It is a composite material with water as the main component (accounting for almost 99% of the weight of the vitreous) and a sparse network of collagen fibers. Interspersed between the fibers, and acting as a shock absorber, are mucopolysaccharides, most notably hyaluran, a molecule capable of binding thousands of water molecules.[1] The structure of the vitreous extends to larger scales beyond the molecular. Various authors have proposed that the transparent configuration of the vitreous has a complex architecture. Possibly because the vitreous is difficult to visualize, the details advocated in these proposals differ greatly.[2–7]

Eisner examined living and autopsy eyes and determined that the vitreous in young people was a uniform matrix but with increasing years specific condensations of the vitreous, which he called tracts, occurred in an onion-skin pattern in the vitreous body (Figure 1).[3,4] In the autopsy eyes the sclera, choroid, and retina were dissected from the vitreous, which was suspended in saline solution. The vitreous of humans was considered to have a low density, so animals with a high-density homogeneous vitreous, bovines and sheep, were used to study rarefactions in the vitreous extending centripetally inward from retinal vessels. Eisner thought the Cloquet canal did not exist after regression of the hyaloidal artery and only a "hyaloid tract" remained. Worst[5] also dissected fresh specimens and removed the sclera, choroid, and retina. Because the vitreous ordinarily has firm attachments to regions such as the vitreous base, optic nerve head, and macula, these areas are prone to damage from the dissection. Therefore Worst allowed the specimens to undergo autolysis to soften the attachments. Although he stated that "all of the enveloping structures will become putrid" by this process, the "vitreous framework is not severely affected." Worst did not state how he knew this to be true. Once the enveloping material could be removed, specimens were injected with ink at various points inside of the vitreous body and cavities became visible, which he called either cisterns or bursae.

While Eisner did not describe any internal cavities in the vitreous cavity, Worst found plenty. These were arranged in a specific configuration, according to Worst; there were 72 small cisterns located behind the ciliary body, 36 medium-sized cisterns at the equator, and approximately 12 more in the posterior pole.[5] In addition there was a large pouch-like lacuna overlying the macula, the premacular bursa. This bursa continued anteriorly through a narrow tube-like structure called the canalis ciliobursale. Over the optic nerve was an absence of formed vitreous called the area of Martegiani. Worst thought remnants of the Cloquet canal could persist after regression of the hyaloid artery that continued anteriorly from the area of

Accepted for publication Aug 26, 2014.

From the Vitreous, Retina, Macula Consultants of New York, New York, New York.

Inquiries to Richard F. Spaide, Vitreous, Retina, Macula Consultants of New York, 460 Park Ave, 5th Floor, New York, NY 10022; e-mail: rickspaide@gmail.com

0002-9394/$36.00
http://dx.doi.org/10.1016/j.ajo.2014.08.035

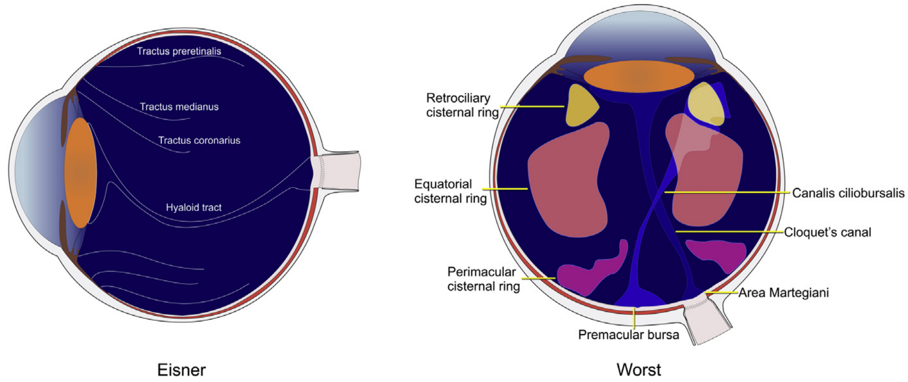

FIGURE 1. Two predominant theories of vitreous organization. (Left) Eisner thought the fibrils of the vitreous condensed into tracts, which were in turn arranged in an onion-skin pattern, as seen in this section taken vertically through the nerve. Eisner thought the Cloquet canal did not exist in the adult and remnants of the regressed structure could be seen as the hyaloid tract. (Right) Worst envisioned a much more complicated structure, as shown in this cross-section through the macula and nerve. The several levels of cisterns included 36 retrociliary, 72 equatorial, and 12 or so perimacular cisterns,[4] which were distributed in arrays rotated about the central axis. There was a region above the macula in which there was a lack of formed vitreous, called the premacular bursa, and this is connected to the narrow canalis ciliobursalis. A conical space above the nerve was called the area of Martegiani, which connected to the Cloquet canal, which could be incomplete. Note that Worst thought there were more than 120 defined bursa, cisterns, and canals, as compared with none in Eisner's model.

Martegiani through the vitreous cavity. The premacular bursa was separated from the area of Martegiani by the "septum papillo-maculare." All cisterns and bursae had the potential to intercommunicate in the central vitreous by an undisclosed architecture.[5] Kishi and Shimizu[6] fixed autopsy eyes, bisected them, and then dropped fluorescein dye onto the bisected eyes. After rinsing the vitreous, they examined the results. They identified a premacular bursa in all 48 of eyes examined with no posterior vitreous detachment, some of which were as young as 2 years old. They also reevaluated the pathophysiology of tractional states on the macula based on this information and renamed the bursa the posterior precortical vitreous pocket. Sebag and Balazs[7,8] emphasized the fibrillar nature of the vitreous in their work. They dissected autopsy eyes and many of their examples show a large premacular hole with posterior herniation of vitreous fibers. They did not demonstrate cisterns, bursa, or Cloquet canal in the posterior portion of the vitreous.

While dissection has been the mainstay of obtaining anatomic information for millennia, there was a lack of a way to independently confirm dissection studies of a structure that is very delicate or potentially prone to change while surrounding structures become "putrid." It is possible that a noninvasive imaging modality would avoid the high likelihood of artifactual damage to the vitreous structure during dissection. Contact B-scan ultrasonography can visualize some aspects of the vitreous cavity, but ocular ultrasonography has low resolution. Optical coherence tomography (OCT) has much greater resolution but faces several important limitations in imaging the vitreous. A method to improve visualization of the vitreous using a technique based on swept source (SS) OCT has been developed that uses dynamic focusing and windowed averaging. This method provides a longer range of vitreous imaging than previously used methods and allows undisturbed visualization of the vitreous anatomy in vivo. In this study swept source OCT with dynamic focusing and windowed averaging obtained novel views of the vitreous in healthy subjects, and the findings appear to have important consequences.

METHODS

• **DERIVATION OF TECHNIQUE:** SS OCT is inherently suited for vitreous imaging because the sensitivity roll-off is much lower than comparable spectral-domain OCT instruments. Therefore a high sensitivity can be maintained across a larger range. There are still problems to contend with in vitreous imaging, even with SS OCT. The illumination beam of the OCT instrument is relatively defocused in the vitreous cavity, the signal produced by the vitreous is low, and the ratio of signal produced by the vitreous is very small in proportion to that produced by the retina, making the display of both in a grayscale image difficult. In crafting a solution to the problem of vitreous imaging, each of these elements will be discussed in turn.

The smallest spot produced by an illumination system is inversely related to its numerical aperture; large numerical aperture systems can focus light to a smaller spot than low numerical aperture systems (Figure 2). Having a smaller spot increases the potential lateral resolution, but because of the cone angle the scan depth that can be imaged is limited and the working distance is reduced. The illumination systems of OCT instruments have a fairly low numerical aperture.[9] This produces a narrow beam over a long