Swept Source OCT

SriniVas Sadda, MD

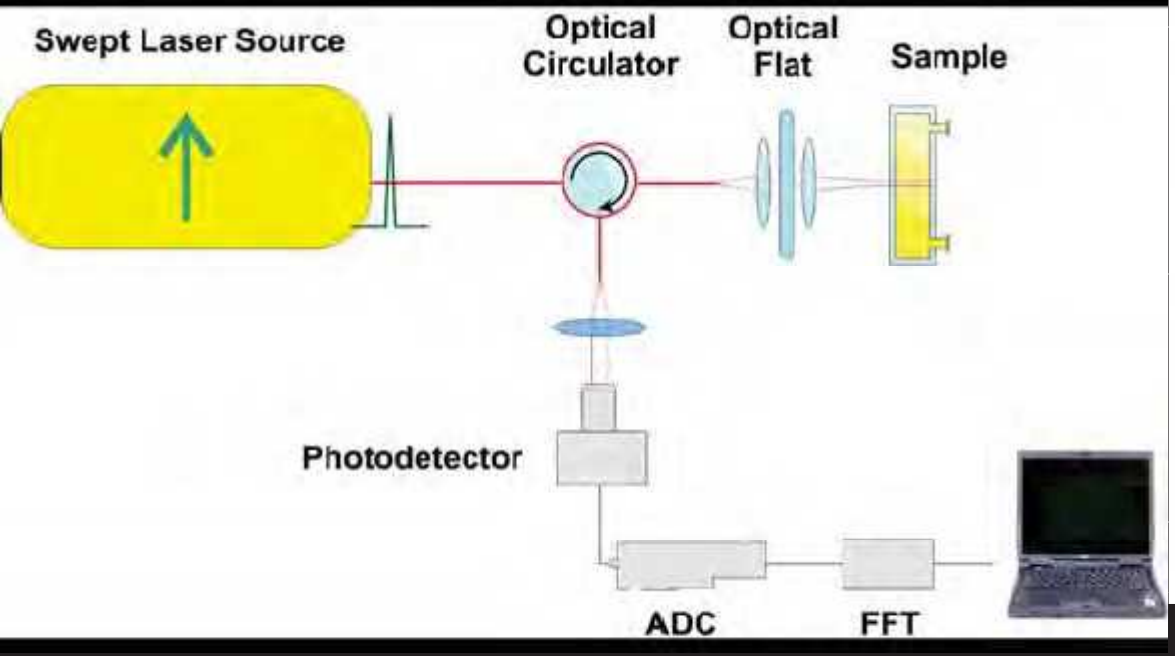
Professor of Ophthalmology
Director,
Medical Retina Unit
Ophthalmic Imaging Unit
University of Southern California
Los Angeles, California, USA

Disclosure

Consulting Fee: Allergan; Carl Zeiss Meditec; Genentech; Optos; Regeneron

What is swept source OCT?

- Swept Source OCT
  - Another Fourier domain OCT technology
  - 5-10X faster than existing SD-OCT instruments
  - Also better sensitivity with less roll-off



Ultrahigh speed 1050nm swept source / Fourier domain OCT retinal and anterior segment imaging at 100,000 to 400,000 axial scans per second

Benjamin Potsaid,[1,2] Bernhard Baumann,[1,3] David Huang,[4] Scott Barry,[2] Alex E. Cable,[2] Joel S. Schuman,[5] Jay S. Duker,[5] and James G. Fujimoto[1,3,*]

[1]Department of Electrical Engineering and Computer Science, and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[2]Advanced Imaging Group, Thorlabs, inc., Newton, NJ 07860, USA
[3]New England Eye Center and Tufts Medical Center, Tufts University, Boston, MA 02116, USA
[4]Doheny Eye Institute, University of Southern California, Los Angeles, CA 90033, USA
[5]UPMC Eye Center, University of Pittsburgh, Pittsburgh, PA 15213, USA
*jgf@mit.edu

Abstract: We demonstrate ultrahigh speed swept source/Fourier domain ophthalmic OCT imaging using a short cavity swept laser at 100,000 - 400,000 axial scan rates. Several design configurations illustrate trade-offs in imaging speed, sensitivity, axial resolution, and imaging depth. Variable rate A/D optical clocking is used to acquire linear-in-k OCT fringe data at 100kHz axial scan rate with 5.3um axial resolution in tissue. Fixed rate sampling at 1 GSPS achieves a 7.5mm imaging range in tissue with 6.0um axial resolution at 100kHz axial scan rate. A 200kHz axial scan rate with 5.3um axial resolution over 4mm imaging range is achieved by buffering the laser sweep. Dual spot OCT using two parallel interferometers achieves 400kHz axial scan rate, almost 2X faster than previous 1050nm ophthalmic results and 20X faster than current commercial instruments. Superior sensitivity roll off performance is shown. Imaging is demonstrated in the human retina and anterior segment. Wide field 12x12mm data sets include the macula and optic nerve head. Small area, high density imaging shows individual cone photoreceptors. The 7.5mm imaging range configuration can show the cornea, iris, and anterior lens in a single image. These improvements in imaging speed and depth range provide important advantages for ophthalmic imaging. The ability to rapidly acquire 3D-OCT data over a wide field of view promises to simplify examination protocols. The ability to image fine structures can provide detailed information on focal pathologies. The large imaging range and improved image penetration at 1050nm wavelengths promises to improve performance for instrumentation which images both the retina and anterior eye. These advantages suggest that swept source OCT at 1050nm wavelengths will play an important role in future ophthalmic instrumentation.

OCIS codes: (170.3880) Medical and biological imaging; (170.4500) Optical coherence tomography; (170.4470) Ophthalmology.

From Potsaid et al, *Optics Express 2010; 18: 20029.*

Improved Speed

- Swept Source OCT
  - At these speeds, fixation/motion is less of an issue
  - Large areas can be scanned quickly and with extensive averaging

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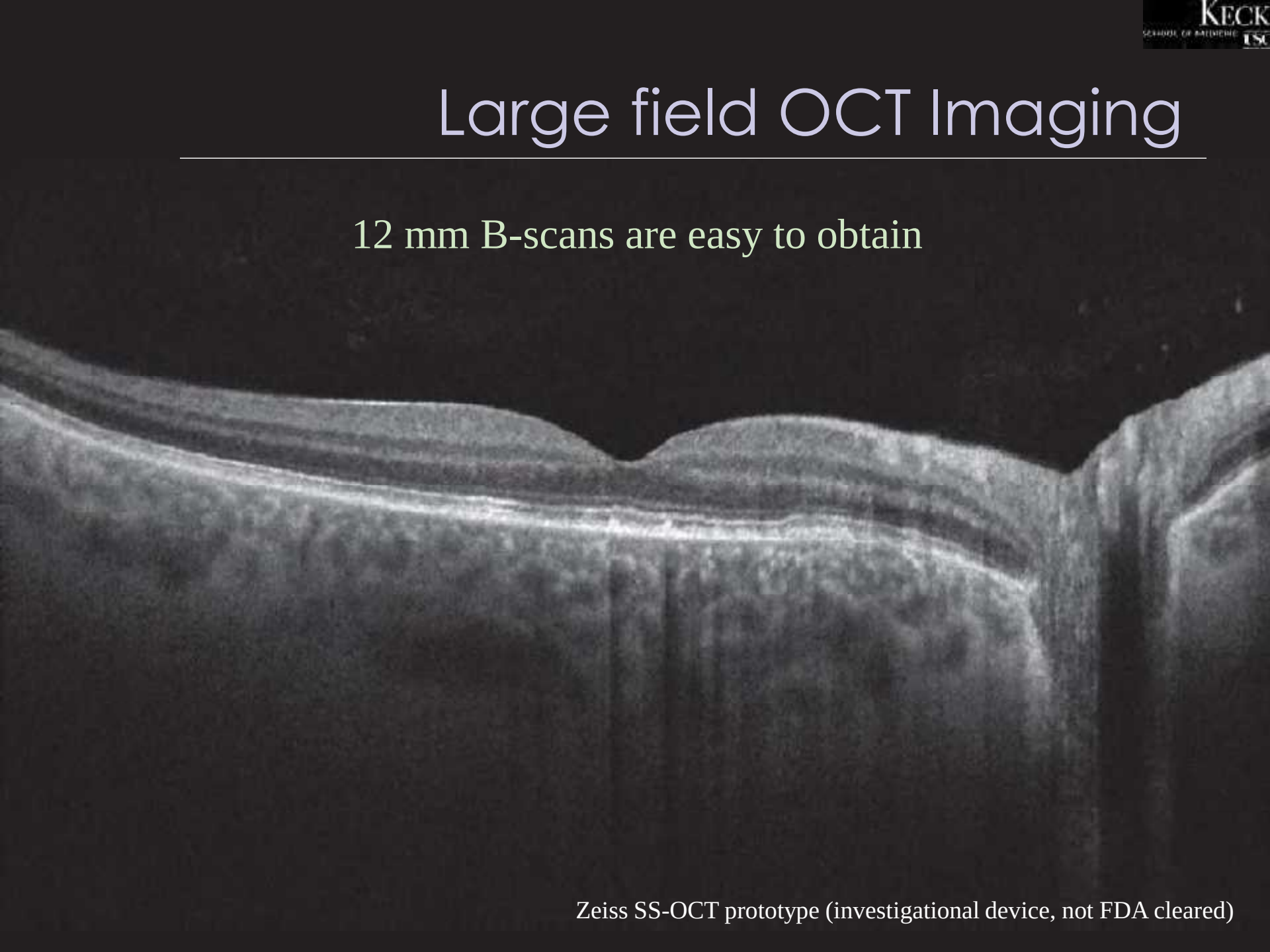
Large field OCT Imaging

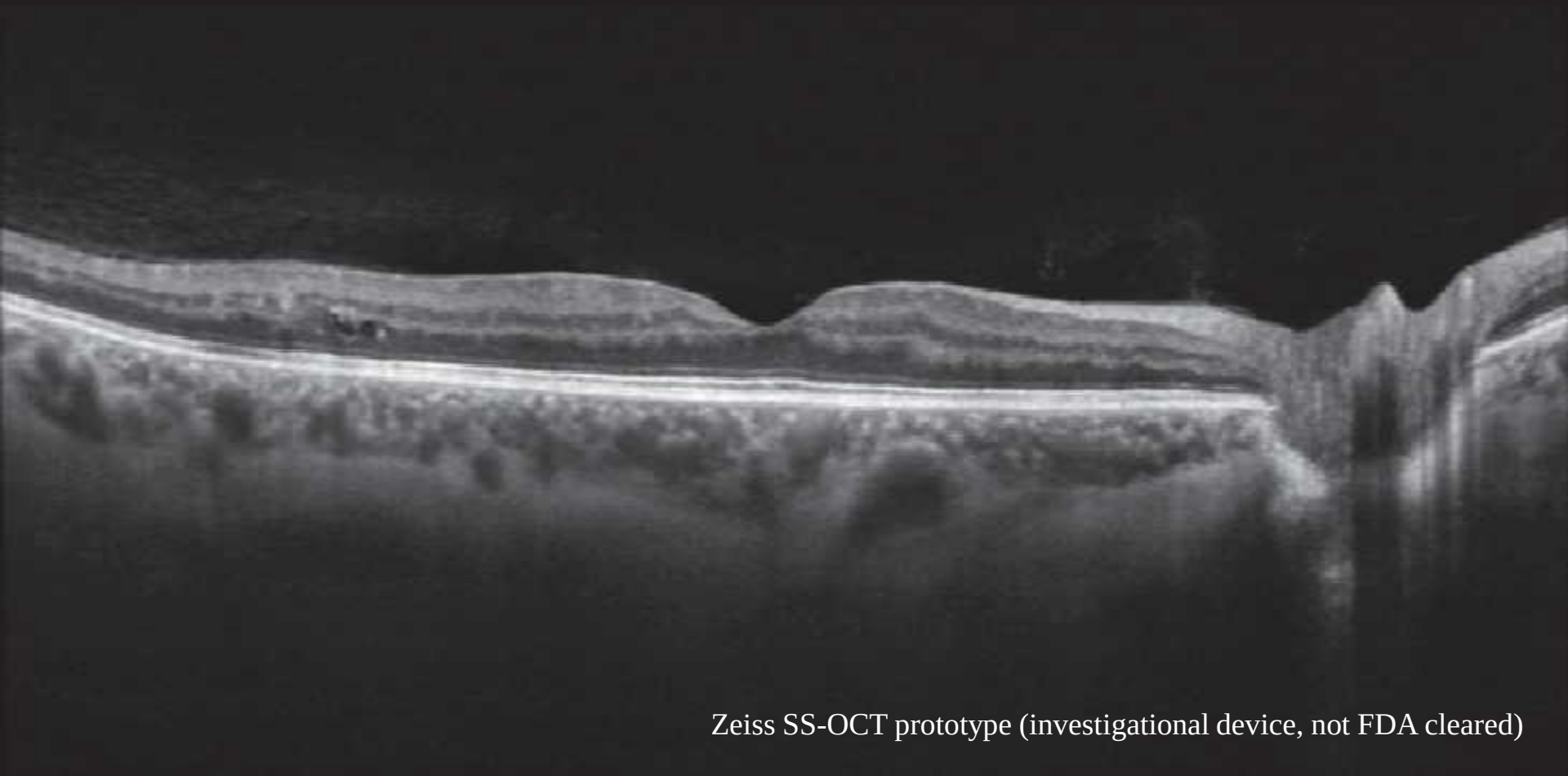
12 mm B-scans are easy to obtain



Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Large field OCT Imaging

Choroid and laminar portions of the optic nerve are well seen



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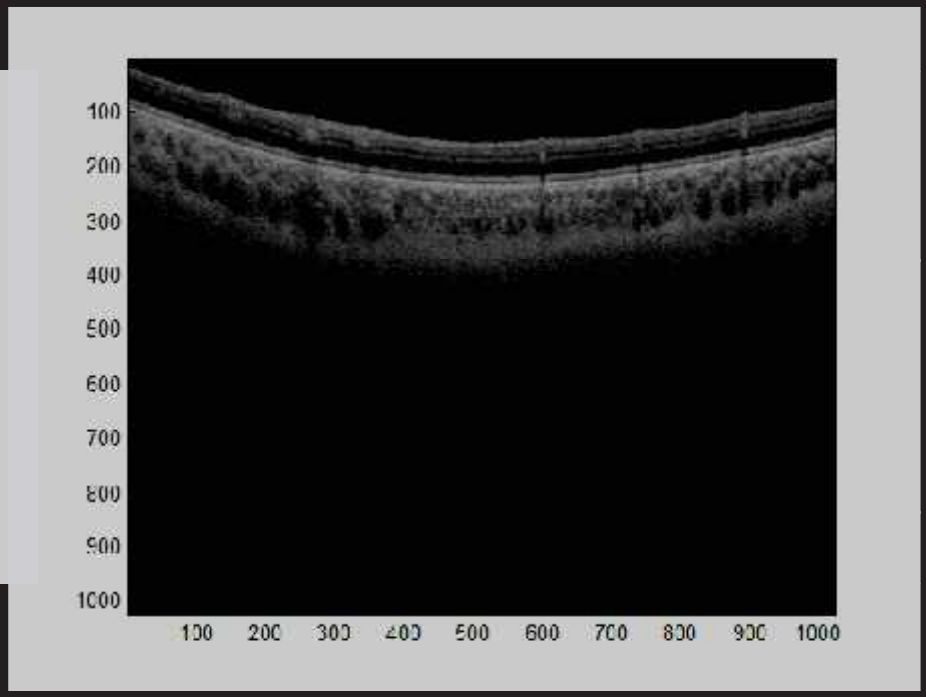

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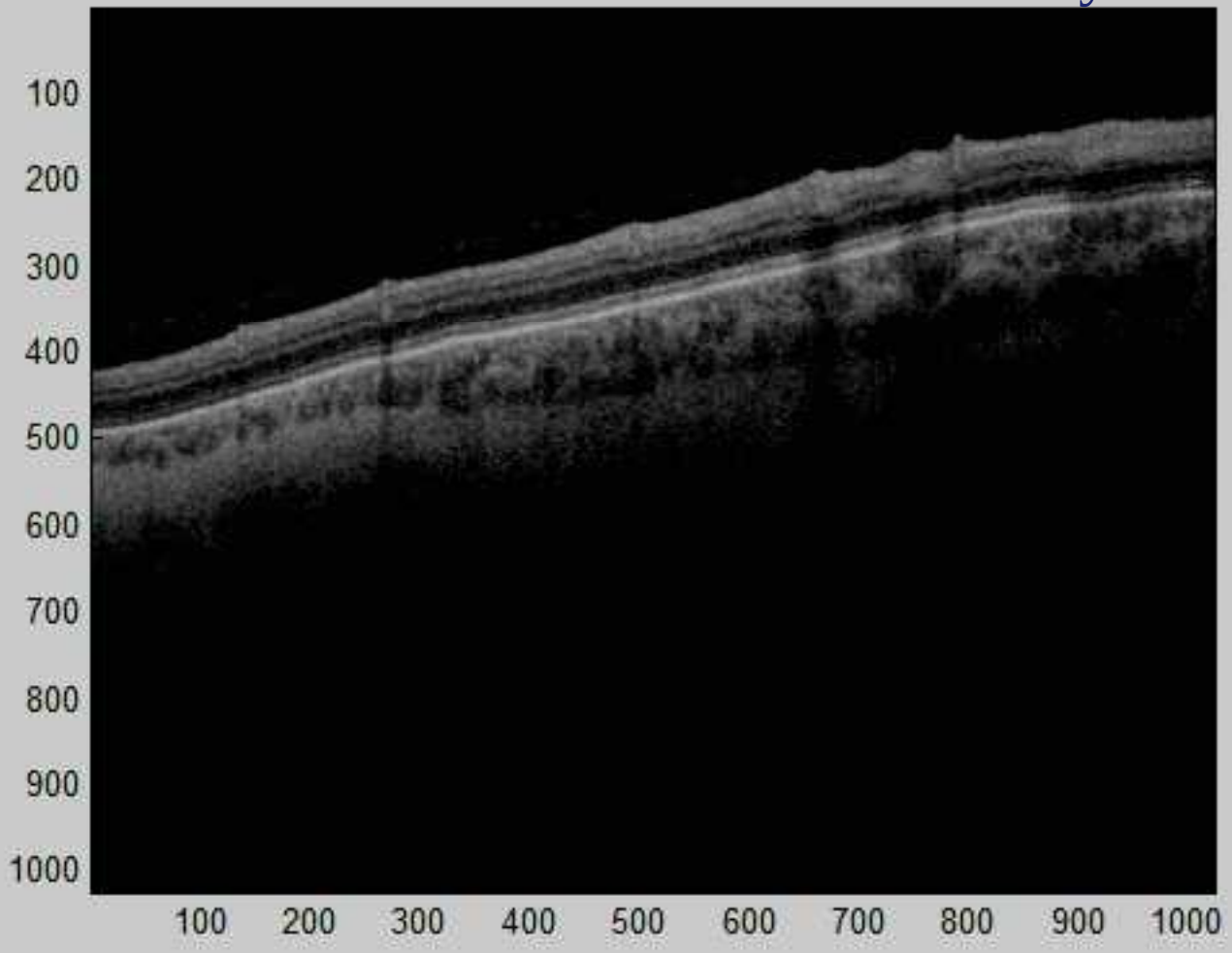
Large field OCT imaging

12 x 9 mm volume scans are also easy



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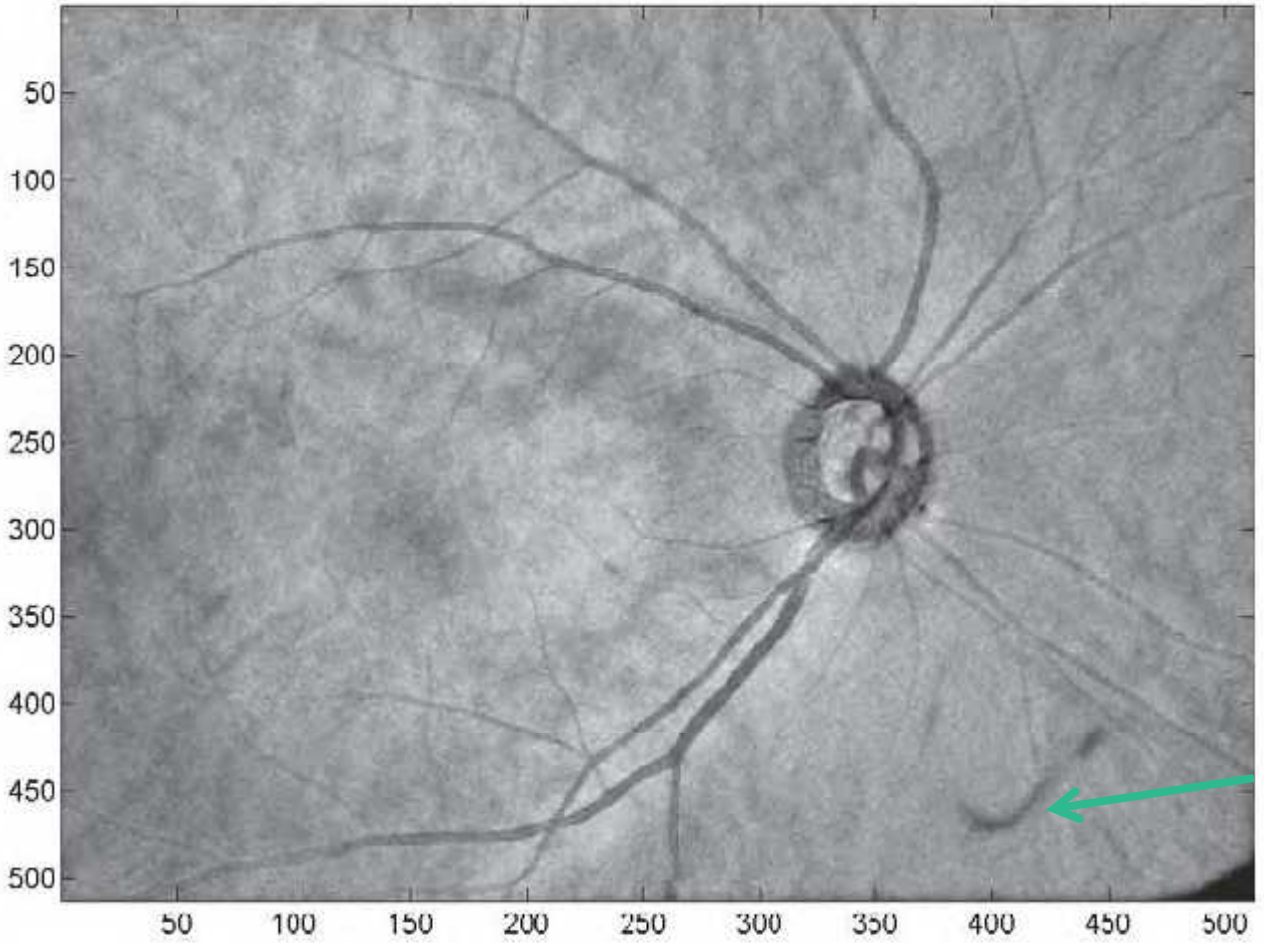
Large field OCT imaging

12 x 9 mm volume scans are also easy

Produce OCT projection maps that truly resemble fundus images



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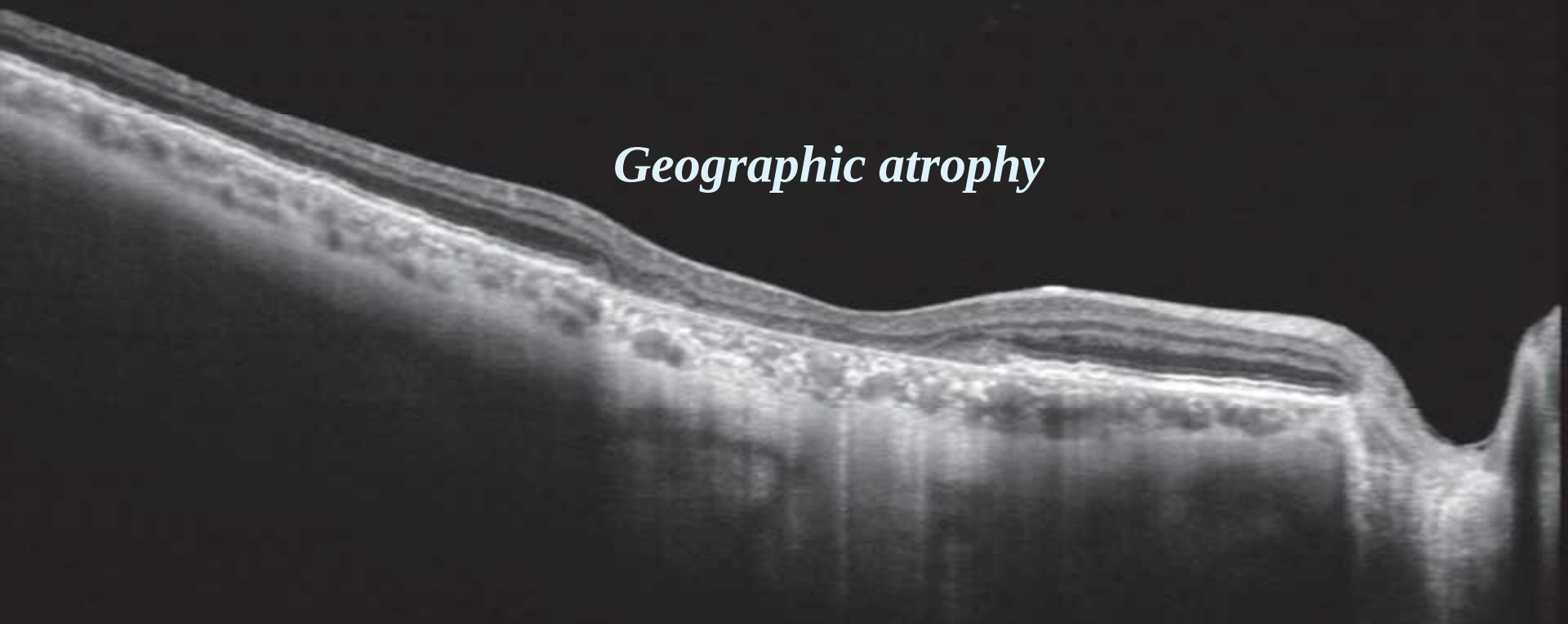
Large field OCT Imaging

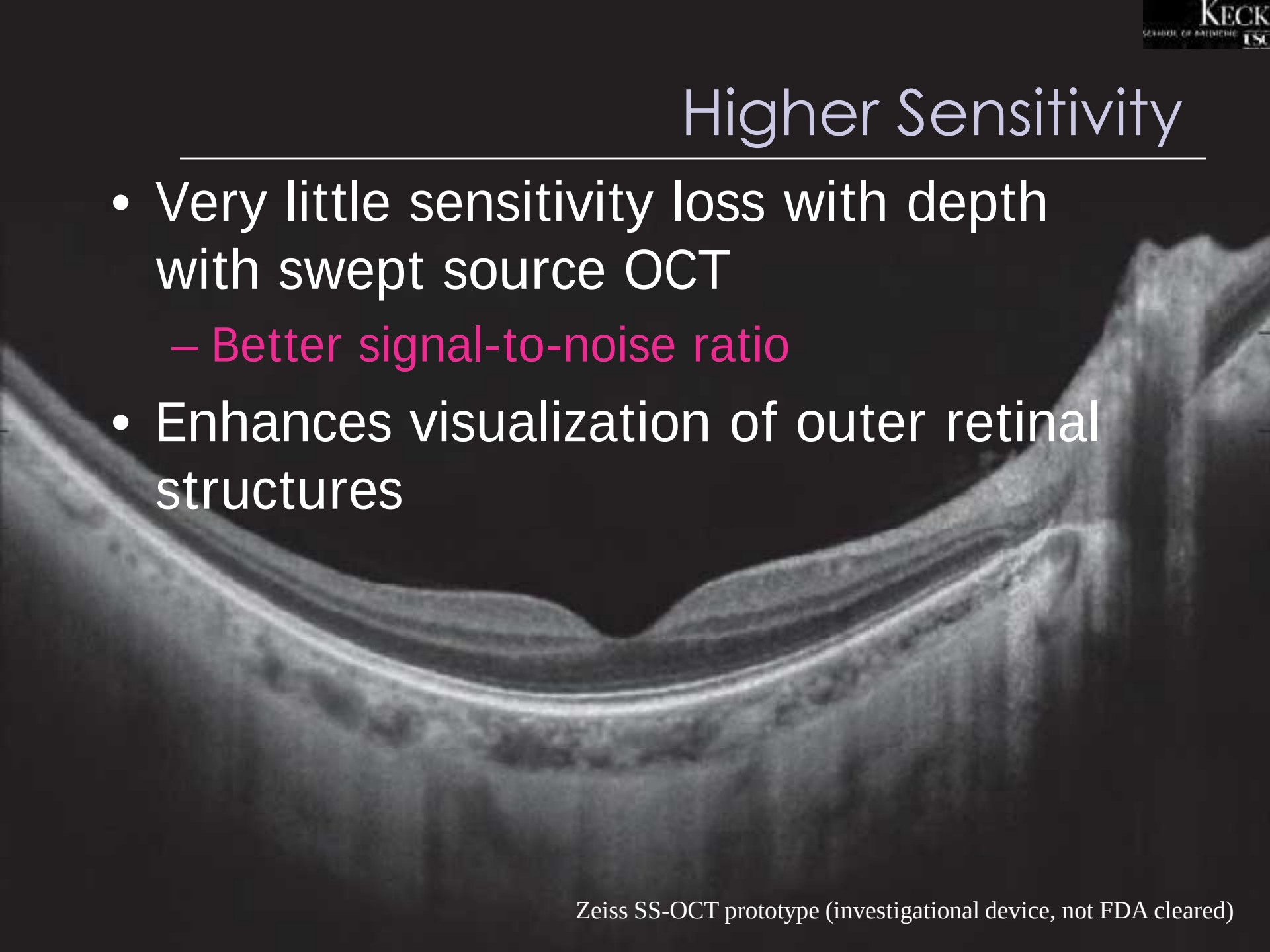
12 mm B-scans – visualize ON and Macula



Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Higher Sensitivity

- Very little sensitivity loss with depth with swept source OCT
  - Better signal-to-noise ratio
- Enhances visualization of outer retinal structures



Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Higher Sensitivity

- Very little sensitivity loss with depth with swept source OCT
  - Better signal-to-noise ratio
- Enhances visualization of outer retinal structures, and deep pathologies

Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Combine high sensitivity with optimized averaging

- Swept Source OCT
  - Extensive averaging allows fine structures to be seen

From Potsaid et al, *Optics Express 2010; 18: 20029.*

A note about image quality…

- Though swept source devices feature better sensitivity than spectral domain devices:
  - devices do vary in the quality of their optics and other components
  - faster scan rates can be associated with degraded quality
- Averaged B-scans can hide these quality differences
- Advisable to look at the un-averaged native images when comparing between devices

A note about image quality…

- Un-averaged native single B-scan image on patient with media opacity and myopia

Even without averaging, despite scan rates > 100K/sec, outer retinal bands are well seen

Note, no apparent sensitivity loss from anterior to posterior regions of retina in this eye with a deep staphyloma from pathologic myopia

Zeiss SS-OCT prototype (investigational device, not FDA cleared)

A note about image quality…

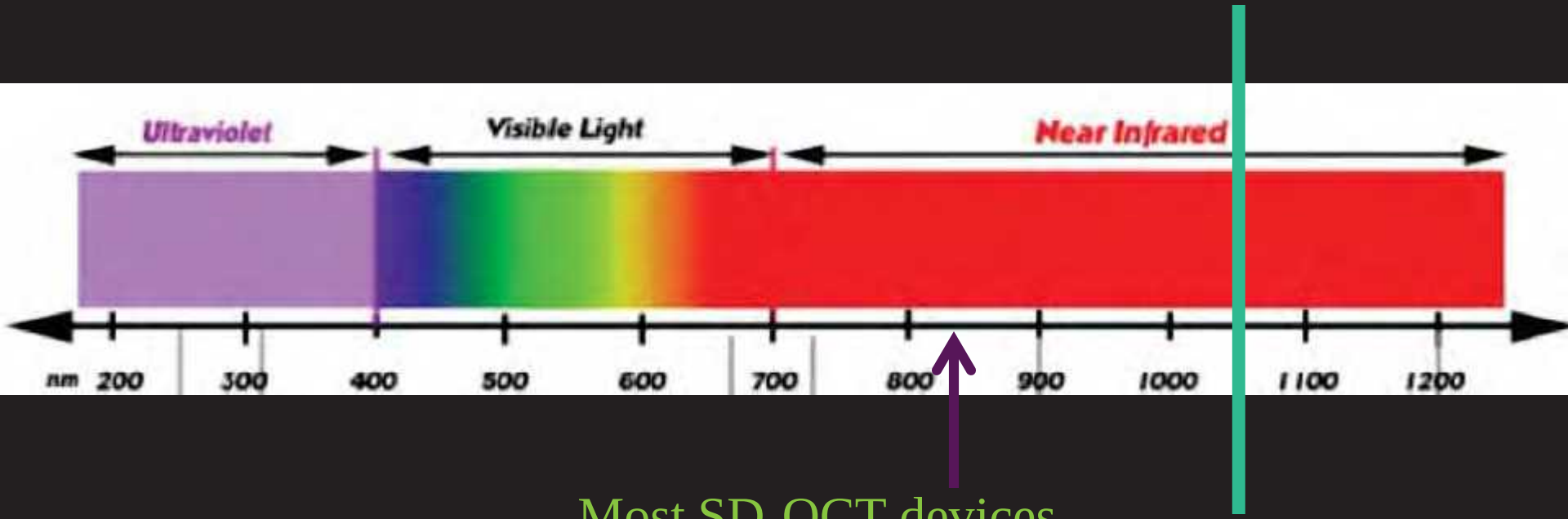
- Underlying high quality B-scan data yields high quality OCT fundus images

High resolution
"Megapixel"

Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Long Wavelength Imaging

- Most Swept Source OCT devices features a light source with a 1050nm center wavelength



OCT and wavelength

- Two “Windows of Opportunity” for retinal OCT imaging

OCT Imaging Windows

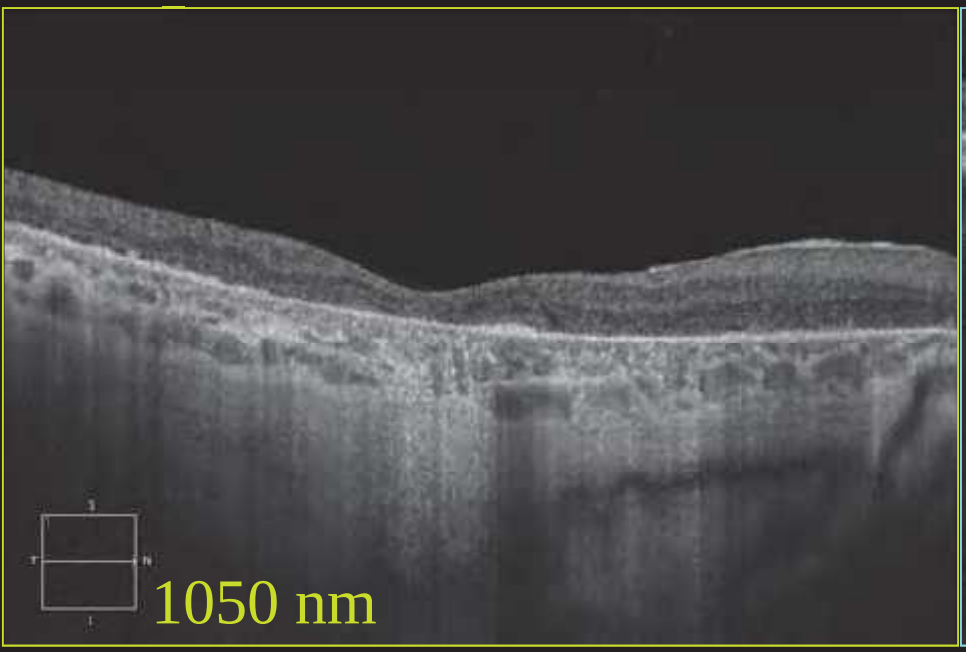
1. Visible to near infrared (950nm) -- BROAD
2. 1000nm – 1100nm -- NARROWER BANDWIDTH (restricted to 100 nm) and still more absorption than at shorter wavelengths

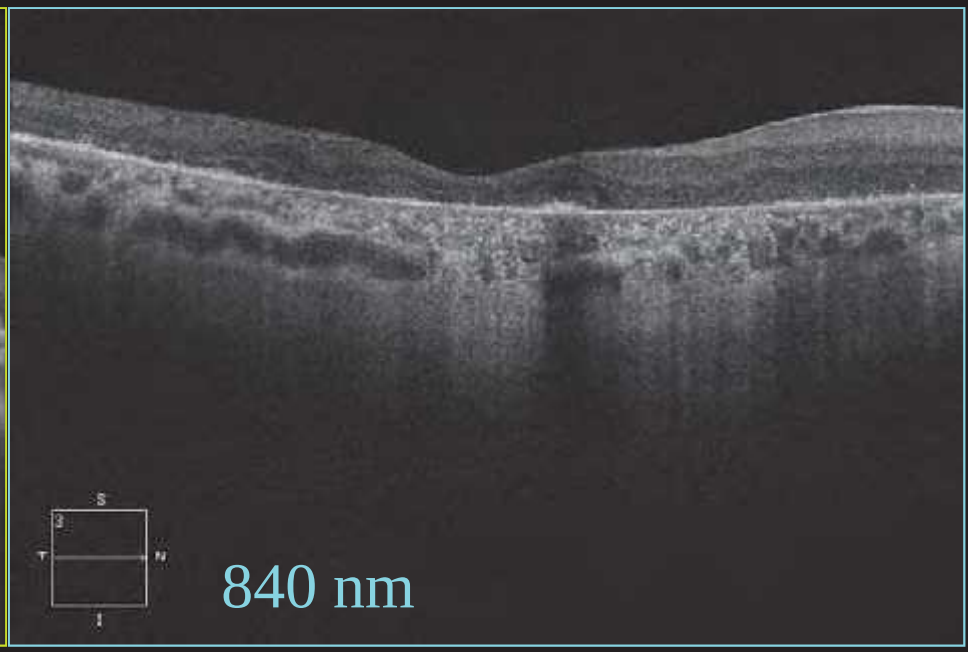
Choroidal Visibility: 1050 vs 840

Comparison Study at Doheny of 1050nm vs 840nm

Results:

- Even when the choroid was fully-visible at 840nm, considerable additional detail was visible at 1050nm

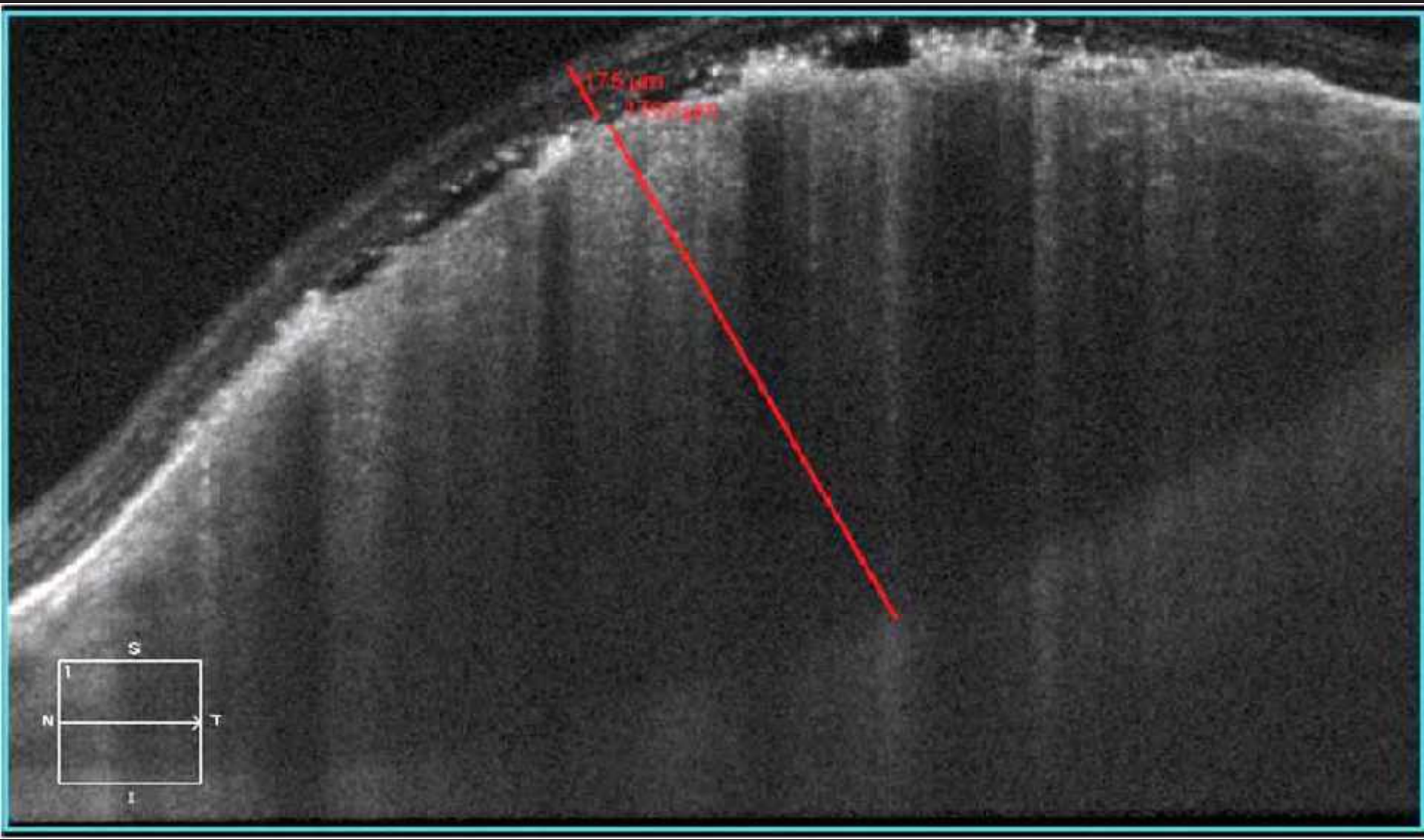




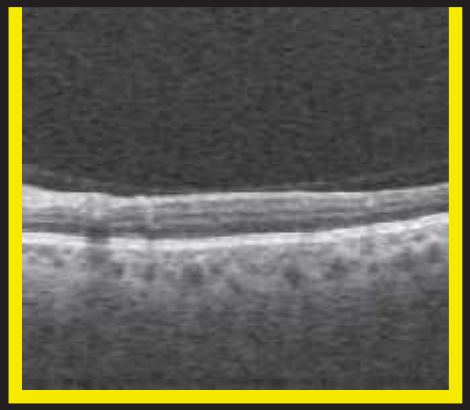
(both spectral domain)

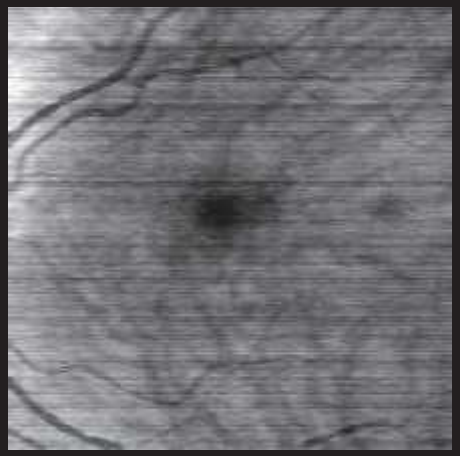
Retinitis Pigmentosa

1.7mm Choroidal Melanoma

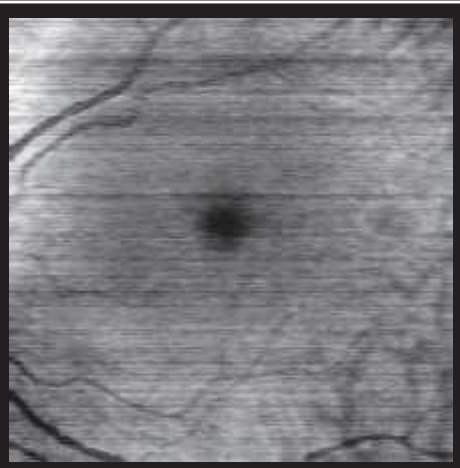


Choroidal imaging with SSOCT

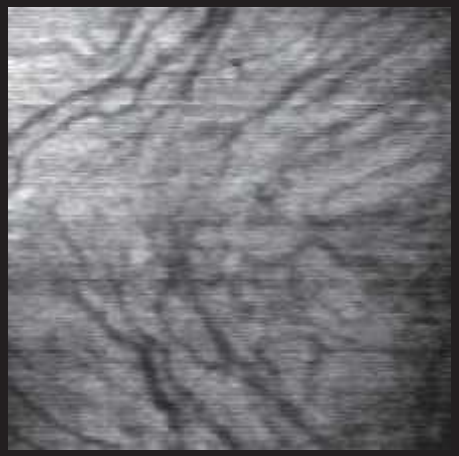




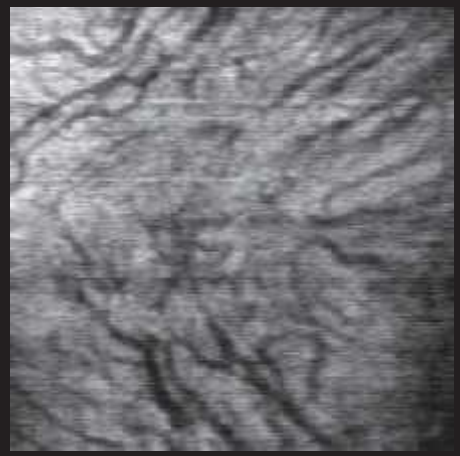
ILM to choroid-sclera



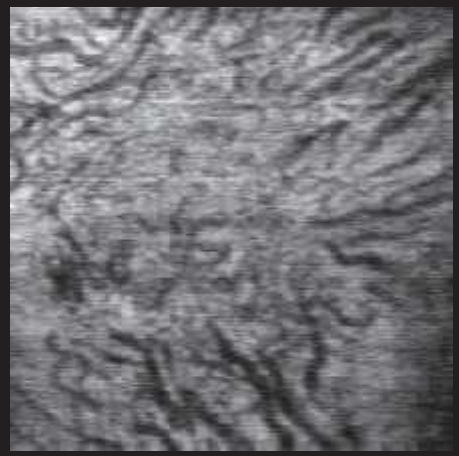
ISOS to BM



Choroid



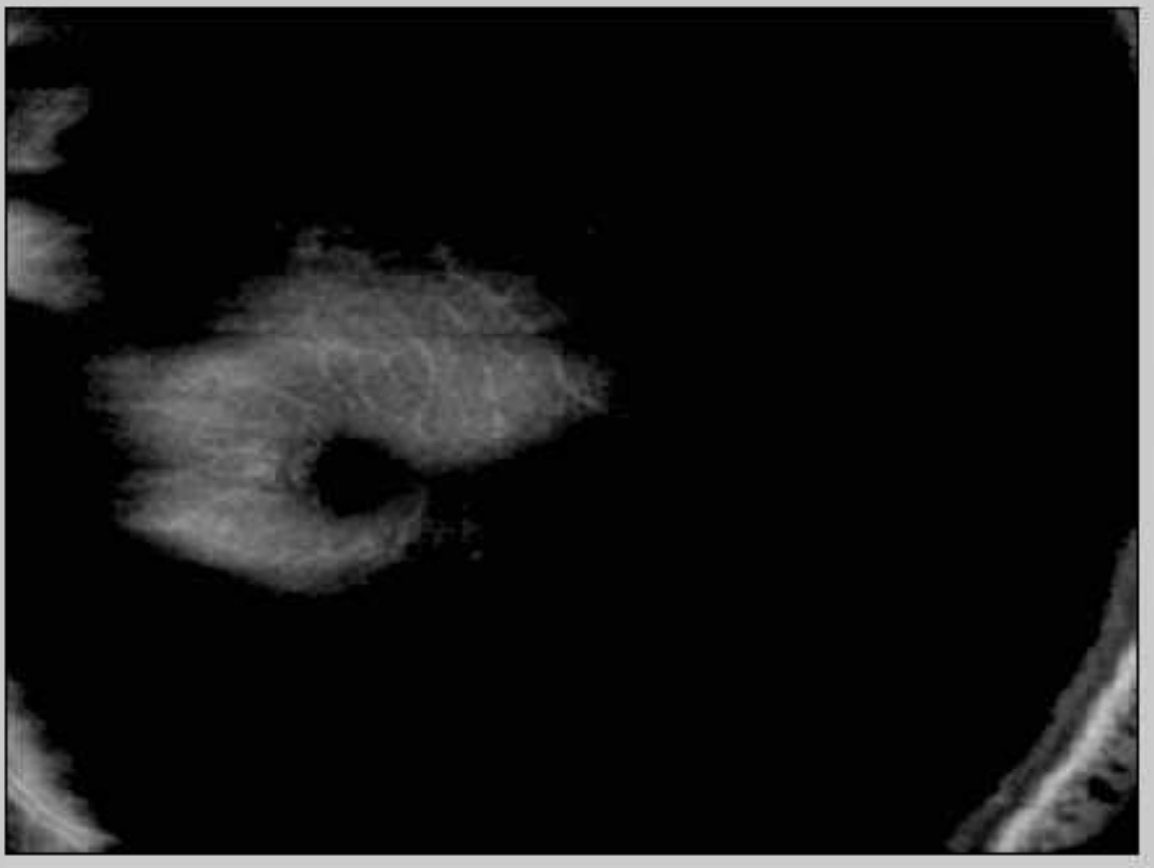
1/3 of choroid

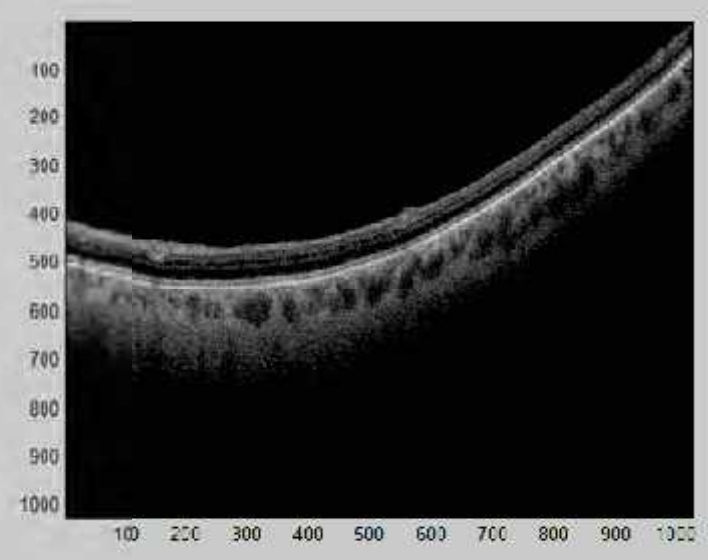


2/3 of choroid

Zeiss Swept Source OCT (prototype, not yet FDA cleared)

En face imaging through retina and choroid





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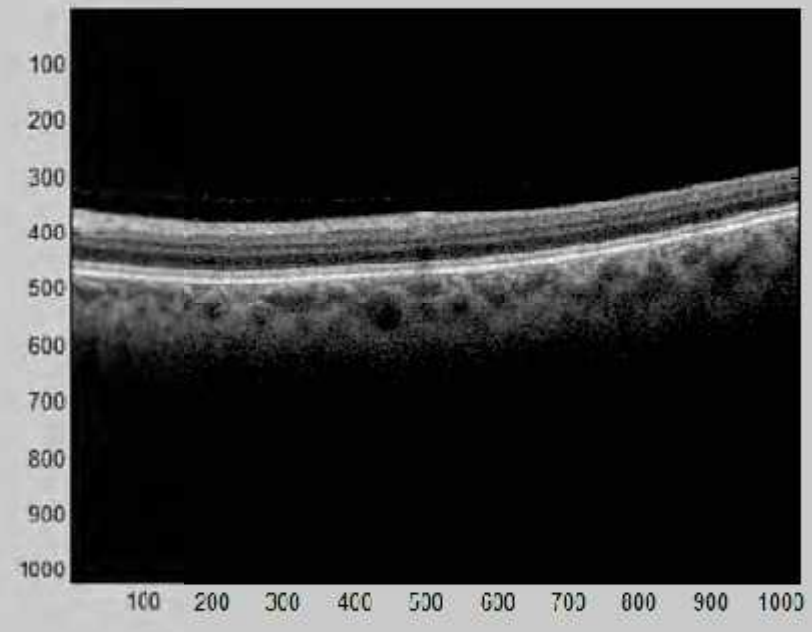
Serous PED



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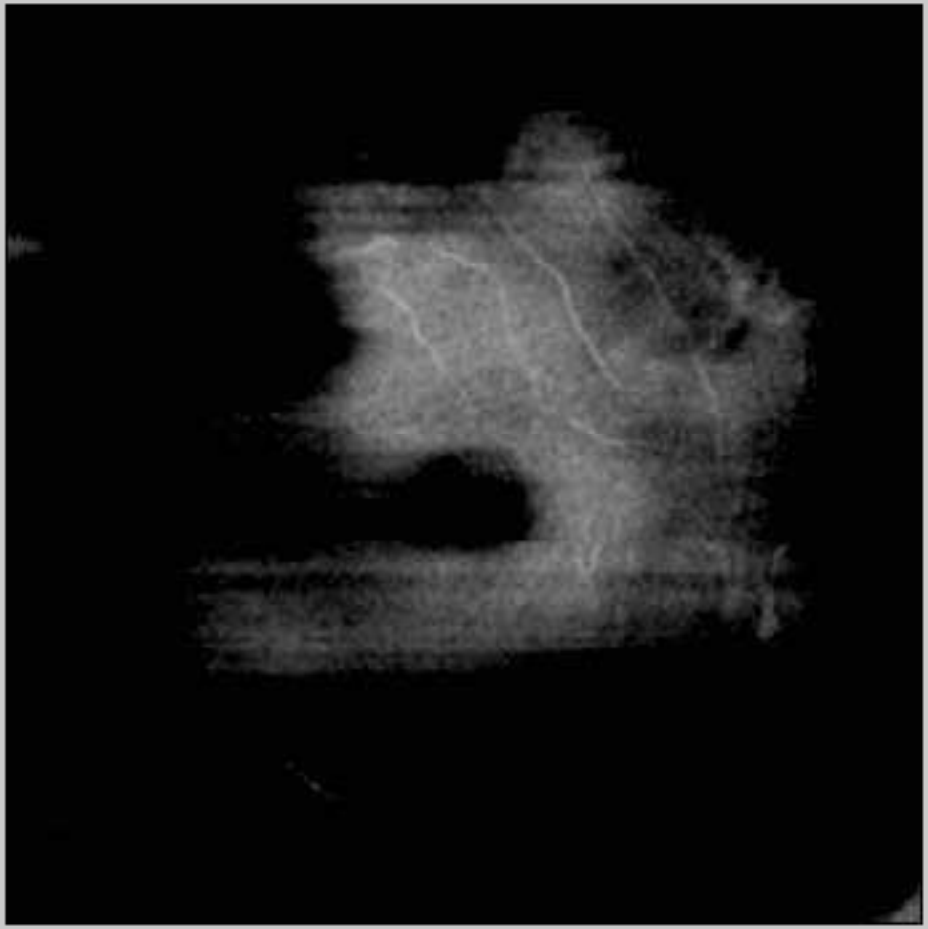
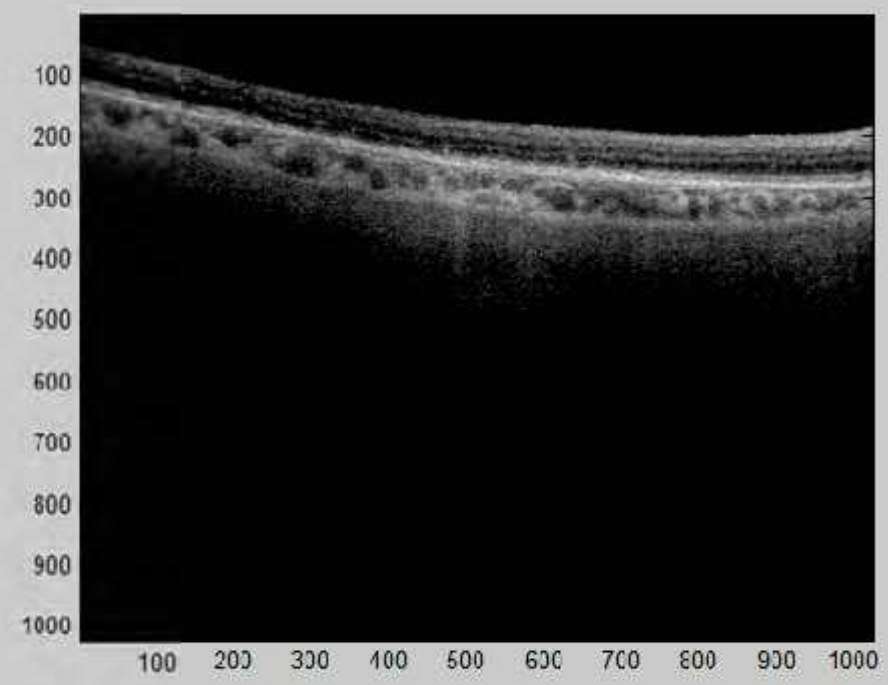
En face imaging through CNV





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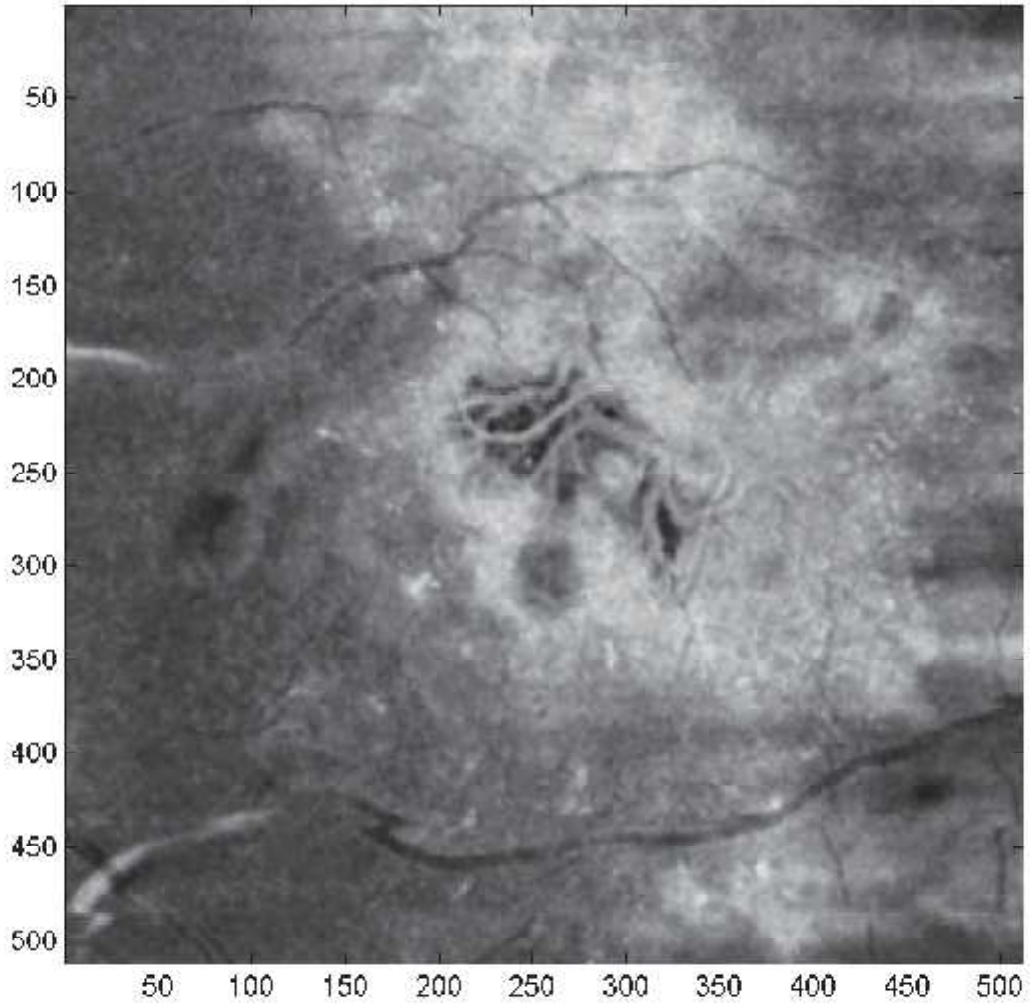
En face imaging through CNV



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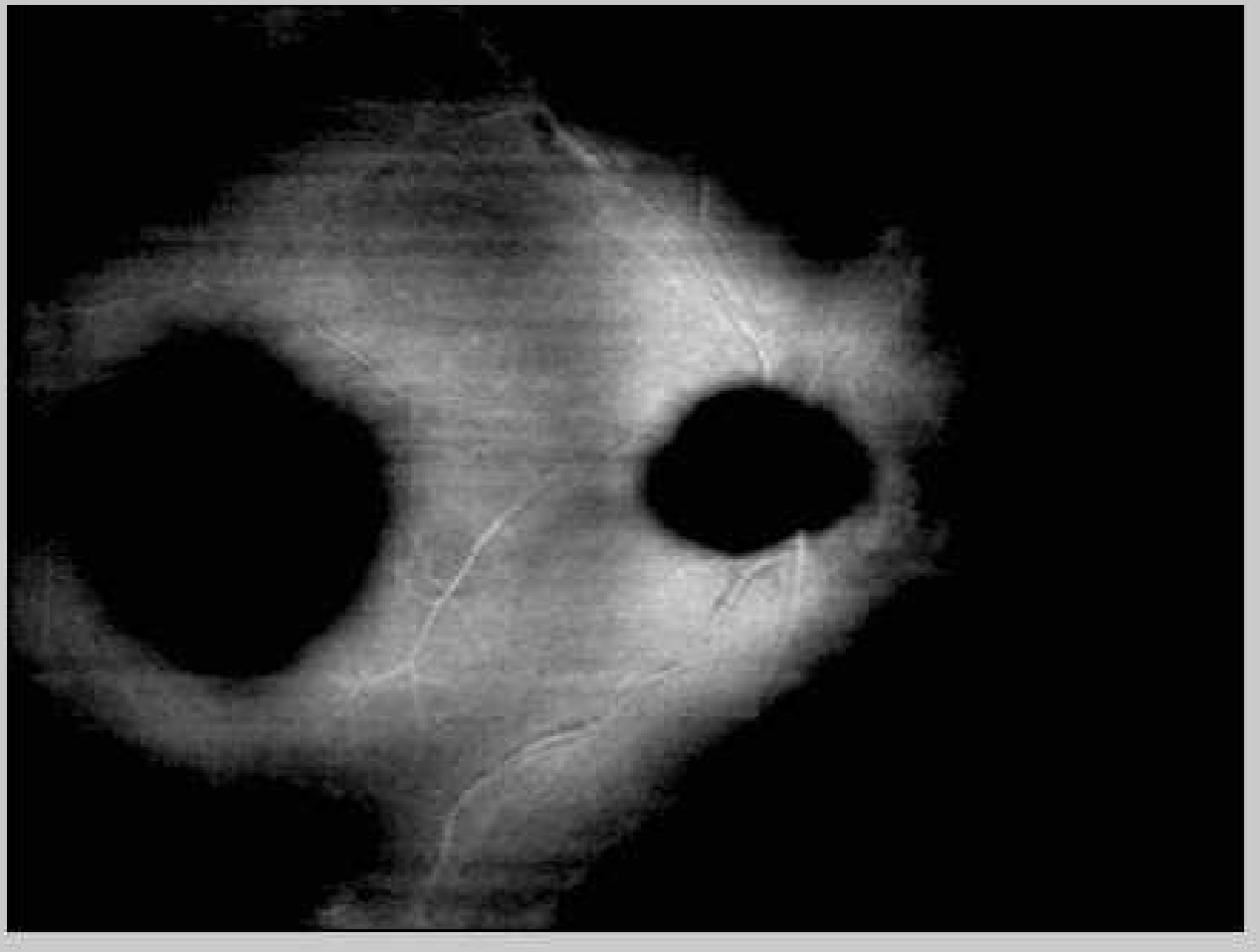
En face imaging through Geographic Atrophy



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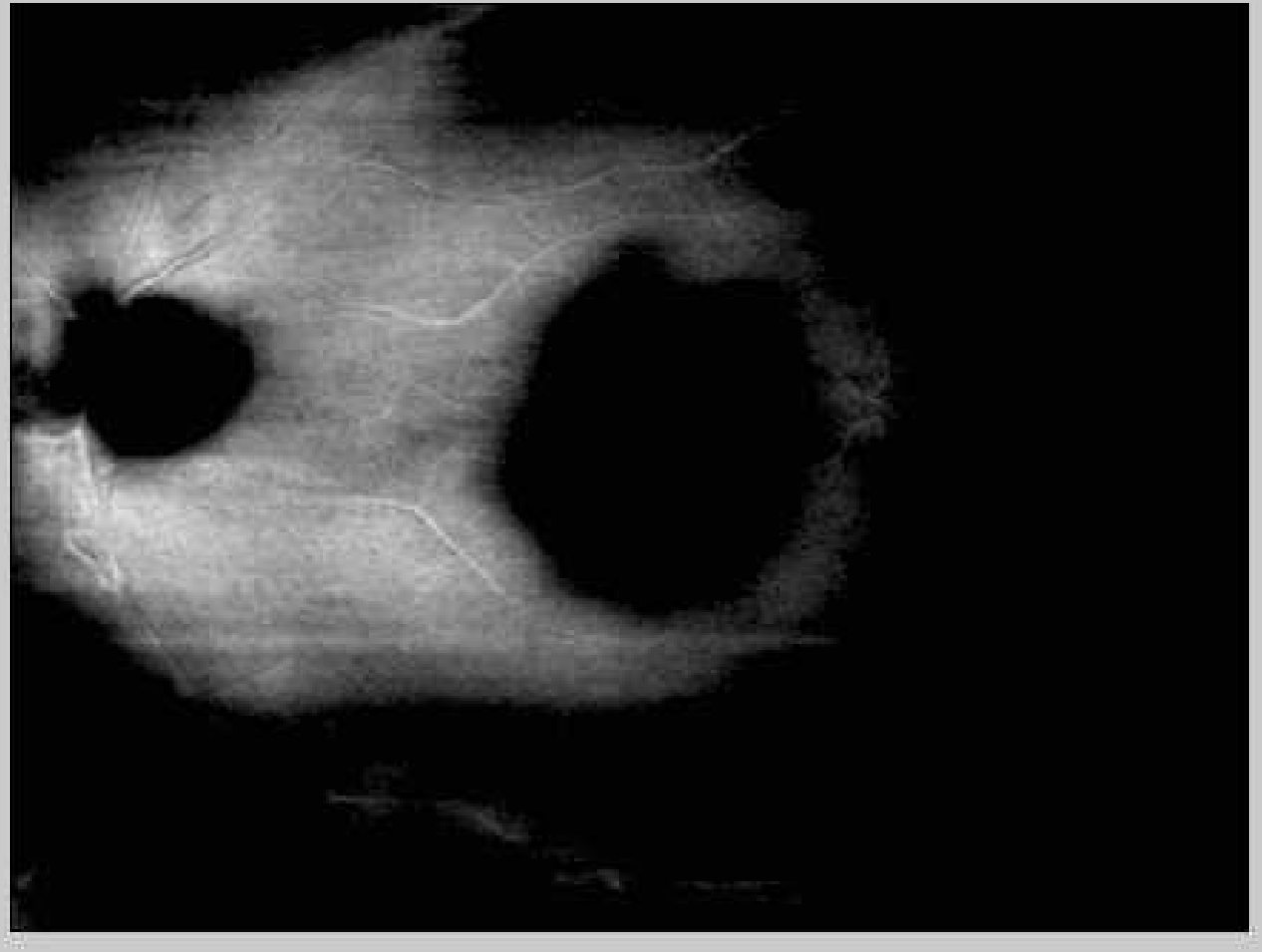
En face imaging through Geographic Atrophy



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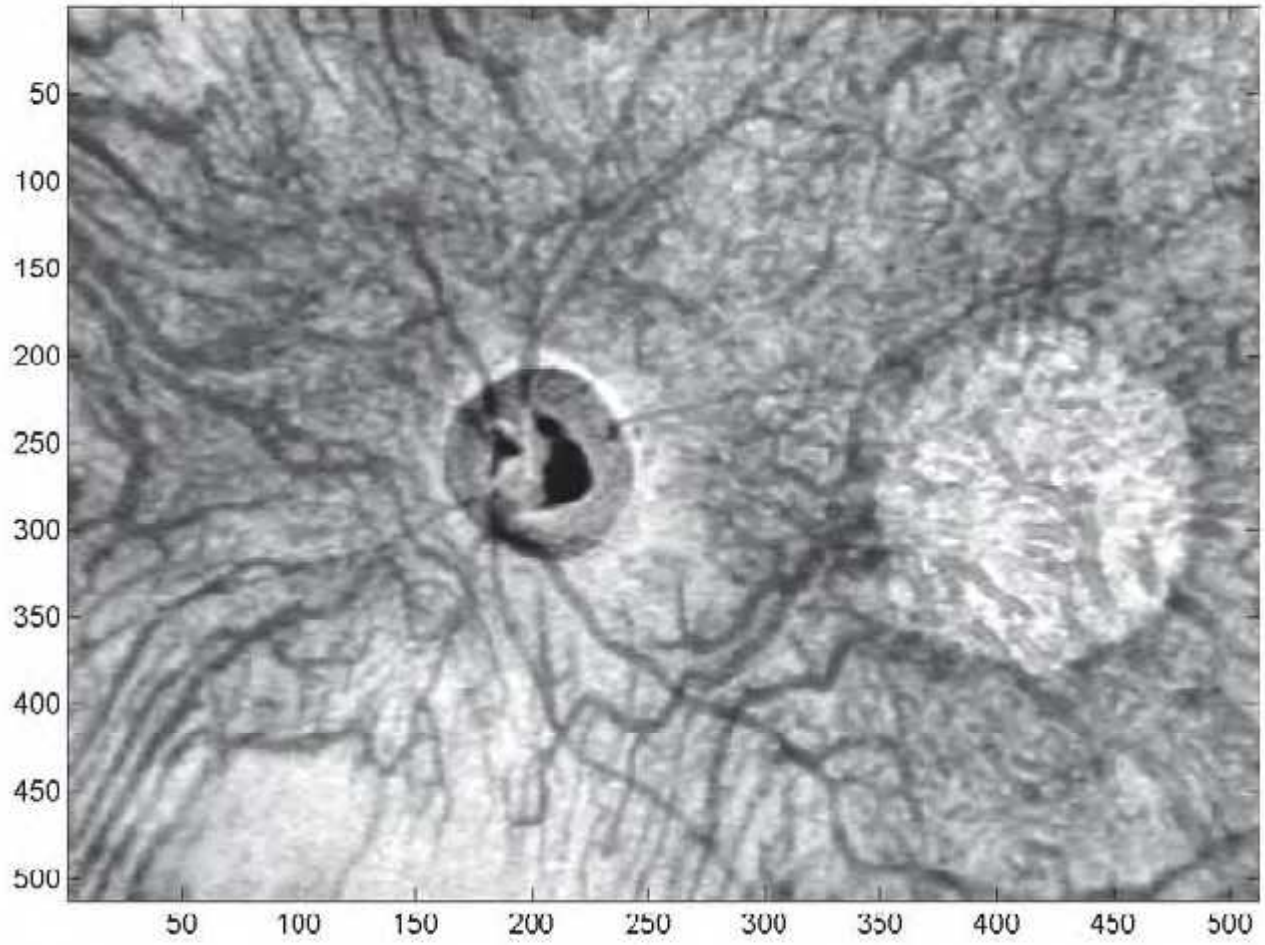
High-resolution en face OCT

En face slabs can be extracted from any layer of interest



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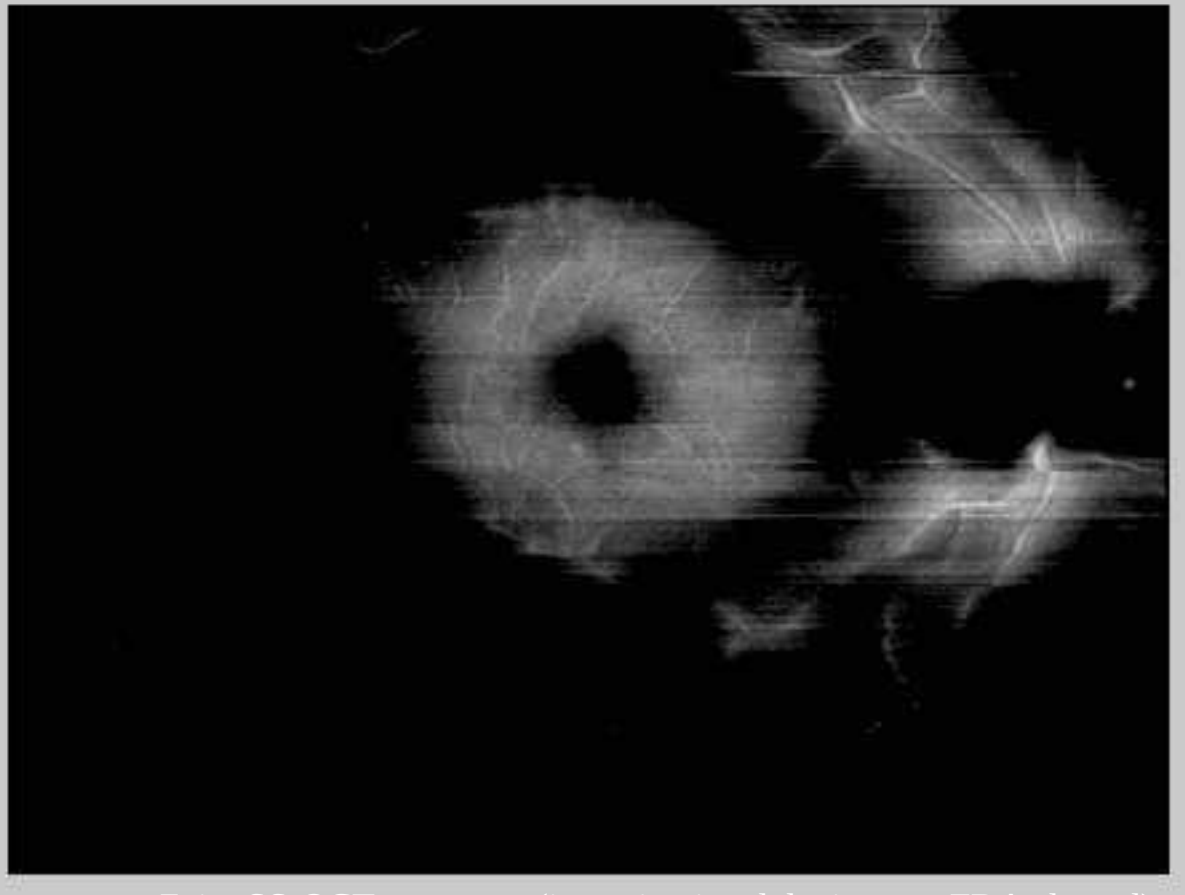
Non-proliferative Diabetic Retinopathy

- Microaneurysms visible on en face images



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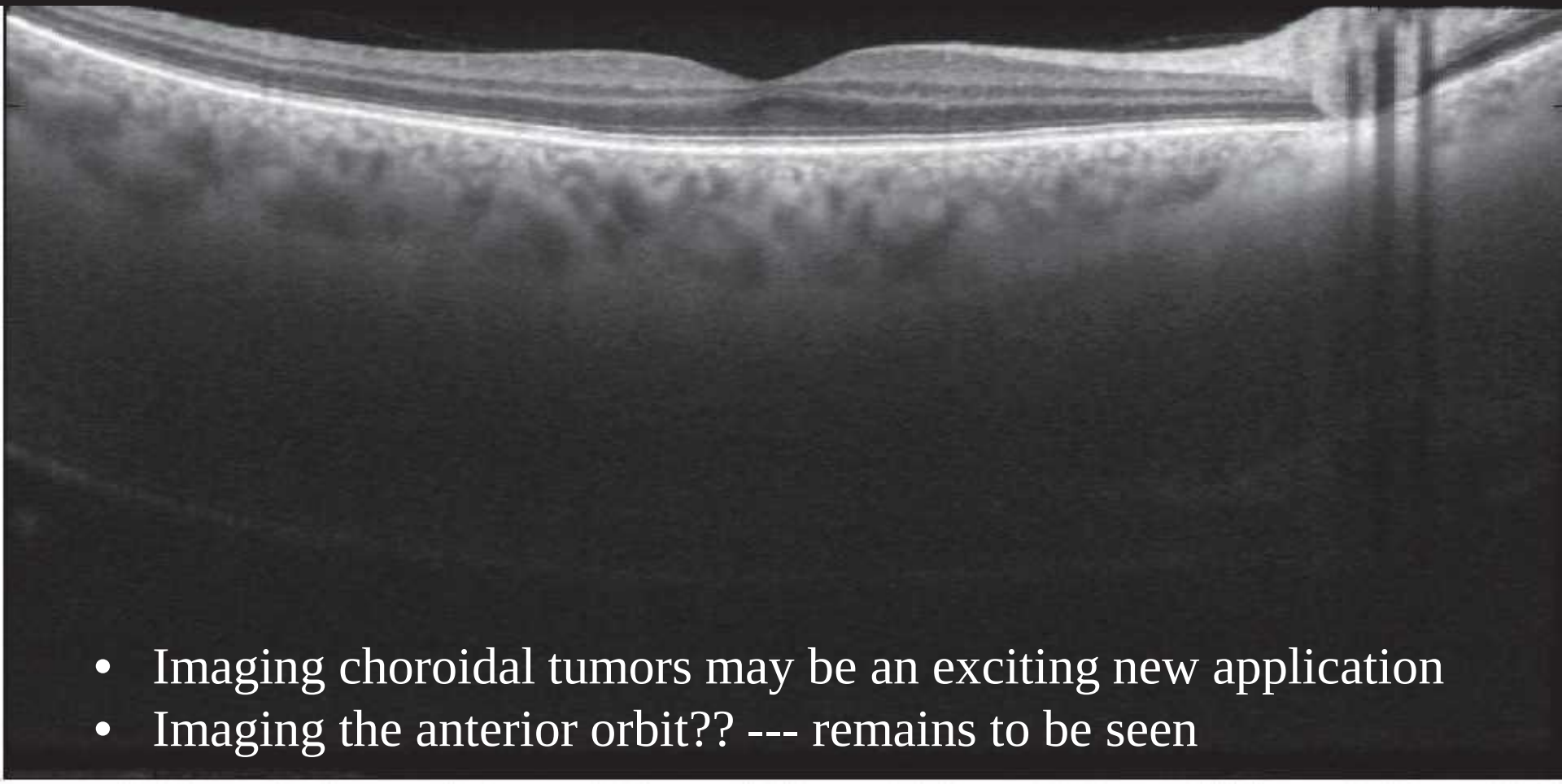
Clinical Applications of Swept Source OCT

- Everything!
  - There is really no advantage of spectral domain over swept source OCT
  - Slightly better axial resolution at 840nm vs 1050nm is outweighed by many other advantages

Clinical Applications of Swept Source OCT

- But why will SS-OCT be a game changer?
- What are the key new applications that will expand the purview of OCT?

Penetrating through the sclera



- Imaging choroidal tumors may be an exciting new application
- Imaging the anterior orbit?? --- remains to be seen

Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Vitreous imaging with SS-OCT

Anatomy and Pathology

Observation of Posterior Precortical Vitreous Pocket Using Swept-Source Optical Coherence Tomography

Hiroaki Itakura, Shoji Kishi, Danjie Li, and Hideo Akiyama

Department of Ophthalmology, Gunma University School of Medicine, Maebashi, Japan

Correspondence: Hiroaki Itakura, Department of Ophthalmology, Gunma University School of Medicine, 3-39-15 Showa-machi, Maebashi, Gunma, 371-8511, Japan; itakurah@med.gunma-u.ac.jp.

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Purpose. To observe posterior precortical vitreous pockets (PPVPs) using swept-source optical coherence tomography (SS-OCT).

Methods. We performed SS-OCT in both eyes of 58 volunteers (36 men, 22 women) using 12-mm horizontal vertical scans through the macula and optic disc. To minimize age-related changes (liquefaction or posterior vitreous detachment), all subjects were a mean of 26.2 (SD 6.6; range, 22–40 years). The refractive errors ranged from −9.5 diopters (D) to +5.8 D. To estimate the PPVP size, we measured the height between the fovea and the anterior border of the PPVP and the maximal width in the 12-mm horizontal scan through the fovea and disc.

Results. SS-OCT visualized the PPVPs as boat-shaped lucency in the macular area bilaterally in all subjects (maximal width, 3314–9987 μm; mean width, 6410.6; central height, 206–1077 μm; mean height, 708.1) in the right eyes, with no significant difference in the left eyes). There was a significant correlation between the PPVP height and myopic refractive error. The posterior wall of the PPVP was a thin vitreous cortex, thinnest at the fovea. The septum was between the nasal border of the pocket and Cloquet's canal, which extended forward and lifted superiorly in all cases. A channel connected Cloquet's canal and the PPVPs bilaterally in 54 (93.1%) of 58 cases.

Conclusions. SS-OCT clarified the boat-shaped PPVP structure in vivo. Although the central height increased with the myopic refractive error, the width was unchanged. A channel connecting Cloquet's canal and PPVP suggested the route of aqueous humor into the PPVP.

Keywords: posterior precortical vitreous pocket, swept-source optical coherence tomography, vitreous humor, Cloquet's canal, channel

A posterior precortical vitreous pocket (PPVP) is a liquefied lacuna anterior to the macular area that is physiologically present in the vitreous of adults.[1] A PPVP first was reported in autopsy eyes in which the vitreous gel was stained with fluorescein. The presence of PPVPs has been confirmed during triamcinolone-assisted vitrectomy[2] and by spectral-domain optical coherence tomography (SD-OCT).[3–5]

The anterior border of a PPVP is vitreous gel and the posterior border is composed of a thin layer of the vitreous cortex attached to the retina. A septum is present between the nasal border of the PPVP and Cloquet's canal.[5] The peculiar structure of the premacular vitreous cortex plays a key role in the development of various vitreomacular disorders, such as macular holes and idiopathic premacular fibrosis.[6,7] However, the physiologic function of PPVPs is unknown.

Worst described the bursa premacularis, which he observed by injecting India ink into the vitreous in postmortem eyes.[8,9] In his original report, the bursa was anterior to the detached convex-shaped vitreous cortex that forms the collapsed space. Based on the concept of the bursa premacularis, the vitreous cortex is anatomically detached from the retina in the macular area. Worst described two channels that connect the bursa and Cloquet's canal.[9] He speculated that inflammation of the anterior chamber after cataract surgery may affect development of cystoid macular edema through the channels.

Swept-source OCT (SS-OCT) is a new generation of OCT that provides higher penetration into the choroid and sclera. SS-OCT enables clear visualization of the vitreous and the choroid. Using SS-OCT, we examined the morphologic features of PPVPs in normal subjects.

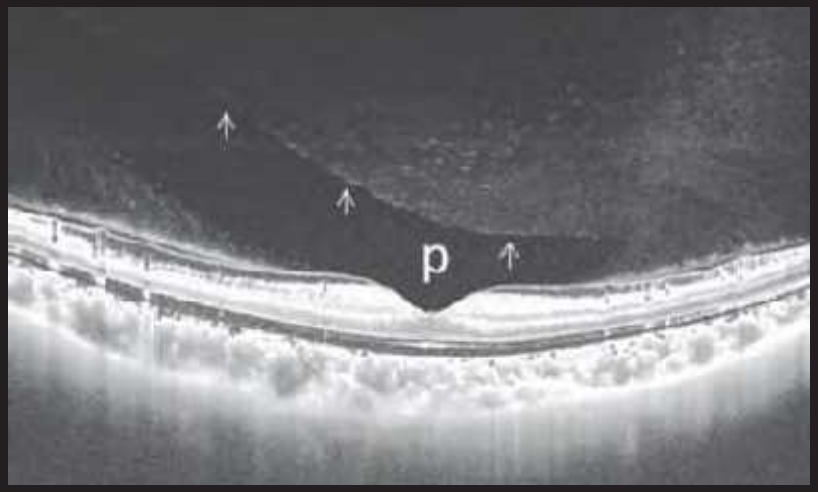
Methods

We performed SS-OCT (3D OCT-1 Atlantis; Topcon, Tokyo, Japan) consecutively in both eyes of 58 healthy volunteers (36 men, 22 women) while they were sitting. This OCT system has an A-scan repetition rate of 100,000 Hz, and its light source operates in the 1-μm wavelength region. The light source is a wavelength-variable laser centered at 1050 nm with a 100-nm tuning range. The axial resolution is 8 μm, the lateral resolution 20 μm, and the imaging depth 2.3 mm in tissue. The ocular fundus was scanned in six horizontal 12-mm scans that included the entire extent of the PPVPs, the centers of which were aligned at the plane through the optic disc and fovea, and two vertical 9.2-mm scans through the fovea and optic disc.

The subject ages ranged from 22 to 40 years (average, 26.2 ± 6.6 years). No eyes had an ocular disease. Subjects over 40 years of age were excluded to minimize age-related changes in the vitreous such as liquefaction or posterior vitreous detachment.[10]

The refractive powers were measured using a commercial topographer (Auto-Ref-Topographer RT-6000; Tomey Corporation, Nagoya, Japan) and ranged from −9.5 diopters (D) to +5.0

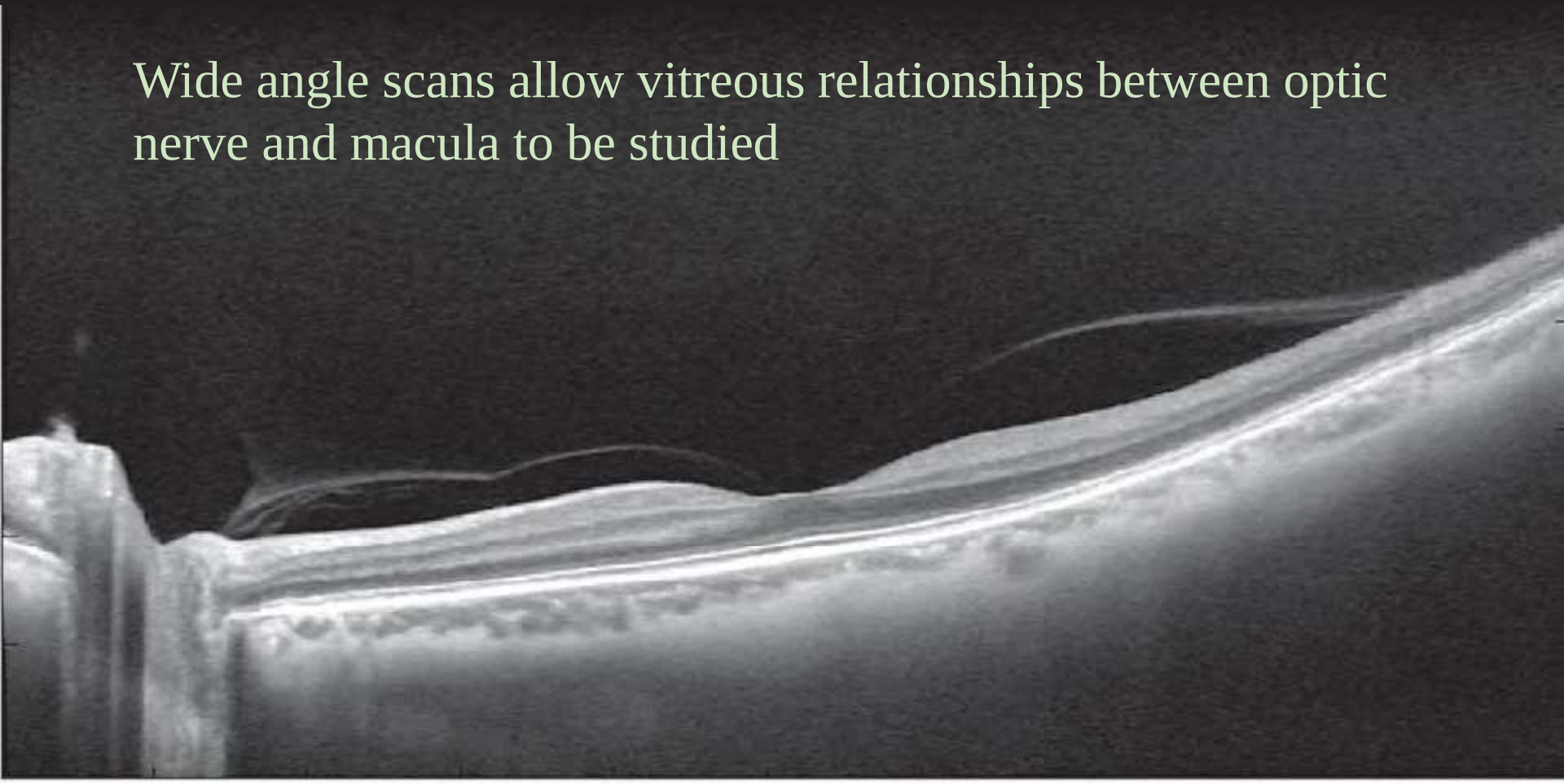
Better sensitivity means better visualization of subtle structures



- Better evaluation of vitreo-macular interface disease and normal vitreous dynamics
- Possibility of quantification of vitreous cell

Vitreous imaging with SS-OCT

Wide angle scans allow vitreous relationships between optic nerve and macula to be studied



Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Evolution of Vitreomacular Detachment in Healthy Subjects

Hiroshi Sakuraba, MD; Shoji Kishi, MD

IMPORTANCE Development of posterior vitreous detachment (PVD) plays an important role in vitreomacular diseases. Spectral-domain optical coherence tomography (SD-OCT) with noise reduction can visualize a posterior precortical vitreous pocket (PPVP) and classify PVD stages according to the state of the posterior wall of the PPVP.

OBJECTIVE To describe the role of the PPVP in early-stage PVDs in healthy individuals.

DESIGN, SETTING, AND PARTICIPANTS We performed biomicroscopy and SD-OCT in the right eyes of 368 healthy volunteers (168 males and 180 females; mean [SD] age, 57.1 [19.4] years; range, 12-89 years).

RESULTS The condition of the posterior wall of the PPVP was classified into stages according to the biomicroscopic findings and SD-OCT images: stage 0, no PVD with PPVP (114 eyes; mean [SD] subject age, 38.7 [16.3] years; range, 12-76 years); stage 1, paramacular PVD with PPVP (147 eyes; mean age, 55.2 [10.3] years; range, 36-77 years); stage 2, perifoveal PVD with PPVP (27 eyes; mean age, 63.3 [8.7] years; range, 46-81 years); stage 3, vitreofoveal separation with persistent attachment to the optic disc (19 eyes; mean age, 65.8 [6.2] years; range, 55-80 years; stage 3a, vitreofoveal separation with an intact posterior wall of the PPVP in 12 eyes; stage 3b, vitreofoveal separation with a defect in the posterior wall of the PPVP in 7 eyes; and stage 4, complete PVD (141 eyes; mean age, 71.2 [8.3] years; range, 48-89 years).

MAIN OUTCOMES AND MEASURES Ages in each PVD stage.

CONCLUSIONS AND RELEVANCE The posterior wall of the PPVP initially detaches at the paramacular area and extends to the perifoveal area, which results in a perifoveal PVD. A vitreofoveal detachment may develop with or without a defect in the PPVP. When the vitreous detaches from the optic disc, a complete PVD develops. An anatomical feature of the PPVP may play a role in the development of a perifoveal PVD.

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Author Affiliation: Department of Ophthalmology, Gunma University School of Medicine, Maebashi, Japan.
Corresponding Author: Hiroshi Sakuraba, MD, Department of Ophthalmology, Gunma University School of Medicine, 3-39-15 Showa-machi, Maebashi, Gunma 371-8511, Japan (hsakuraba@med.gunma-u.ac.jp).

Recent advancements in optical coherence tomography (OCT) have identified the key role that perifoveal posterior vitreous detachments (PVDs) play in the development of macular holes,[1,2] vitreomacular traction syndrome,[3] and some aspects of diabetic macular edema.[4] Before OCT was introduced, the anatomy of the posterior vitreous was hard to visualize during a biomicroscopic examination because of its transparency. The vitreous anatomy was studied biomicroscopically[5,6] in postmortem eyes. Sebag[7] reported that anomalous PVD causes vitreomacular traction syndrome, results in vitreoschisis with macular pucker or macular holes, and contributes to some cases of diabetic macular edema.

Worst[5,6] described bursa premacularis, a liquefied area of the vitreous anterior to the macula, which was observed by injecting India ink into the cisternal canal of the vitreous in postmortem eyes. We identified a posterior precortical vitreous pocket (PPVP) at autopsy in eyes in which the vitreous gel was stained with fluorescein.[8] A PPVP is a physiologic liquefied lacuna whose posterior wall is a thin layer of vitreous cortex situated anterior to the macular area. Although PPVPs are difficult to observe with biomicroscopy, triamcinolone acetonide–assisted vitrectomy[9] confirmed their presence. Time-domain OCT showed the vitreous cortex slightly detached from the macular area but failed to identify a PPVP.[10] Recently developed spectral-domain OCT (SD-OCT) with noise reduction can depict the PPVPs.[11-14]

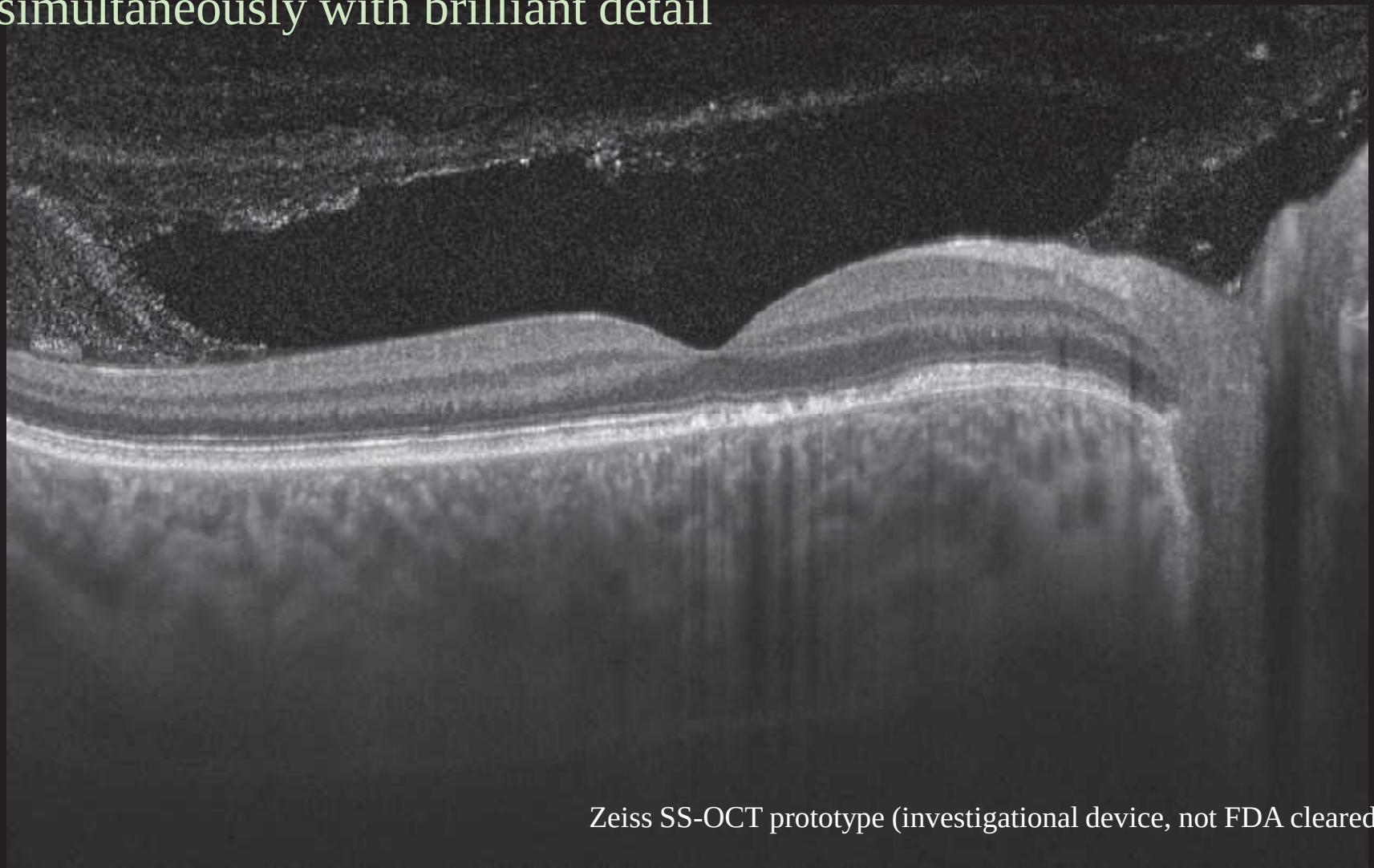
In the current study, we used SD-OCT to evaluate the role of the PPVP in the development of PVDs in healthy individuals.

Methods

We performed SD-OCT with noise reduction (Cirrus OCT, version 4.5; Carl Zeiss Meditec) in the right eyes of 368 healthy

Vitreous imaging with SS-OCT

With SS-OCT, both the vitreous and choroid can be imaged simultaneously with brilliant detail



Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Anterior segment imaging with SS-OCT

Swept-source anterior segment optical coherence tomography in late-onset capsular block syndrome: High-resolution imaging and morphometric modifications after posterior capsulotomy

Alberto Neri, MD, Marco Pieri, MD, Federico Olcelli, MD, Rosachiara Leuci, MD, Stefano A. Candolfi, MD, Claudio Macaluso, MD

PURPOSE: To study the characteristics of late-onset capsular block syndrome (CBS) using swept-source anterior segment optical coherence tomography (AS-OCT) and assess morphometric variations after treatment with neodymium:YAG (Nd:YAG) laser posterior capsulotomy.

SETTING: Ophthalmology, University of Parma, Parma, Italy.

DESIGN: Case series.

METHODS: Patients with late-onset CBS had an ophthalmology evaluation, including slitlamp photography and AS-OCT, before and 1 month after Nd:YAG laser posterior capsulotomy. The diameter of the anterior capsulorhexis, the posterior displacement of the posterior capsule, and the anterior chamber depth (ACD) were measured using AS-OCT. Measurements before and after Nd:YAG laser posterior capsulotomy were compared using the paired *t* test.

RESULTS: The study evaluated 6 patients. Slitlamp examination showed accumulation between the intraocular lens (IOL) and the posterior capsule of milky-white or particulate liquefied material that appeared hyperreflective on AS-OCT and caused posterior displacement of the posterior capsule (mean 1.38 mm). The diameter of the anterior capsulorhexis (mean 4.5 mm) was smaller than the IOL optic in all cases. After uneventful Nd:YAG laser posterior capsulotomy the corrected distance visual acuity improved in all patients ($P<.01$). The ACD (IOL position) and refraction did not change significantly after the capsulotomy ($P=.15$ and $P=.98$, respectively).

CONCLUSIONS: Anterior segment OCT allowed accurate imaging and measurement of anterior segment parameters in late-onset CBS. No displacement of the IOL was found after treatment with Nd:YAG laser posterior capsulotomy. Neodymium:YAG laser posterior capsulotomy was an effective and safe therapy in the 6 late-onset CBS cases.

Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned.

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Capsular block syndrome (CBS), a rare complication of continuous curvilinear capsulorhexis (CCC) for cataract extraction and intraocular lens (IOL) implantation, consists of the retention of material in the capsular bag. Initially described by Holtz[1] and Davison,[2] CBS was later classified according to the time of onset as intraoperative, early-onset postoperative, and late-onset postoperative.[3] The late-onset form of CBS, occurring 1 month or later after cataract surgery, consists of the accumulation of a clear, particulate, or milky-white liquid substance in the space between the IOL posterior face and the posterior capsule.

Late-onset CBS may be associated with decreased visual acuity, impaired contrast sensitivity, and glare, while myopic or hyperopic shifts deriving from the displacement of the IOL optics, typically found in early-onset CBS, are not usually present in late-onset

Deep penetration (1050nm) and high sensitivity of SSOCT allows visualization of full extent of lens/IOL and angle recess

Anterior segment imaging with SS-OCT

Imaging the Iris with Swept-Source Optical Coherence Tomography: Relationship between Iris Volume and Primary Angle Closure

Heather Mak, BS, Guohui Xu, BM, Christopher Kai-Shun Leung, MD, MB, ChB

Objective: To measure iris volume and anterior segment parameters using a swept-source anterior segment optical coherence tomography (OCT) and investigate factors associated with iris volume and iris volume change after pupil dilation in eyes with open angles and angle closure.

Design: Cross-sectional study.

Participants: A total of 86 eyes, including 31 eyes from 21 patients with primary angle closure (PAC) or PAC suspect, 31 eyes from 20 patients with primary open-angle glaucoma (POAG), and 24 eyes from 15 normal subjects, were included.

Methods: The anterior segment parameters and iris were imaged and measured by the Casia SS-1000 OCT (Tomey, Nagoya, Japan) in room light, dark, and after pharmacologic dilation. Linear mixed models were used to examine the association between iris volume and change in iris volume after dilation and each of the following: age, sex, anterior chamber volume (ACV), axial length, pupil diameter, and angle width.

Main Outcome Measures: Iris volume.

Results: The mean iris volume significantly decreased from light to dark and after pharmacologic dilation in angle closure (40.0±5.2, 38.8±5.4, and 32.5±4.5 mm^3, respectively), POAG (40.2±5.3 39.4±5.4, and 33.6±4.2 mm^3, respectively), and normal eyes (40.1±4.2 39.1±3.9, and 33.0±4.4 mm^3, respectively). From room light to dark, the iris volume of 16.7% normal, 19.4% POAG, and 19.4% angle closure eyes increased iris volume ($P = 0.960$). After pharmacologic dilation, iris volume decreased in all eyes. Iris volume was negatively associated with ACV and positively associated with axial length ($P < 0.001$). The change in iris volume per millimeter change in pupil diameter was 2.11, 2.01, and 1.80 mm^3/mm in the angle closure, POAG, and normal groups, respectively ($P \geq 0.414$). A smaller ACV ($P = 0.049$) and older age ($P = 0.036$) were associated with a smaller change in iris volume per millimeter change in pupil diameter. A larger iris volume, smaller ACV, and greater pupil diameter were significant determinants of a smaller angle width (all $P \leq 0.003$).

Conclusions: The mean iris volume decreased after pupil dilation in open-angle and angle closure eyes, and the degree of reduction was less in eyes with a smaller ACV. Both iris volume and ACV were important determinants of the anterior chamber angle.

Financial Disclosure(s): The author(s) have no proprietary or commercial interest in any materials discussed in this article. *Ophthalmology 2013;■:1–8*

The iris is a dynamic structure governing the configuration of the anterior chamber angle. Although quantification of iris dimension is difficult with gonioscopy, the introduction of anterior segment optical coherence tomography (OCT) has facilitated the measurement of iris curvature, iris thickness, and iris area. An increase in iris curvature, iris thickness, and iris area has been shown to be independently associated with narrow angles (defined as having <180° of visible posterior trabecular meshwork), after adjusting for age, sex, anterior chamber depth, axial length, and pupil size.[1,2] Although these associations highlight the importance of iris measurement in evaluating the risk of angle closure, iris parameters measured in a 2-dimensional image would be inadequate to describe the 3-dimensional iris structure. In the studies by Aptel and Denis[3] and Aptel et al,[4] iris volume was estimated from 4 cross-sectional images captured at 45° intervals by a time-domain anterior segment OCT. They found that iris volume decreased after dilation in eyes with open angles. By contrast, in the fellow eyes of patients with an episode of acute primary angle closure (PAC), iris volume increased. Using the same OCT instrument and similar methodology for measurement of iris volume, Quigley[5] showed that in a group of 90 subjects with open-angle glaucoma and angle closure, glaucoma suspects, and controls, 10% had a gain in iris volume in which 2 eyes had angle closure. Although these studies provide important preliminary data suggesting an association between dynamic iris response and PAC, estimating iris volume with only

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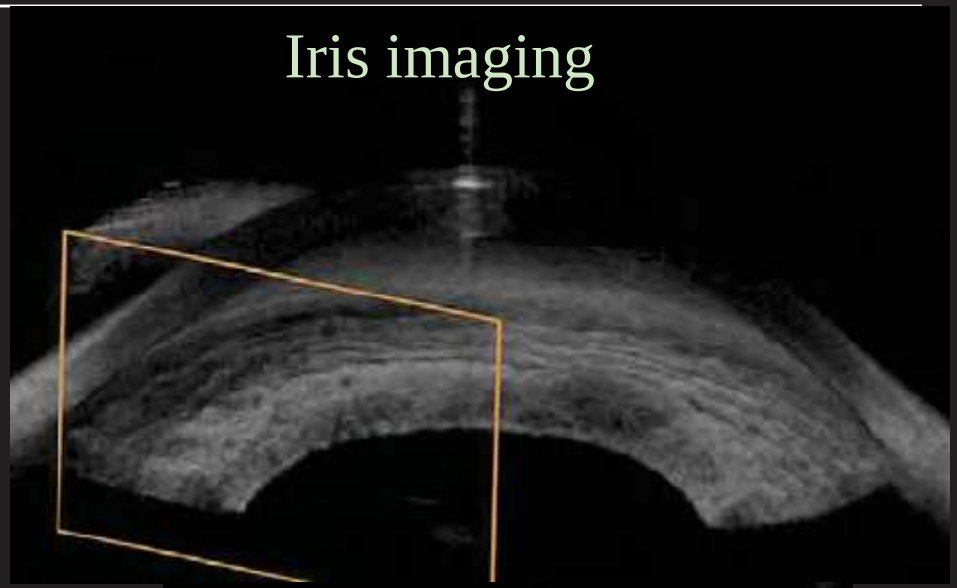
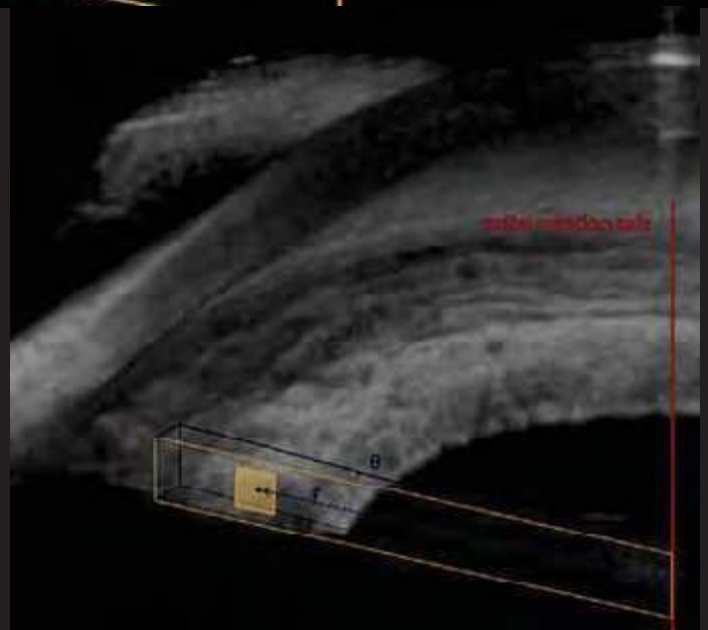
http://dx.doi.org/10.1016/j.ophtha.2013.05.004

Iris imaging





Anterior segment imaging with SS-OCT

Anterior Chamber Angle Imaging with Swept-Source Optical Coherence Tomography: Measuring Peripheral Anterior Synechia in Glaucoma

Isabel Lai, MB, BS, Heather Mak, BSc, Gilda Lai, BSc, Marco Yu, BSc, Dennis S. C. Lam, MD, FRCOphth, Christopher K. S. Leung, MD, MR, ChR

Objective: To investigate the use of swept-source optical coherence tomography (OCT) for measuring the area and degree of peripheral anterior synechia (PAS) involvement in patients with angle-closure glaucoma.

Design: Cross-sectional study.

Participants: Twenty-three eyes with PAS (detected by indentation gonioscopy) from 20 patients with angle-closure glaucoma (20 eyes had primary angle-closure glaucoma and 3 eyes had angle-closure glaucoma secondary to chronic anterior uveitis [n = 2] and Axenfeld-Rieger syndrome [n = 1]).

Methods: The anterior chamber angles were evaluated with indentation gonioscopy and imaged by swept-source OCT (Casia OCT, Tomey, Nagoya, Japan) in room light and in the dark using the "angle analysis" protocol, which was composed of 128 radial B-scans each with 512 A-scans (16-mm scan length). The area and degree of PAS involvement were measured in each eye after manual detection of the scleral spur and the anterior irido-angle adhesion by 2 masked observers. The interobserver variability of the PAS measurements was calculated.

Main Outcome Measures: The agreement of PAS assessment by gonioscopy and OCT, the area and the degree of PAS involvement, and the intraclass correlation coefficient (ICC) of interobserver PAS measurements.

Results: The area of PAS (mean ± standard deviation) was 20.8 ± 16.9 mm^2 (range, 3.9–74.9 mm^2), and the degree of PAS involvement was 196.5 ± 70.9 degrees (range, 42–314 degrees). There was no difference in the area of PAS ($P = 0.90$) and the degree of PAS involvement ($P = 0.95$) between images obtained in room light and in the dark. The interobserver ICCs were 0.99 (95% confidence interval [CI], 0.98–1.00) for the area of PAS and 0.99 (95% CI, 0.97–1.00) for the degree of PAS involvement. There was good agreement of PAS assessment between gonioscopy and OCT images (kappa = 0.79; 95% CI, 0.67–0.91).

Conclusions: Swept-source OCT allows visualization and reproducible measurements of the area and degree of PAS involvement, providing a new paradigm for evaluation of PAS progression and risk assessment for development of angle-closure glaucoma.

Financial Disclosure(s): The author(s) have no proprietary or commercial interest in any materials discussed in this article. *Ophthalmology 2013;120:1144–1149 © 2013 by the American Academy of Ophthalmology.*

Peripheral anterior synechia (PAS) represents adhesional contact between the peripheral iris and the anterior chamber angle, which can be found in primary and secondary angle closure, acute angle closure, and chronic angle-closure glaucoma. The extent of PAS correlates with the level of intraocular pressure (IOP).[1–3] Measuring the degree of PAS and following its progression would be of relevance and importance for risk assessment of angle-closure glaucoma. Nevertheless, the examination of PAS has depended on indentation gonioscopy,[4] which largely provides qualitative or semiquantitative evaluation of PAS involvement. The advent of anterior segment optical coherence tomography (OCT) technology, including the Visante OCT (Carl Zeiss Meditec, Dublin, CA) and the slit-lamp OCT (SL-OCT, Heidelberg Engineering, GmbH, Dossenheim, Germany), allows noncontact, cross-sectional imaging of the anterior chamber angle.[4] However, the relatively slow scan speed of these instruments (2000 A-scan/s and 200 A-scan/s, respectively) has limited circumferential assessment of the angle and the extent of PAS involvement.

The Casia OCT (Tomey, Nagoya, Japan) is a commercially available swept-source OCT (swept-source laser wavelength of 1310 nm) recently introduced for anterior segment and anterior chamber angle imaging.[5,6] With a scan speed of 30 000 A-scans/s and an axial resolution of <10 μm, multiple high-resolution, cross-sectional images of the angle can be captured within seconds, facilitating examination and measurement of PAS. The objectives of this study

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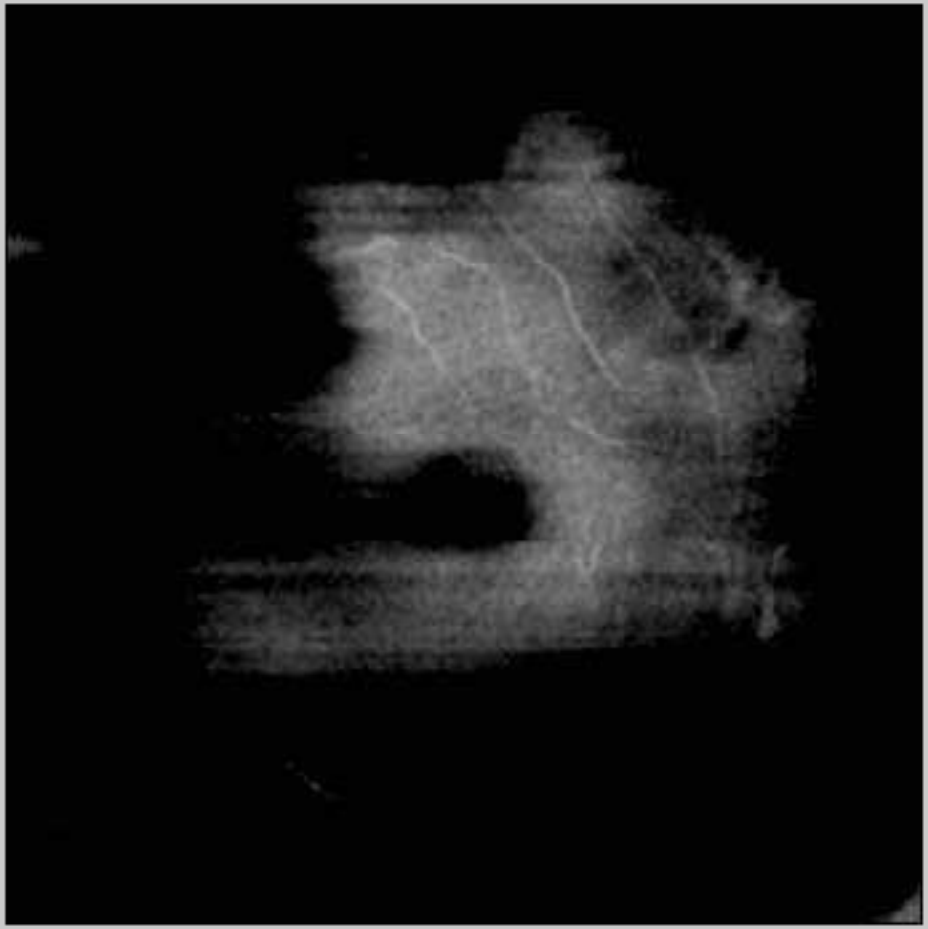
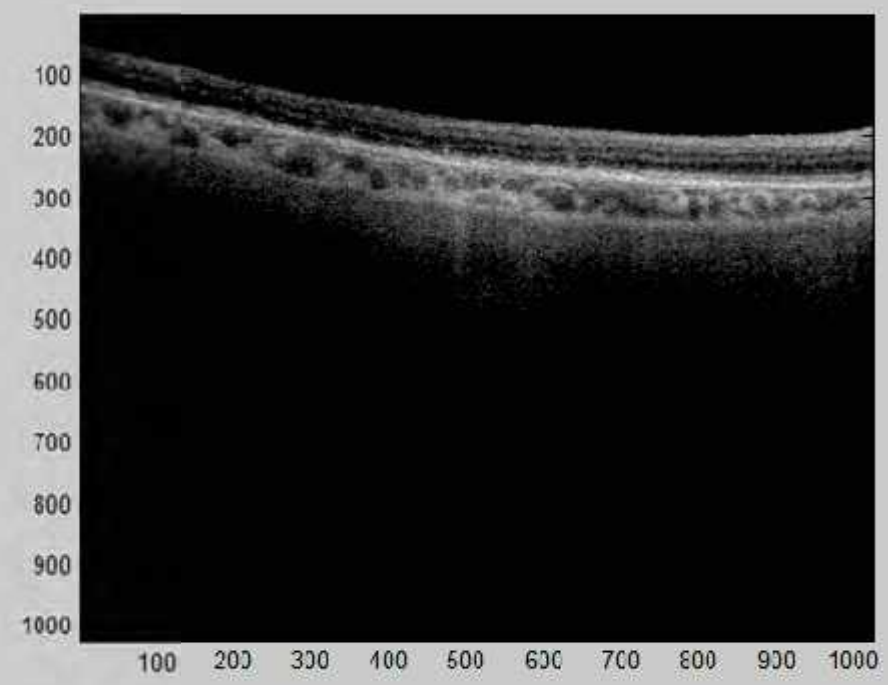
Iris imaging

Evaluation of the trabecular outflow system, Schlemm's canal, and collector channels is an area of current interest

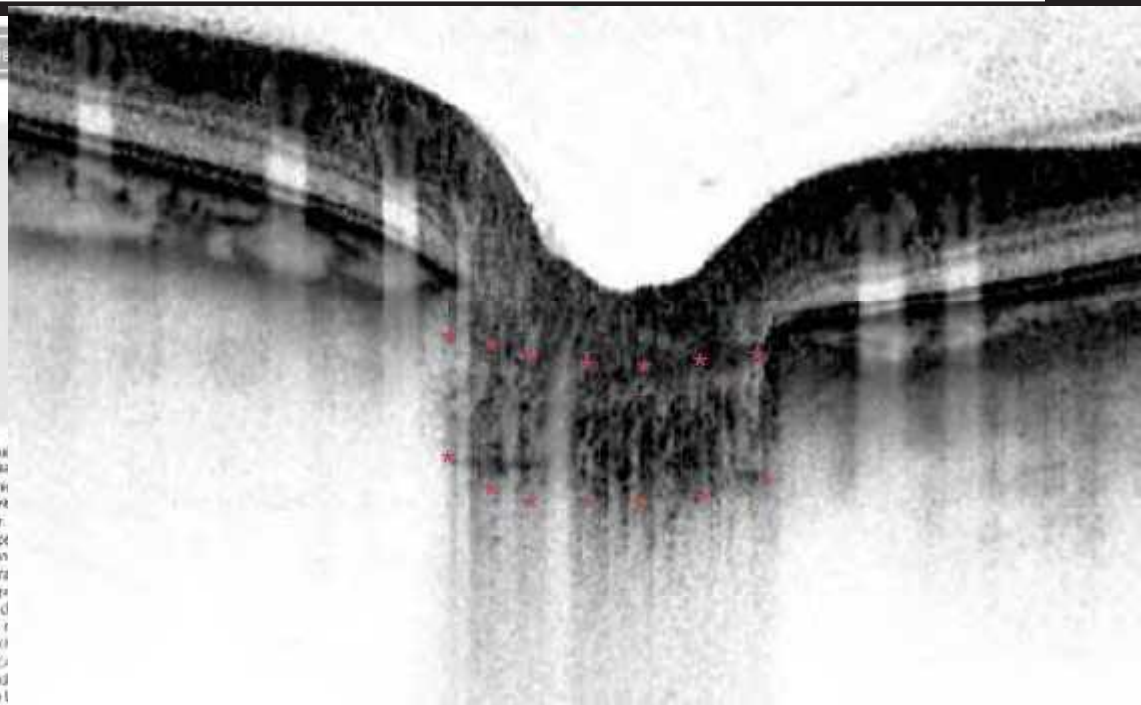
Choroidal imaging with SS-OCT





Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Optic Nerve Head Imaging with SSOCT



EXPERT REVIEWS

Improved visualization of deep ocular structures in glaucoma using high penetration optical coherence tomography

Expert Rev. Med. Devices 10(5), 621–629 (2013)

Kaweh Mansouri[1,2], Brenda Nuyen[1] and Robert N Weinreb[1]

[1]Hamilton Glaucoma Center and Department of Ophthalmology, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0946, USA
[2]Department of Ophthalmology, Glaucoma Service, Geneva University Hospital, Geneva, Switzerland
*Author for correspondence
Tel.: +1 858 534 7314
Fax: +1 858 534 7314
kawehm@yahoo.com

The introduction of optical coherence tomography (OCT) has revolutionized ophthalmology through the ability to non-invasively image the retina in vivo. Glaucoma is the leading cause of irreversible blindness worldwide. Despite major advances in imaging technology, the pathogenesis of glaucoma remains poorly understood at present. The lamina cribrosa (LC) is the presumed site of axonal injury in glaucoma. Its thinning and deformation have been suggested to contribute to glaucoma development and progression by impeding axoplasmic flow within the optic nerve fibers, leading to apoptosis of retinal ganglion cells. To visualize the deep ocular structures such as the choroid and the LC, OCT imaging has been used, particularly the enhanced depth imaging (EDI)-OCT modality of spectral domain (SD)-OCT. However, the posterior laminar surface especially is not seen clearly using this method. A new generation of OCTs, swept-source (SS)-OCT, is able to visualize the LC and the choroid in vivo. SS-OCT employs a longer wavelength compared with conventional OCT, generally set at 1050 nm (instead of 840 nm). We review current knowledge of the LC, findings from trials that use SD-OCT and EDI-OCT, and our experience with a prototype SS-OCT to quantify choroid changes and visualize the LC in its entirety.

Keywords: choroid • glaucoma • lamina cribrosa • swept-source optical coherence tomography

Glaucoma is a leading cause of blindness worldwide [1]. It is defined as a group of progressive optic neuropathies with characteristic retinal ganglion cell damage at the optic disc and a concomitant pattern of visual field loss [2]. However, the mechanisms of the disease remain poorly understood. Many individuals remain undiagnosed or treated inadequately, and the public health impact of glaucoma will only increase as the world's population ages [3].

The axons of the retinal ganglion cells converge to form the neuroretinal rim of the optic disc before exiting the eye through the lamina cribrosa (LC), a scleral structure at the optic nerve head that is characterized by sheets of porous connective tissue. The LC is presumed to provide mechanical support to these optic nerve fibers within the deep optic disc region [4]. Structural thinning of the LC via deformation and compression, has been associated with glaucoma [5,6]. Changes in the LC pore shape and size also have been correlated with progression of the disease [7–9]. Overall, deformation of the LC likely impedes axoplasmic flow disrupting transport of trophic factors important to survival of retinal ganglion cells [10,11]. Thus, structural changes in the LC may play a role in neuronal death characteristic of glaucoma. Also, from a biomechanical perspective, the LC represents a discontinuity in the spherical casing of the eye, which makes it more vulnerable to the stress loading that may play a role in glaucoma [12]. Therefore, understanding the forces that affect the structure of the LC will further elucidate the mechanisms of glaucoma. Characterization of both

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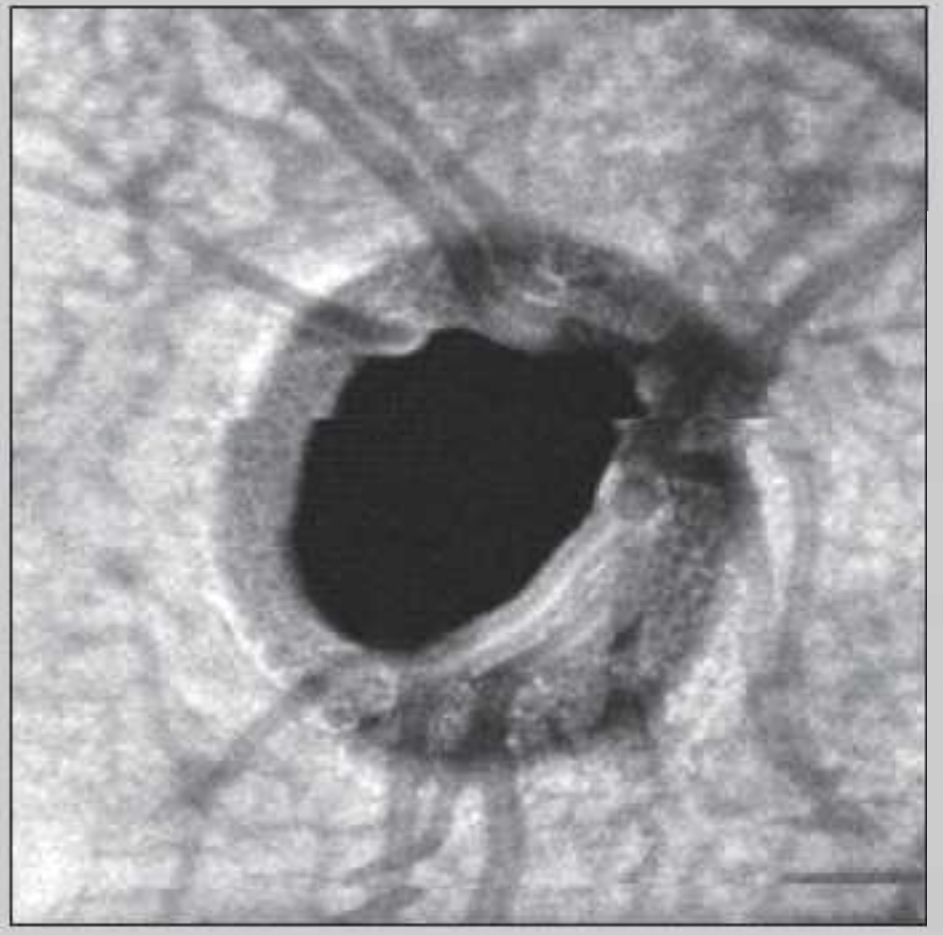
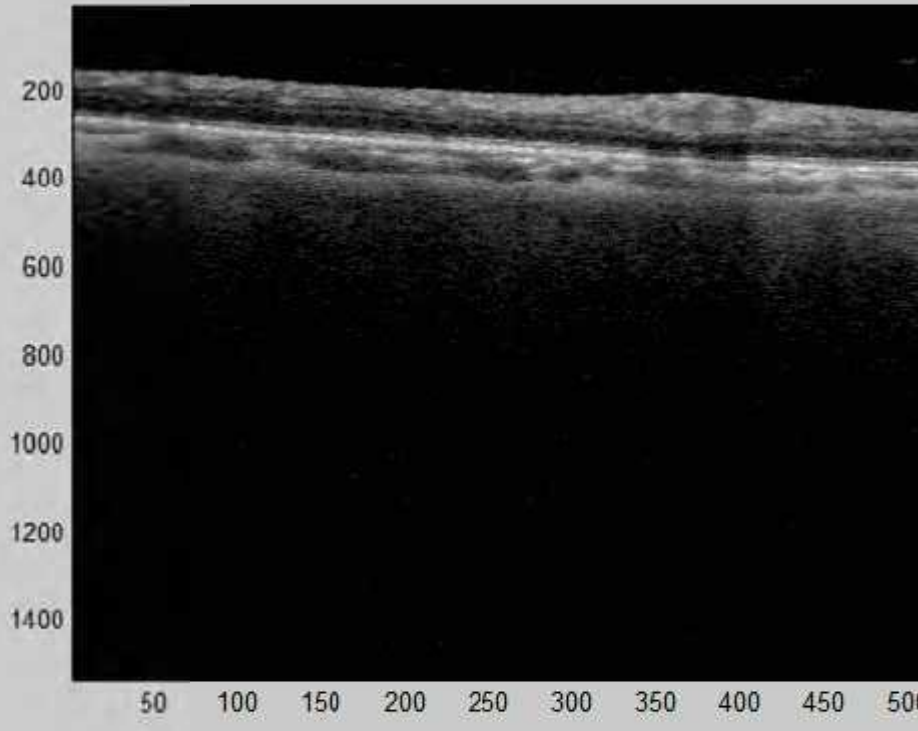
Glaucomatous nerves with SSOCT

Drance hemorrhages are associated with tears in the lamina



Moderate to severe glaucoma



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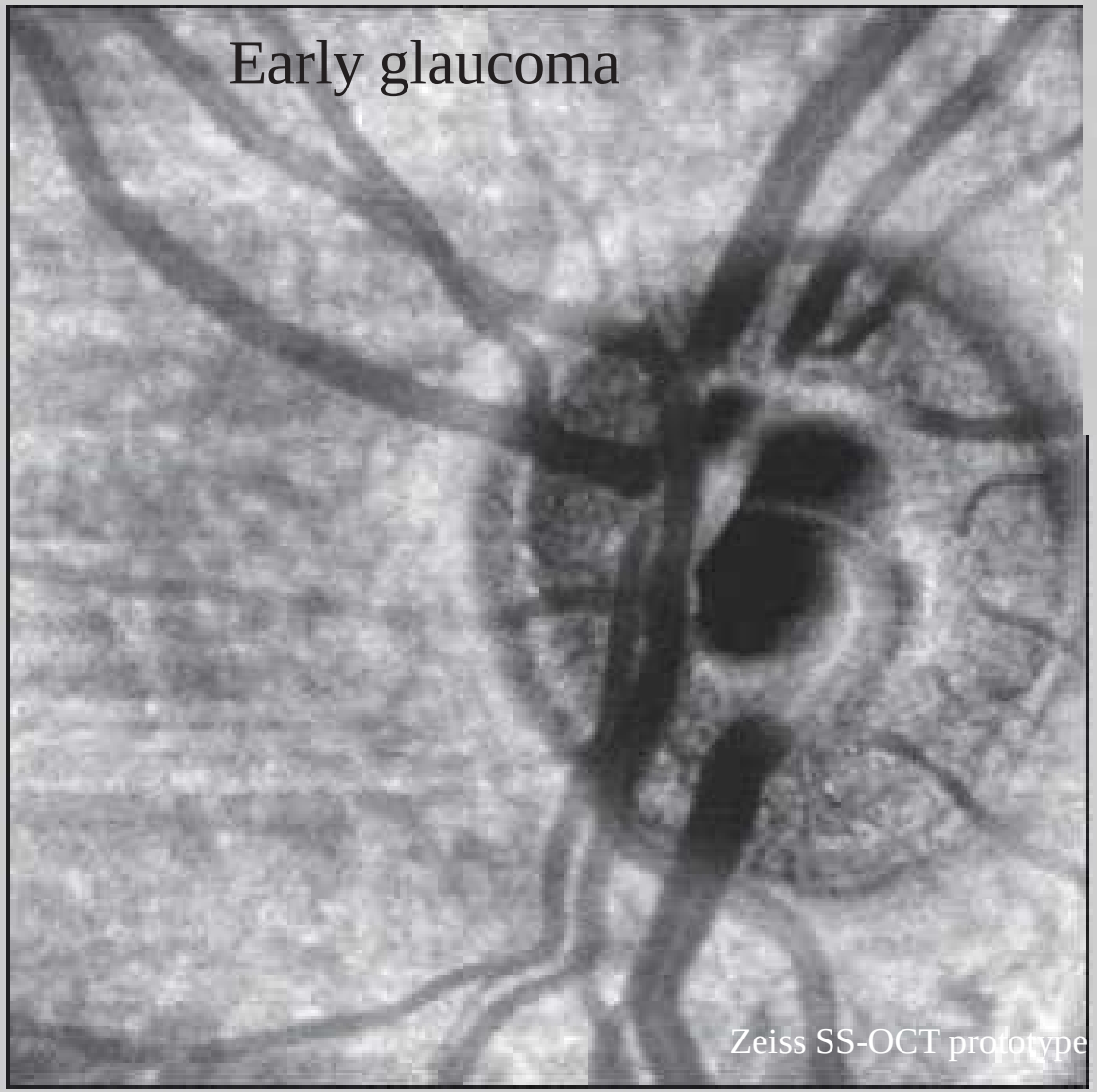
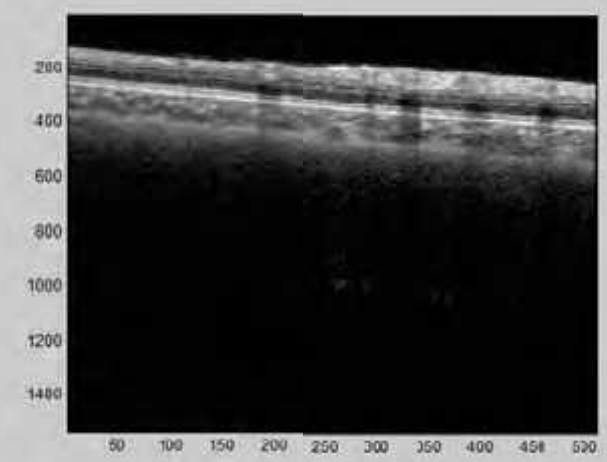
Glaucomatous nerves with SSOCT





Zeiss SS-OCT prototype (investigational device, not FDA cleared)

Summary

- Swept source OCT represents the next evolution of OCT technology
- Its higher speed, higher sensitivity, and expected longer wavelength light source, offer important advantages over existing commercial SD-OCT devices
- SS-OCT will likely further expand the applications and importance of OCT

Thank you!