Advances in Ocular Imaging

Sunil K. Srivastava, MD

Staff Physician

Cole Eye Institute, Cleveland Clinic

Cole Eye Institute

Financial Disclosure

- Consultant/Advisory Board: Bausch and Lomb, Allergan, Alimera, Clearside, Regeneron, Eleven, Santen, Sanofi, Zeiss, Optos
- Research Grants: Bausch and Lomb, Allergan, Novartis, Clearside, Zeiss, Sanofi
- Licensing Royalty: Bioptigen, Synergetics
- Grant Funding: Ohio Department of Development TECH-13-059,
- Duke BRP Collaboration, Subcontractor: NIH/NEI R01-EY023039-0

Cole Eye Institute

Ocular Imaging

- Continues to revolutionize our field
- Improvements in imaging
  - Allow early diagnosis
  - Allow us to treat earlier/appropriately
  - Allow us to monitor patients over time
- Improvements in Imaging
  - Seem to occur daily

Cole Eye Institute

What its like to buy a new machine

Cole Eye Institute

Which is the best imaging test to buy?

Cole Eye Institute

I won't argue about which tool is the best

Cole Eye Institute

Before I buy a system, is it useful?

- What information can be gained?
- How does it impact patient care?
- Reality – in times of cost containment – we have to prove why its worth the cost and time

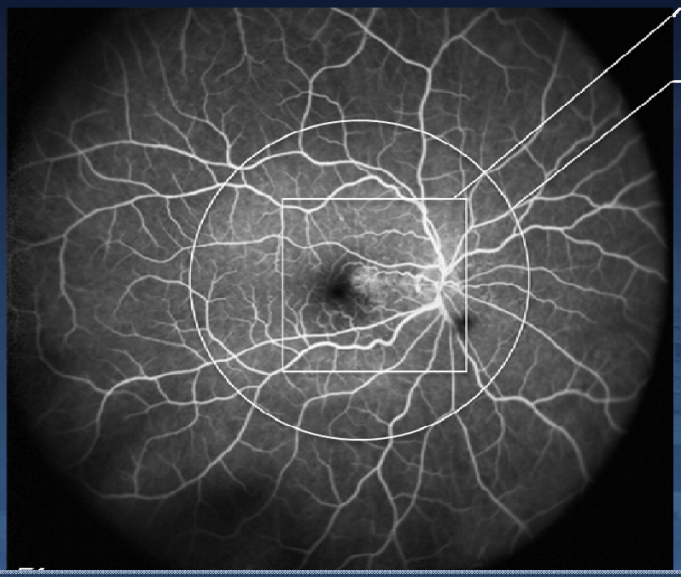
Cole Eye Institute

Purpose of this lecture

- Discuss three relatively new imaging modalities and impact on clinical practice
  - Wide field Imaging
  - OCT Angiography
  - Intraoperative OCT
- Discuss the future of software development and its impact

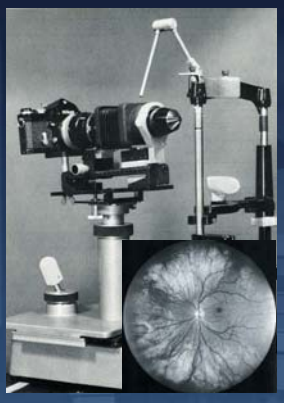
Cole Eye Institute

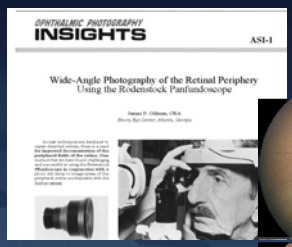
What does wide field offer?

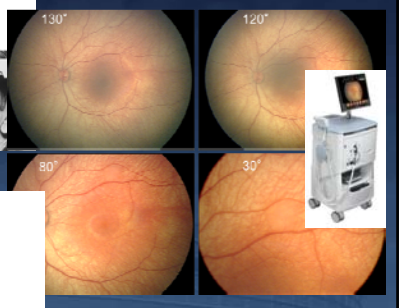


Cole Eye Institute

Since 1970: Contact Systems

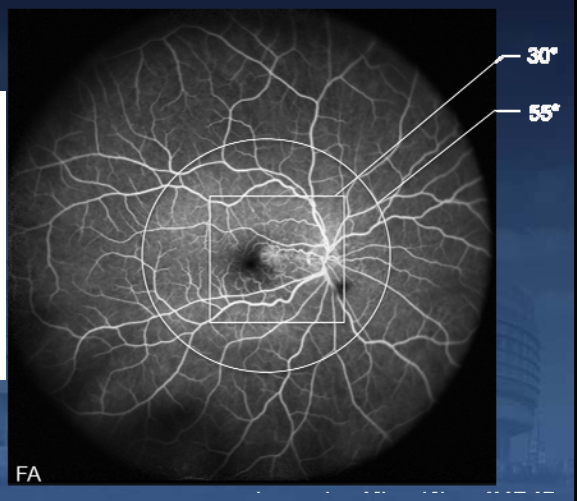






Cole Eye Institute

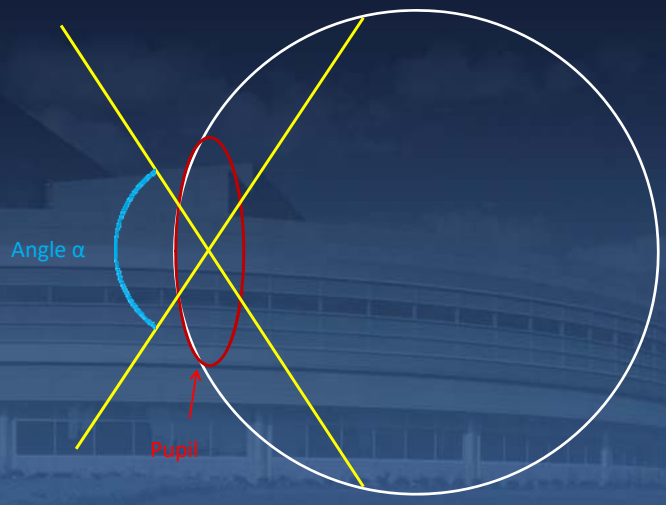
Heidelberg Non-Contact Widefield



Courtesy Heidelberg Engineering

Cole Eye Institute

Heidelberg Non-Contact Widefield



Courtesy Prithvi Mruthyunjaya, MD

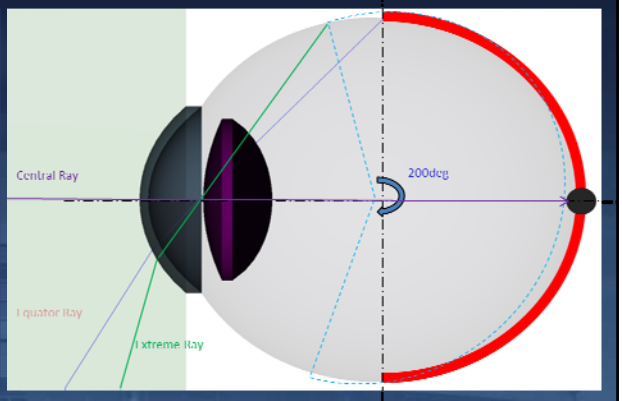
Cole Eye Institute

Heidelberg Non-Contact Widefield

Courtesy Heidelberg Engineering

Cole Eye Institute

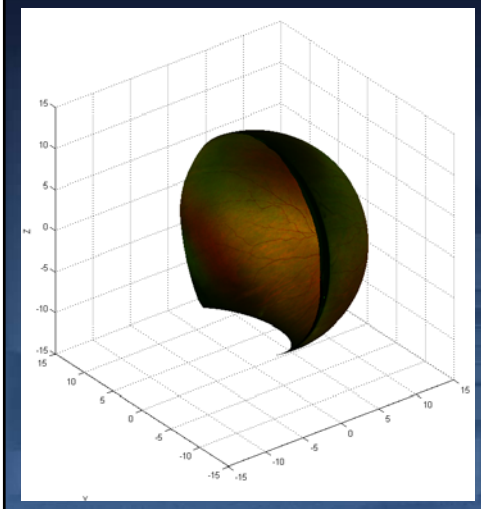
Optos

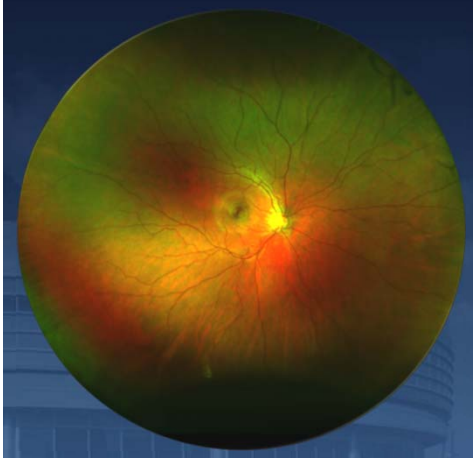


Courtesy Optos Plc

Cole Eye Institute

Optos

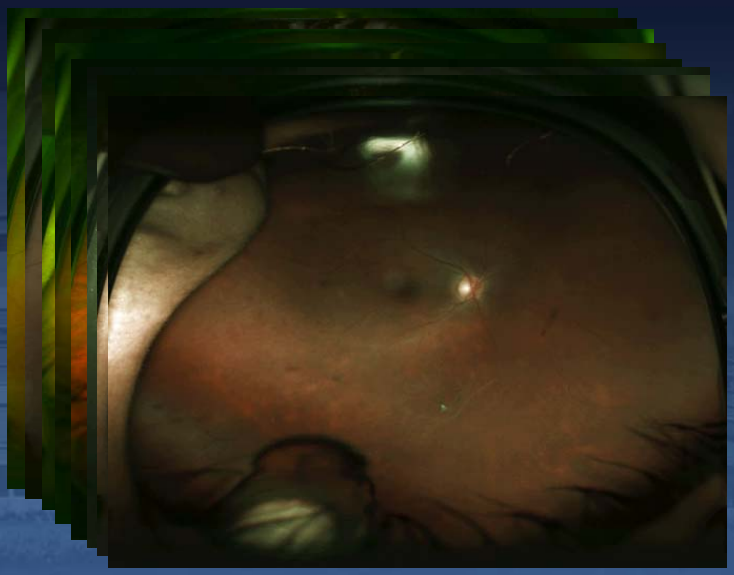




Courtesy Prithvi Mruthyunjaya, MD

Cole Eye Institute

Optos Artifacts



Cole Eye Institute

The eye scanner that saw too much: How a 'problem' spotted by a supermaket tester caused unnecessary panic

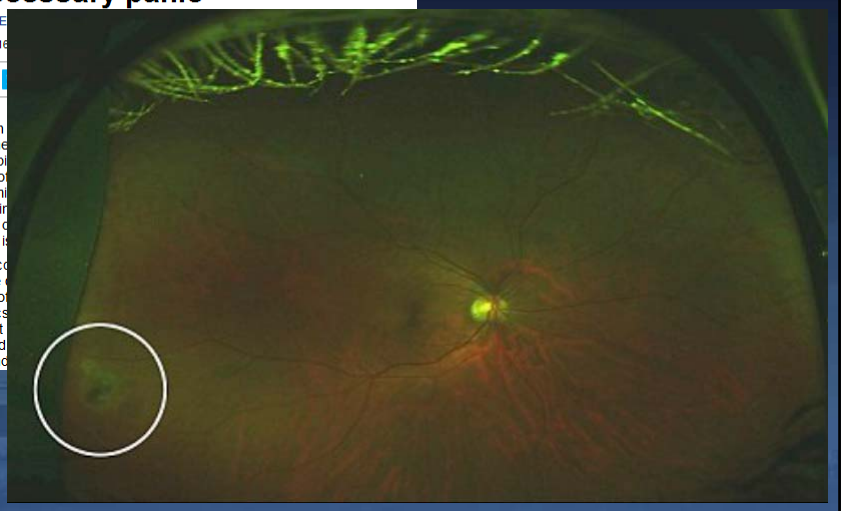
By ANGELA E

PUBLISHED: 16

Share

As a health
to try out ne
tests. It's bi
hundreds o
alone claimi
early-warnir
from heart d
UK market i

They can co
for a home
hundreds o
MOT. Critics
tests aren't
the 'worried
positive and



Cole Eye Institute

Widefield Imaging Clinical Utility

- Documentation
- Diagnosis
- Treatment
- Analysis

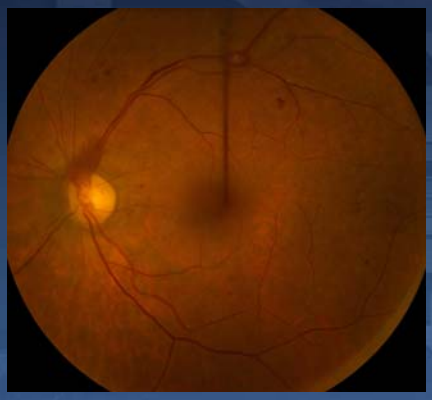
Cole Eye Institute

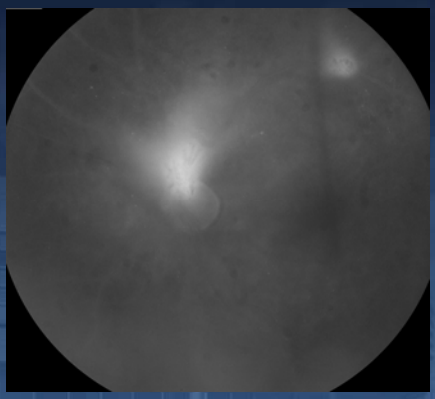
Diabetes

Cole Eye Institute

Identification of Neovascularization

- NVD

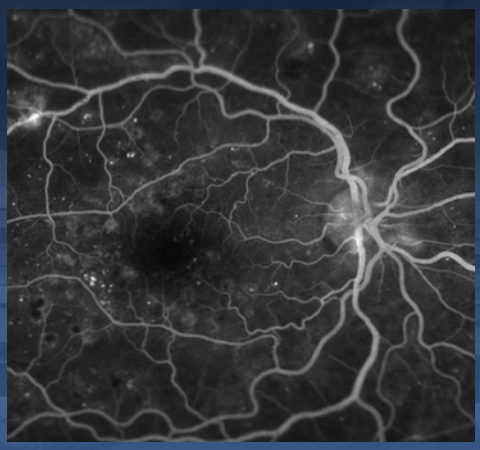




Cole Eye Institute

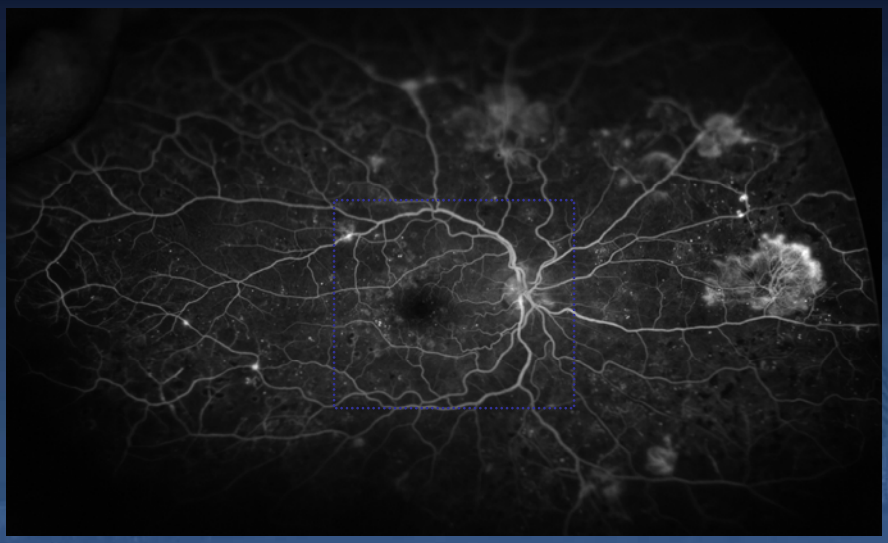
Identification of Neovascularization

- NVE



Cole Eye Institute

Identification of Neovascularization

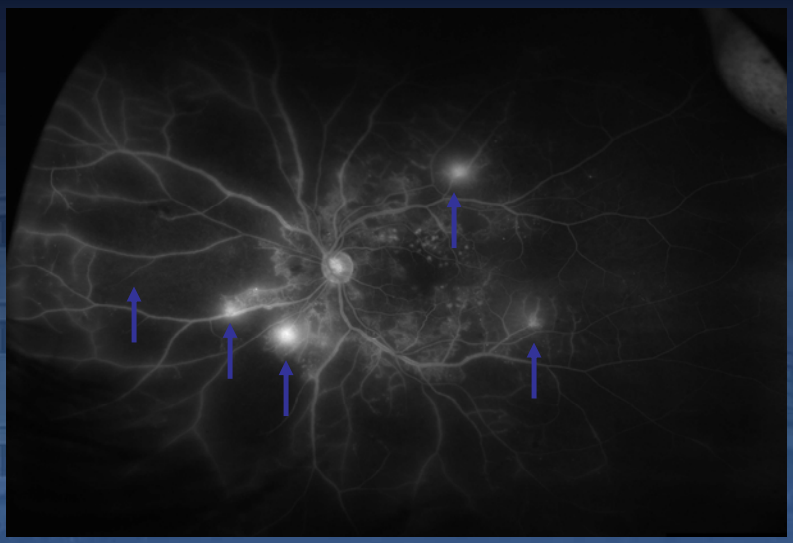


Cole Eye Institute

Identification of Neovascularization

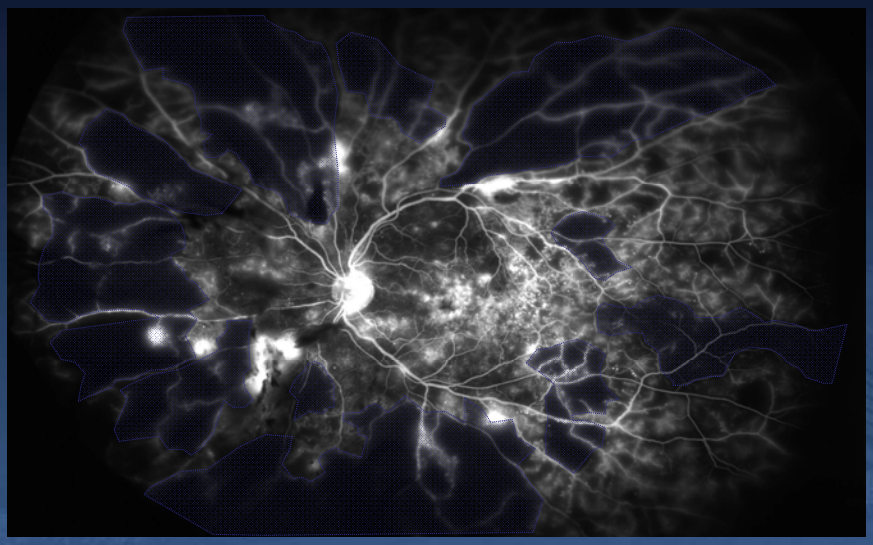
Cole Eye Institute

Identification of Neovascularization



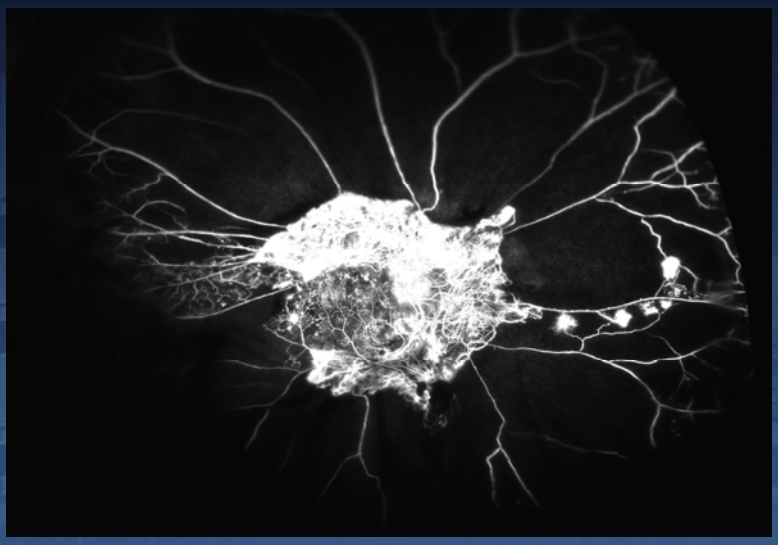
Cole Eye Institute

Peripheral Ischemia



Cole Eye Institute

Peripheral Ischemia

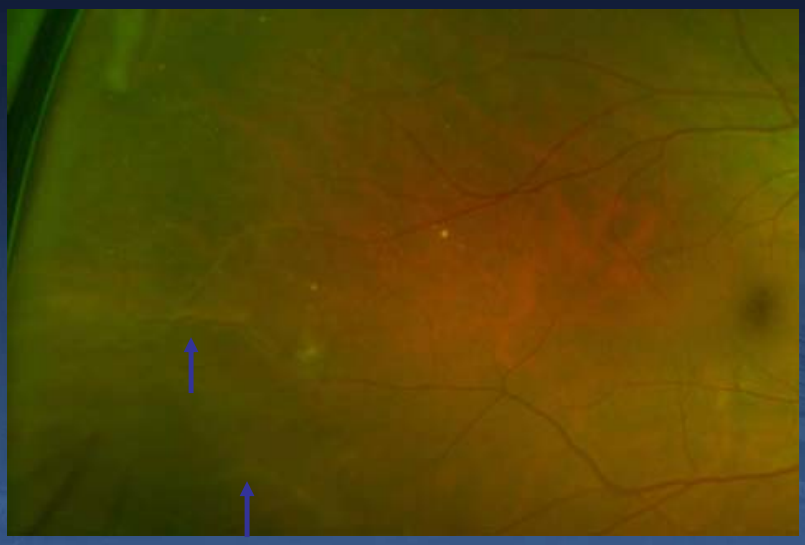


Cole Eye Institute

Diabetic Eye Exam

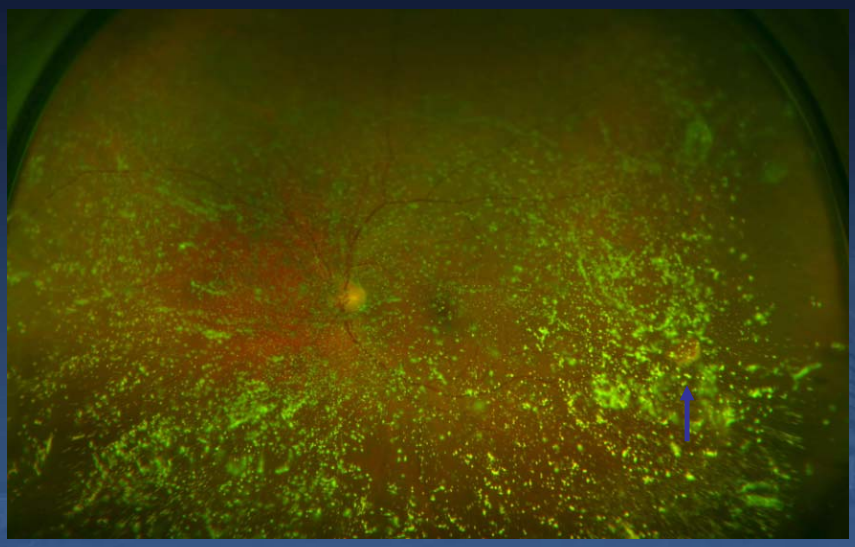
Cole Eye Institute

Diabetic Eye Exam

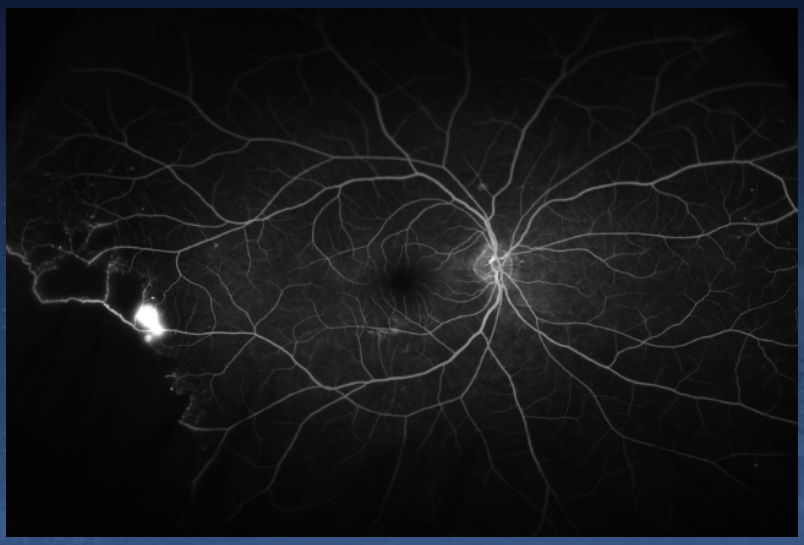


Cole Eye Institute

Diabetic Eye Exam

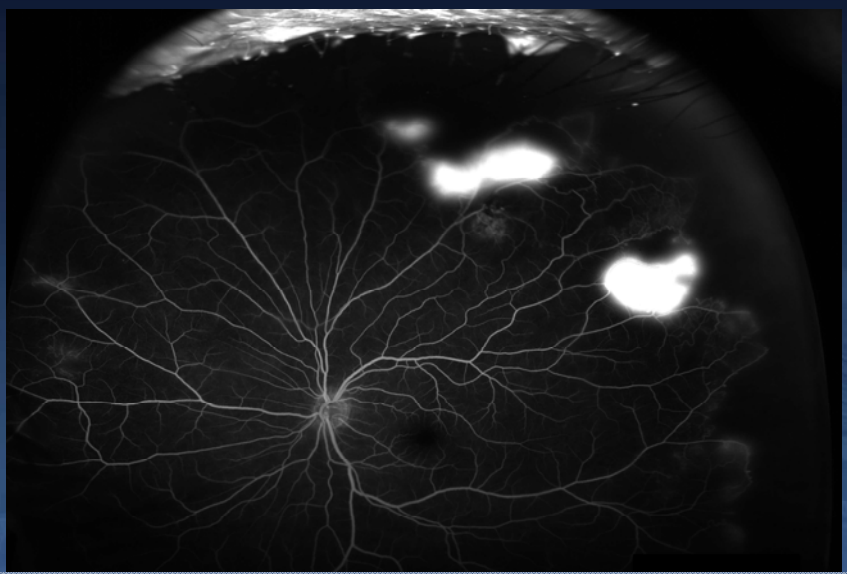


Cole Eye Institute



Cole Eye Institute

Sickle cell



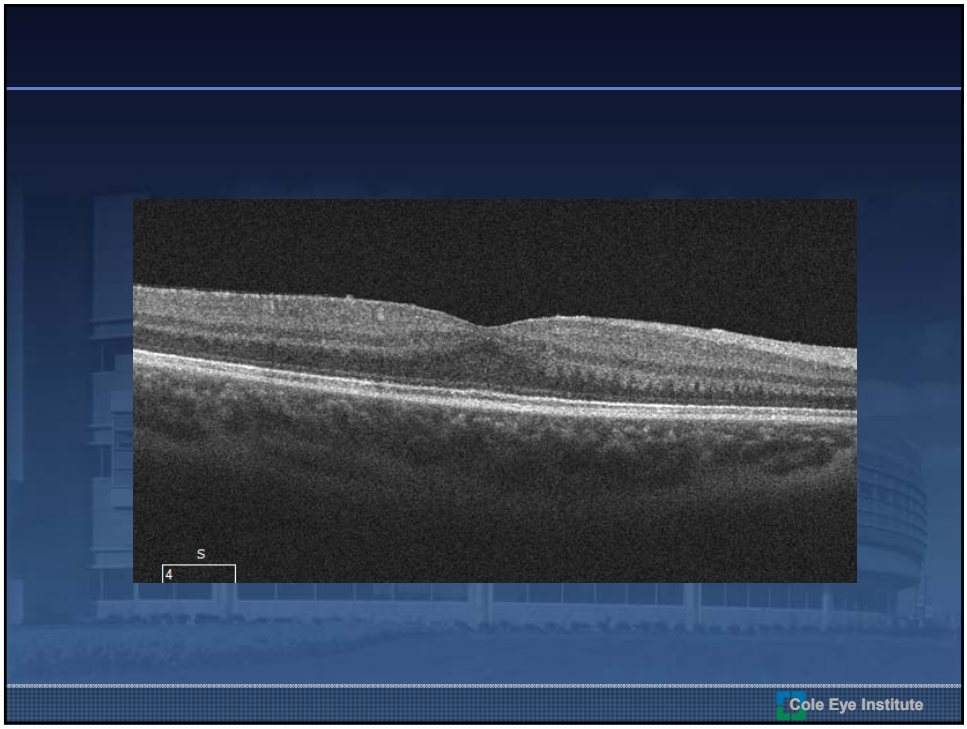
What about Uveitis?

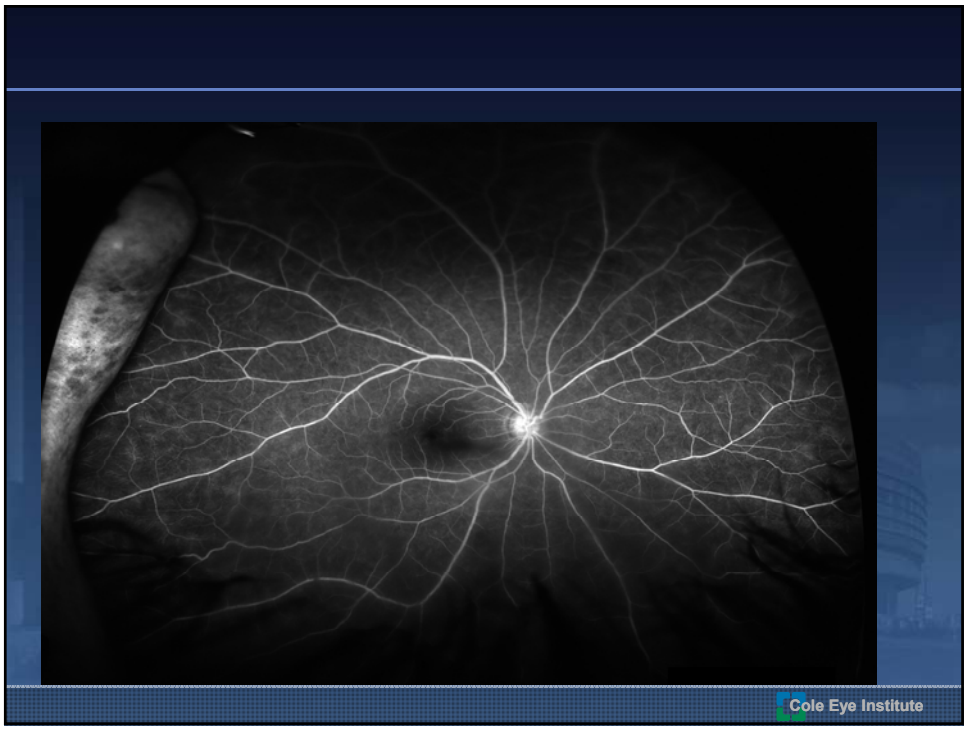
- Inflammatory disease may be an ideal disease
- Consequences of inflammation are often beyond the posterior pole
- Decisions on therapy sometimes are made on incomplete information
- Especially true for retinal vasculitis, pars planitis

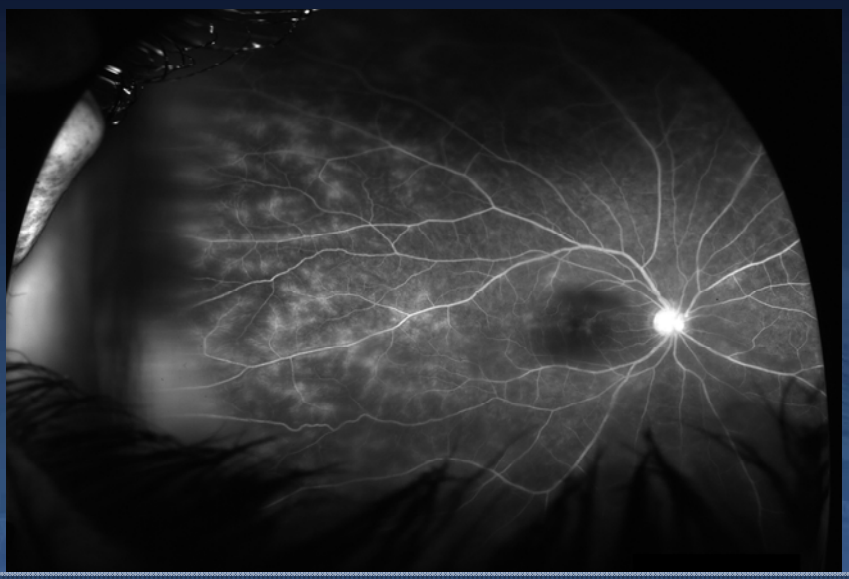
Cole Eye Institute

- 16 year old girl presents with decreased vision right eye greater than left eye for 12 months
- Diagnosed with uveitis
- Treated with low dose methotrexate
- CME is gone, OCT is normal
- Why can't she see
- Few cells in the back of the eye

Cole Eye Institute


S
4
Cole Eye Institute


Cole Eye Institute



Wide field angiography

- Identification of leakage – sign of activity

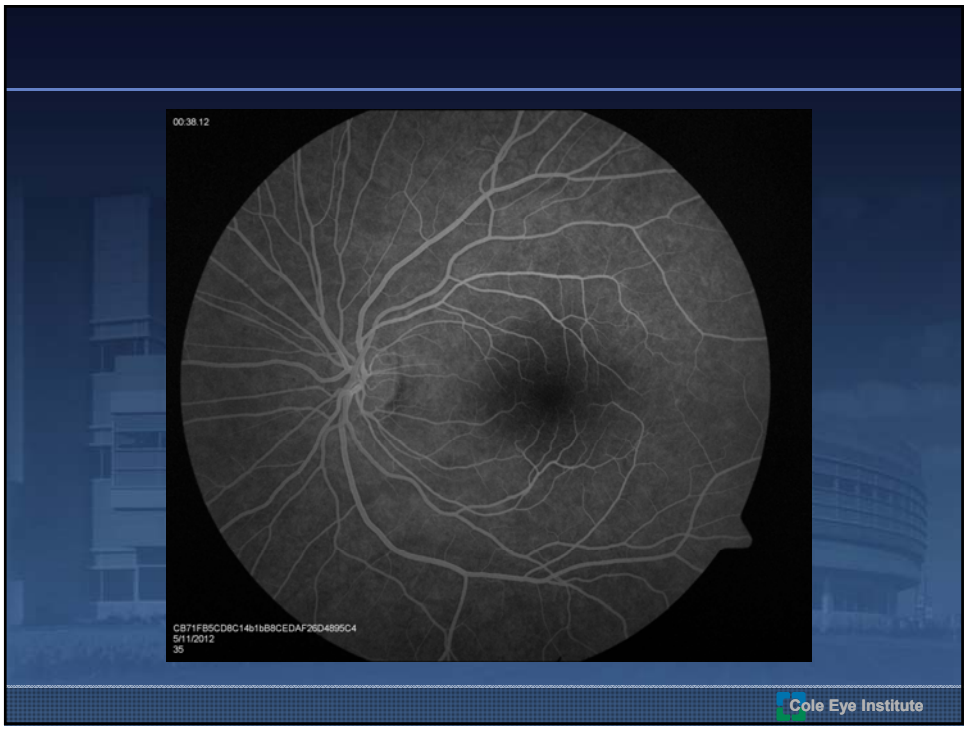
Case Presentation

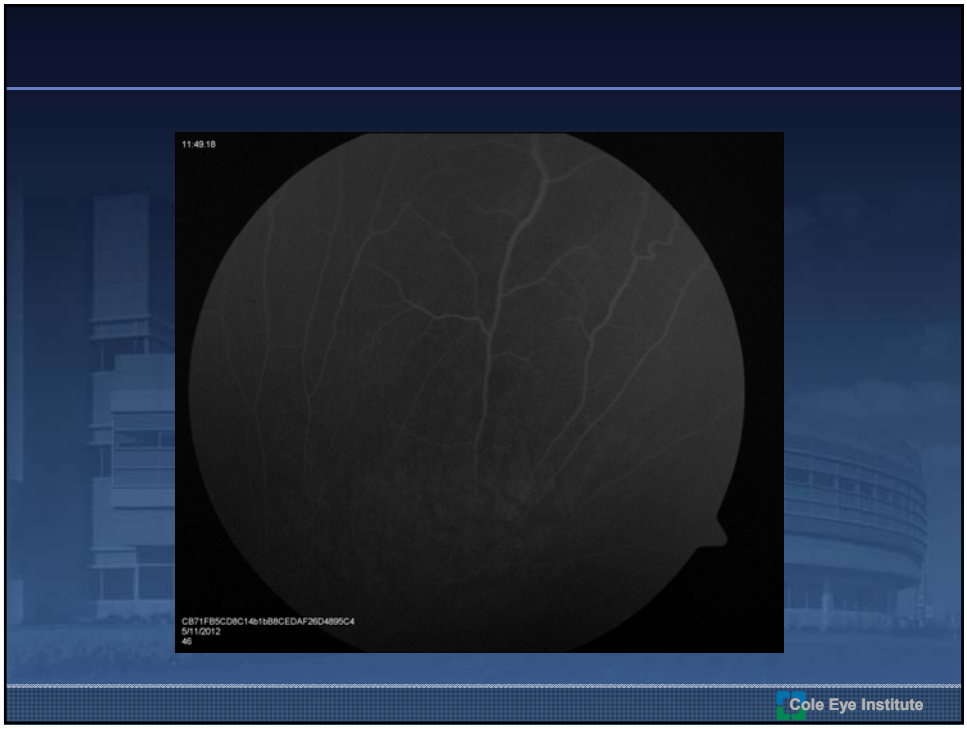
- 29 year old female
- SLE
- Presents with complaints of recurrent vision changes OS
- Loses vision then comes back
- 20/20 OU

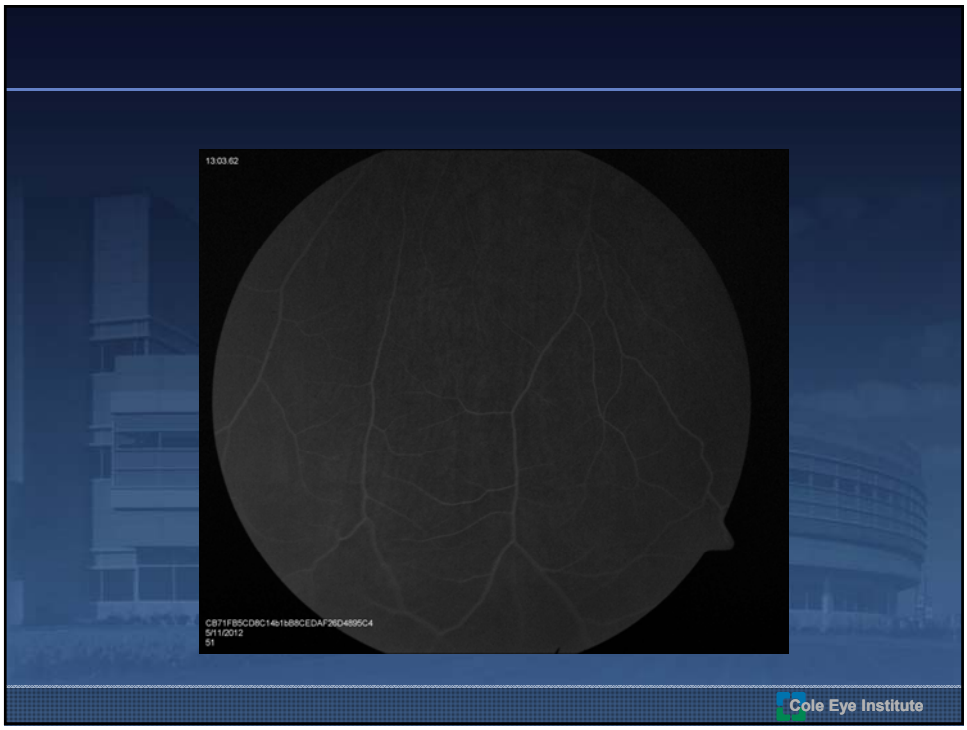
Cole Eye Institute

Cole Eye Institute


CB71FB5CD8C14b1bB8CEDAF26D4895C4
5/11/2012
17


00:38.12
CB71FB5CD8C14b1bB8CEDAF26D4895C4
5/11/2012
35
Cole Eye Institute


11:49:18
CB71FB5CD8C14b1b88CEDAF26D4895C4
5/11/2012
46
Cole Eye Institute


13:03:62
CB71FB5CD8C14b1b88CEDAF26D4895C4
5/11/2012
51
Cole Eye Institute

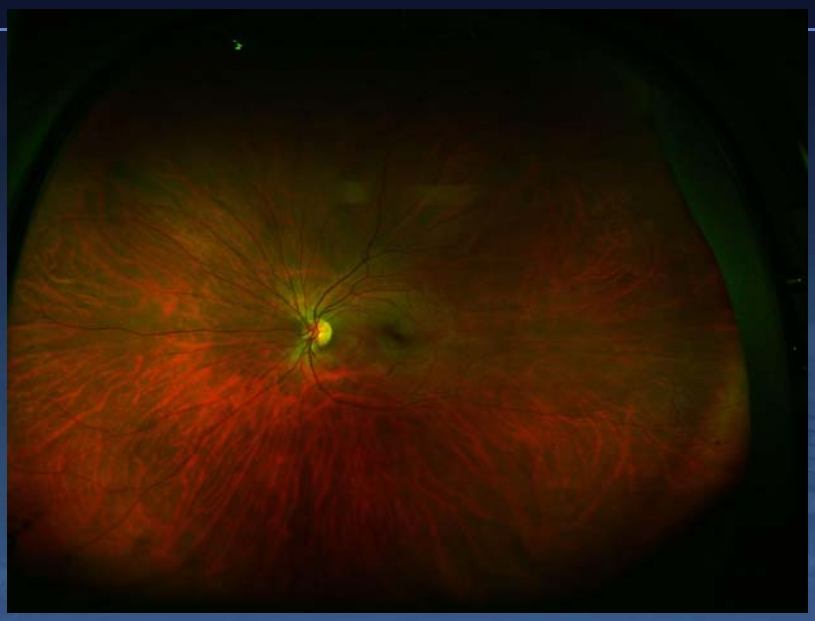
Case Presentation

- FA quiet
- But symptomatic – increase immunosuppression

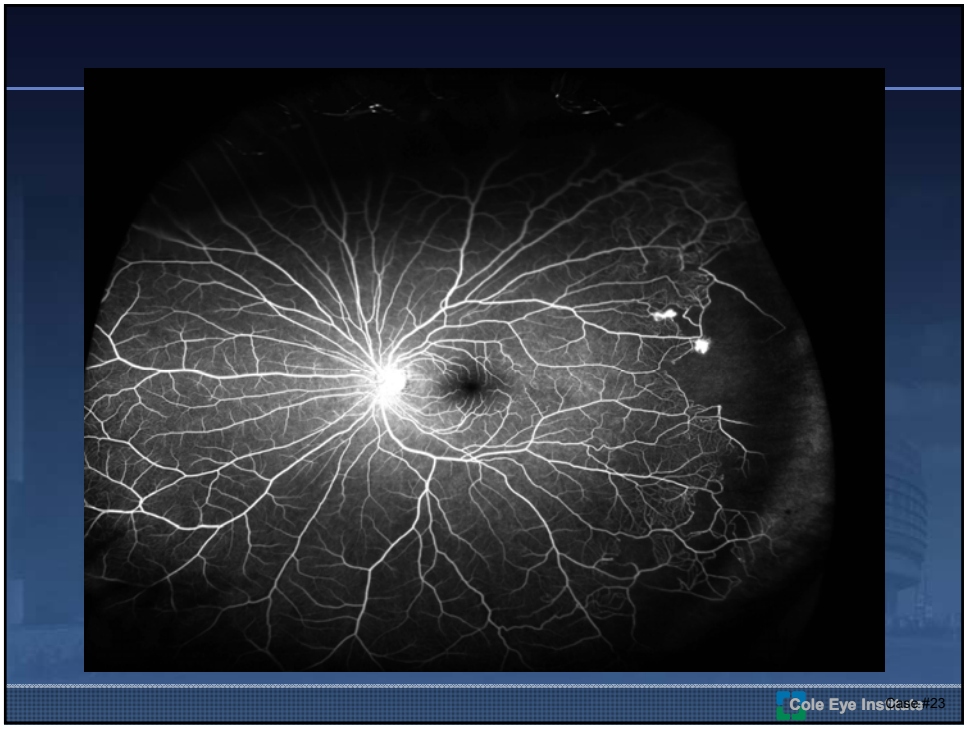
Case Presentation

- Over next few months – a few episodes of vision loss OS
- Quiet exams
- Neg FA
- Then…

Cole Eye Institute



Cole Eye Institute Case #23


Cole Eye Institute
Case #23


Cole Eye Institute
Case #23

Case Discussion

- Next step?

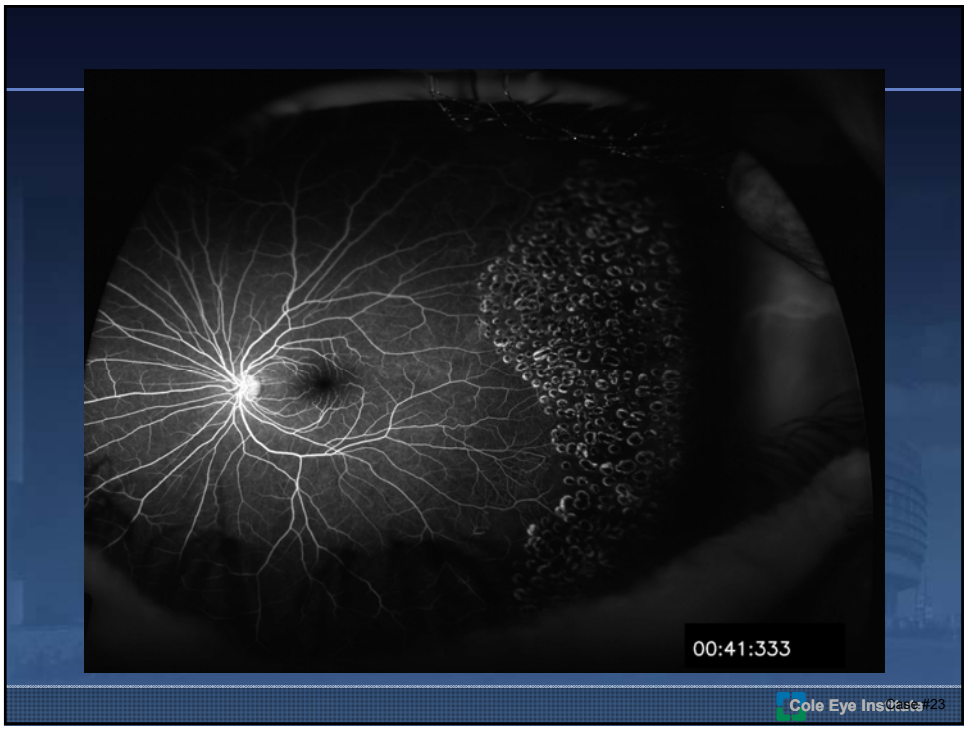

00:33:207
Cole Eye Institute
Case #23

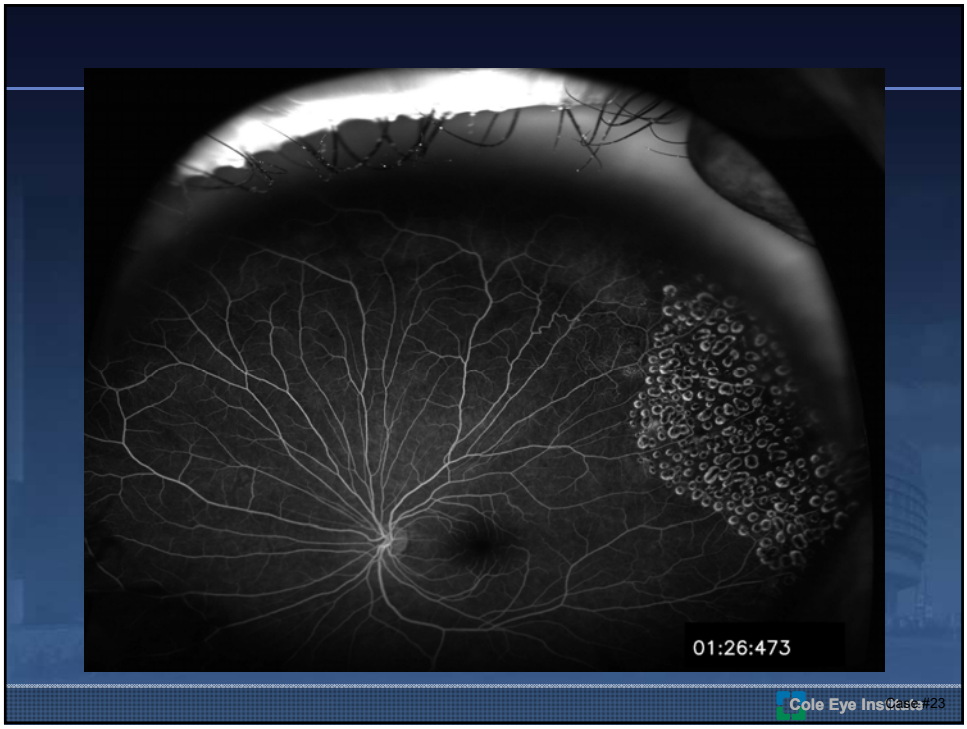

06:11:586
Cole Eye Institute
Case #23

Case Presentation

- Next step
- Yell at the fellow

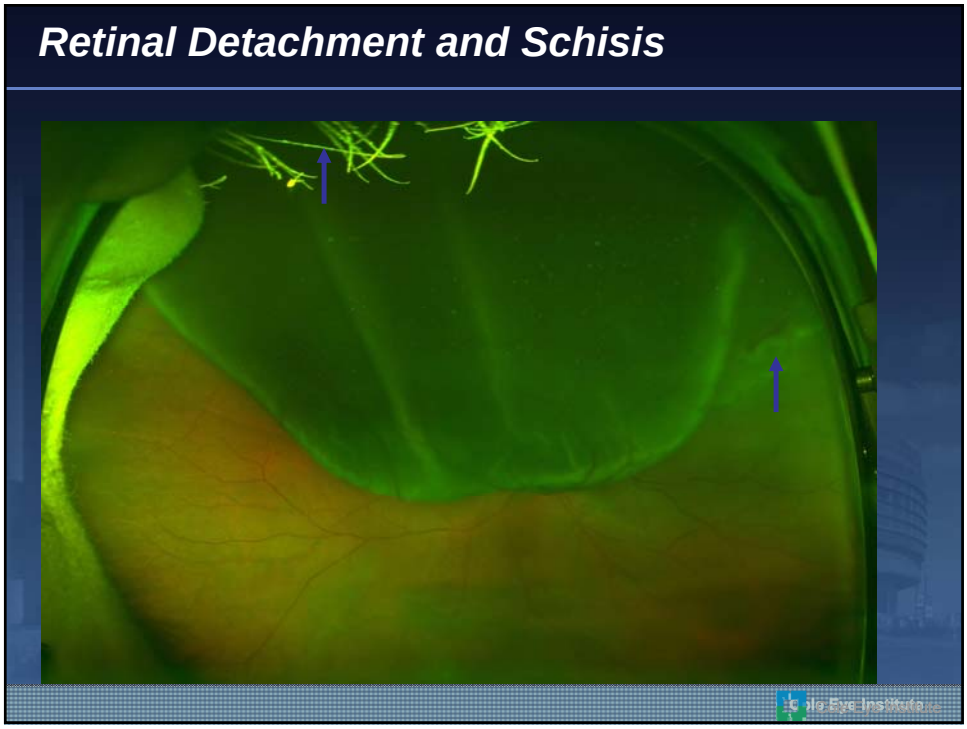

01:01:288
Cole Eye Institute
Case #23

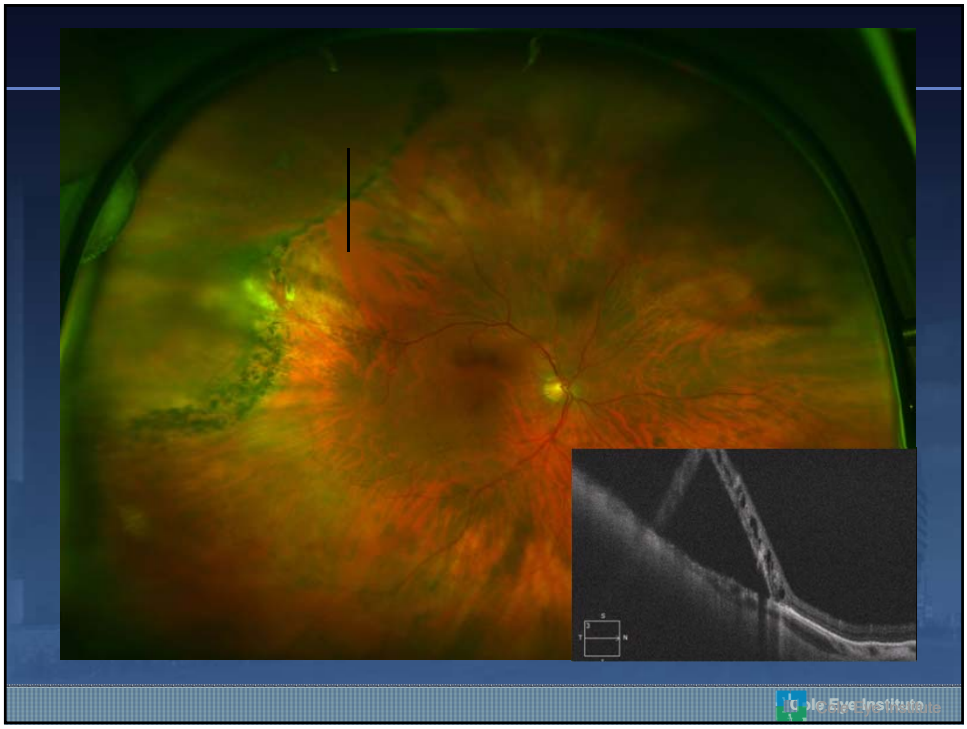

00:41:333
Cole Eye Institute
Case #23

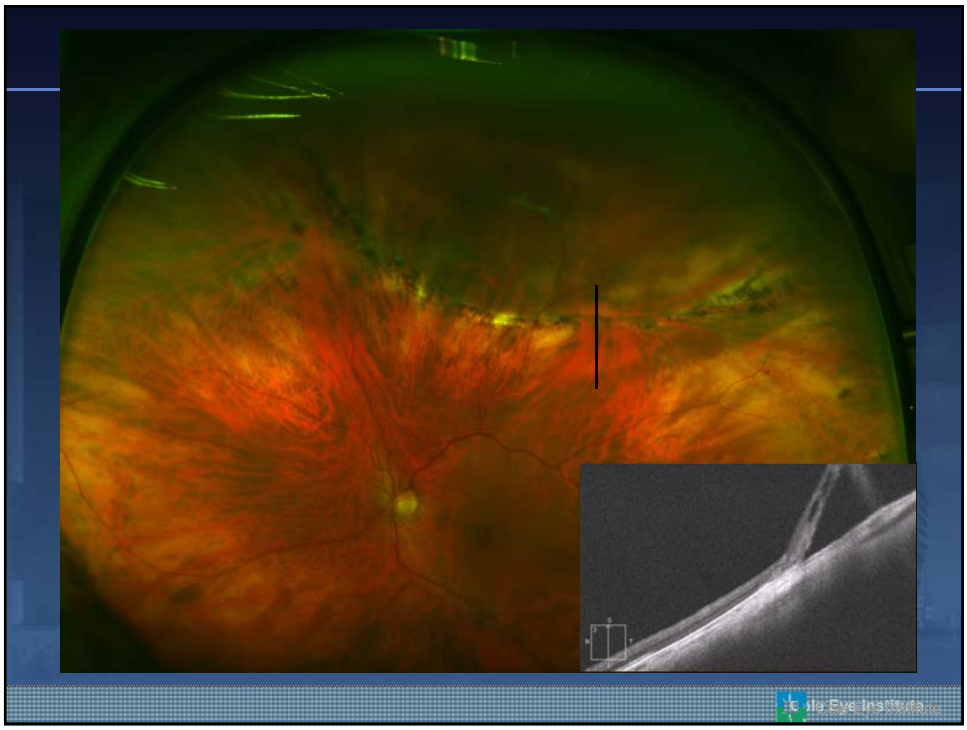

01:26:473
Cole Eye Institute
Case #23


01:39:694
Cole Eye Institute
Case #23

Retinal Detachment and Schisis







What's the evidence?

- Campbell JP, Leder HA, Sepah YJ et al Am J Ophthal 2012
  - Disease activity in widefield + exam 63% vs. standard imaging + exam 51%
  - Disease management changed widefield 48% vs. standard 16%
- Campbell JP, Leder HA, Sepah YJ et al J Ophthalmic Inflamm Infect
  - Disease activity in retinal vasculitis with wide field 68% vs. 45% standard angiogram

Cole Eye Institute

Cleveland Clinic Experience

- IRB approved retrospective review
- Patients evaluated using Optos 200Tx between May 2012 and December 2013
- Wide field images were compared to simulated 50 degree image (high magnification)
- Designed and implement a custom Imaging analysis software to quantitate leakage

Cole Eye Institute

Peripheral findings on Wide Field Angiography

- 254 patients x 2 eyes = 508 eyes
- Non-perfusion:14% of eyes
- Leakage: 47.4% of eyes
- Peripheral Lesions: 7.7% of eyes
- Neovascularization: 3.7% of eyes
- Peripheral exudates: 1.5% of eyes

Cole Eye Institute

Fluorescein Leakage

- 1053 eye images reviewed
- 600 eyes identified with fluorescein leakage
- Central leakage only: 138 eyes
- Central and Peripheral Leakage: 63 eyes
- Diffuse leakage: 221 eyes
- Peripheral leakage: 188 eyes

Cole Eye Institute

Impact of Widefield Angiography

- Without it – miss 27% of eyes with peripheral leakage only
- Severity:
  - Central and peripheral leakage now seen
  - Diffuse leakage more accurately identified
- If limit analysis to just findings in periphery only:
  - Impacted decision on therapy: 27% of patients
  - Used to rule out inflammation: 19% of patients

Cole Eye Institute

Fluorescein Leakage and Inflammatory Activity

- 600 eye images with leakage
- 567 eye images with leakage were deemed clinically active
- 13 eyes were found clinically active of 408 eyes without leakage

Cole Eye Institute

Sensitivity and Specificity

FA Leakage	Active Yes	Active No
Yes	567	33
No	13	395

Sensitivity: 97%
Specificity: 92%
Positive Predicative Value: 94.5%
Negative Predicative Value: 96.9%

Cole Eye Institute

Comparison of Widefield to Clinical Activity

	Leakage on Widefield	No Leakage on Widefield
Mean AC Cell	.22*	.12
Mean Vitreous Haze	.54*	.15

* P < .005

Cole Eye Institute

Impact of resolution of leakage?

Cole Eye Institute

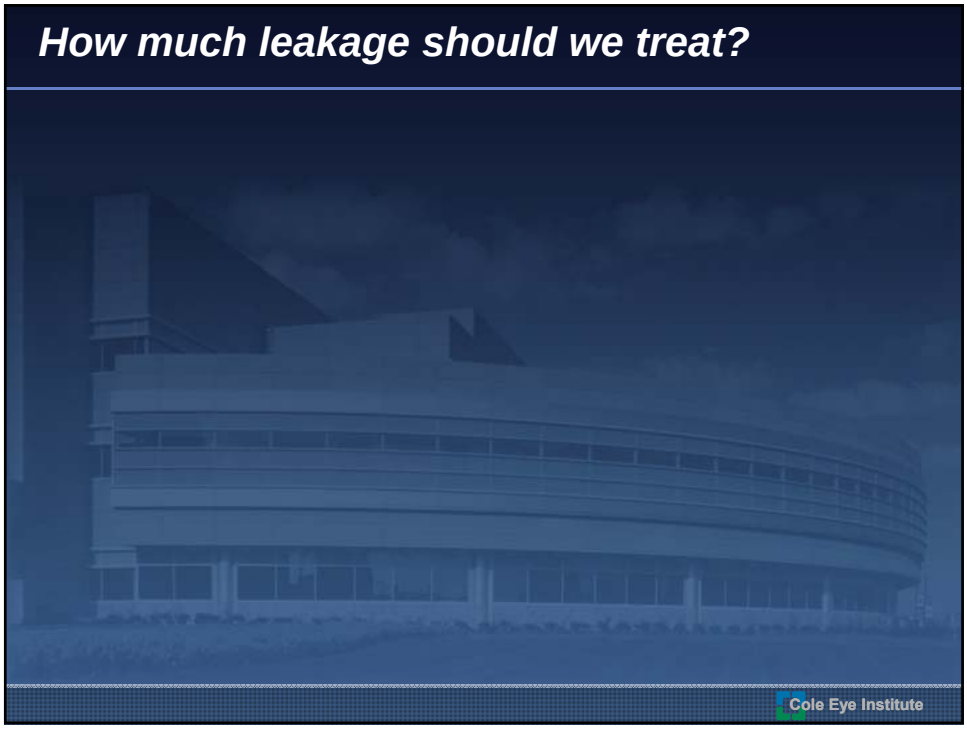
Vision Change in eyes with Baseline Leakage in Retisert Clinical Trials

	No Leakage at 24 Months	
Level	**Change**	**P-value**
Overall	-0.12 (-0.18,-0.07)	< 0.001
Retisert Implant Eyes	-0.17 (-0.23,-0.11)	< 0.001
Fellow Eyes	-0.05 (-0.15,0.05)	0.36
Standard of Care eyes	-0.19 (-0.39,0.00)	0.054

Srivastava et al ARVO 2012

Cole Eye Institute

How much leakage should we treat?



Cole Eye Institute

After Ozurdex, 20/40 (2 months later 20/20)

Cole Eye Institute

What about this eye? 20/20

Cole Eye Institute

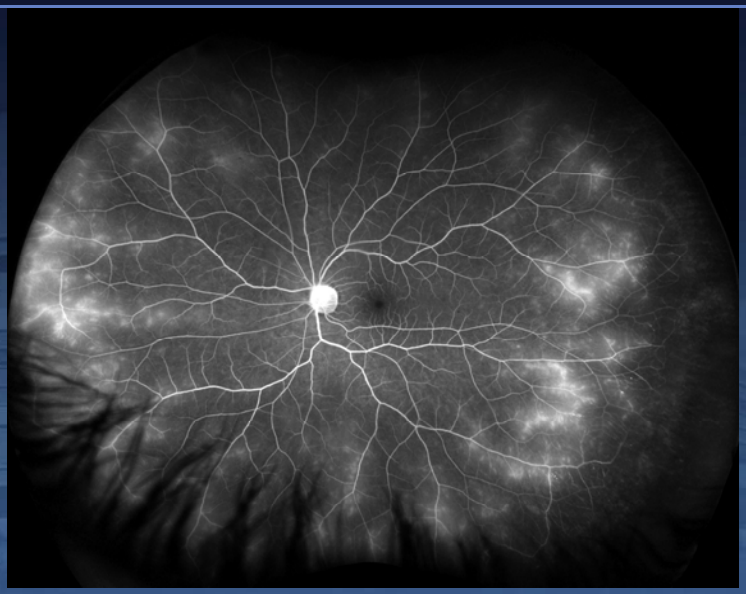
IBD patient – 20/20 OU

Cole Eye Institute

IBD patient 20/20 OU – Treat?

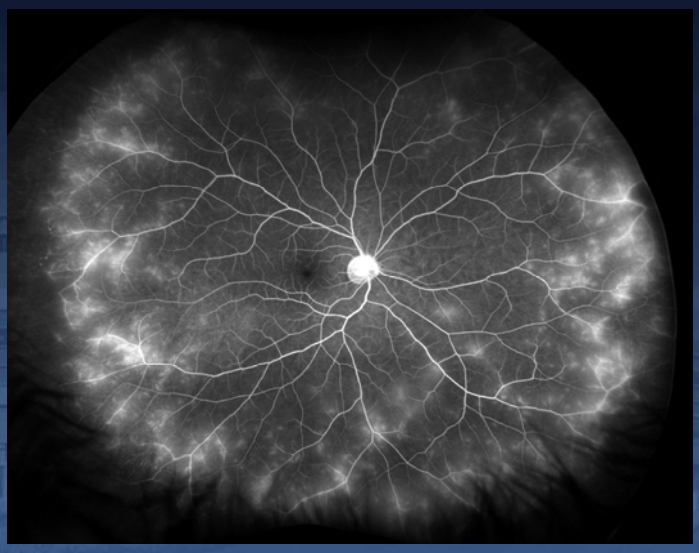
Cole Eye Institute

6 months later



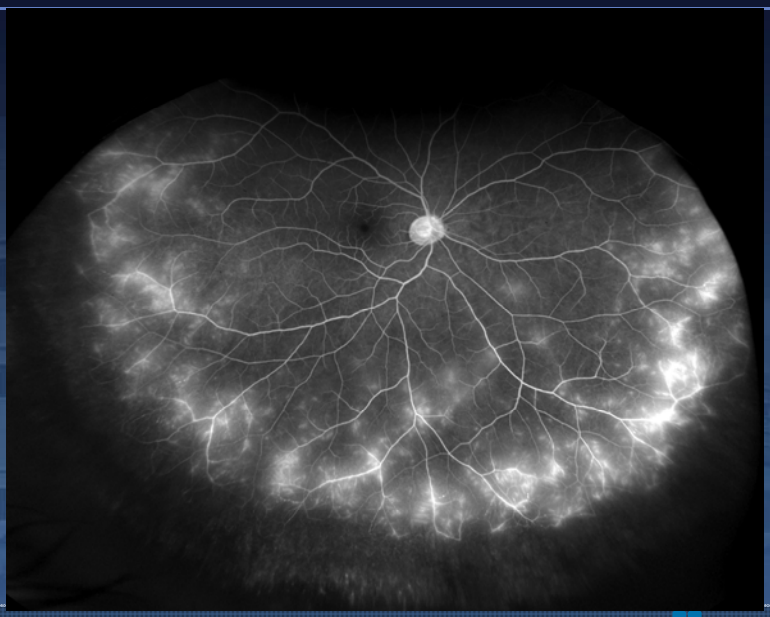
Cole Eye Institute

6 months later



Cole Eye Institute

6 months later – still 20/20 Treat?



Cole Eye Institute

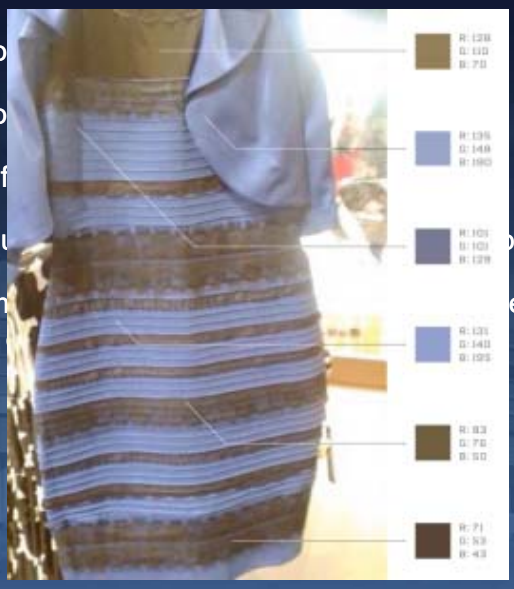
Widefield Angiography

- Can identify consequences of inflammation not seen previously
- May impact treatment decisions
- Which one should I buy?
- Both systems are great and have their own advantages and disadvantages
- Both now perform wide field ICG

Cole Eye Institute

But, Imaging can only enhance

- Can't rep
- Can't rep
- Imaging f
- Imaging u pretation
- Improven e, but complex



Cole Eye Institute

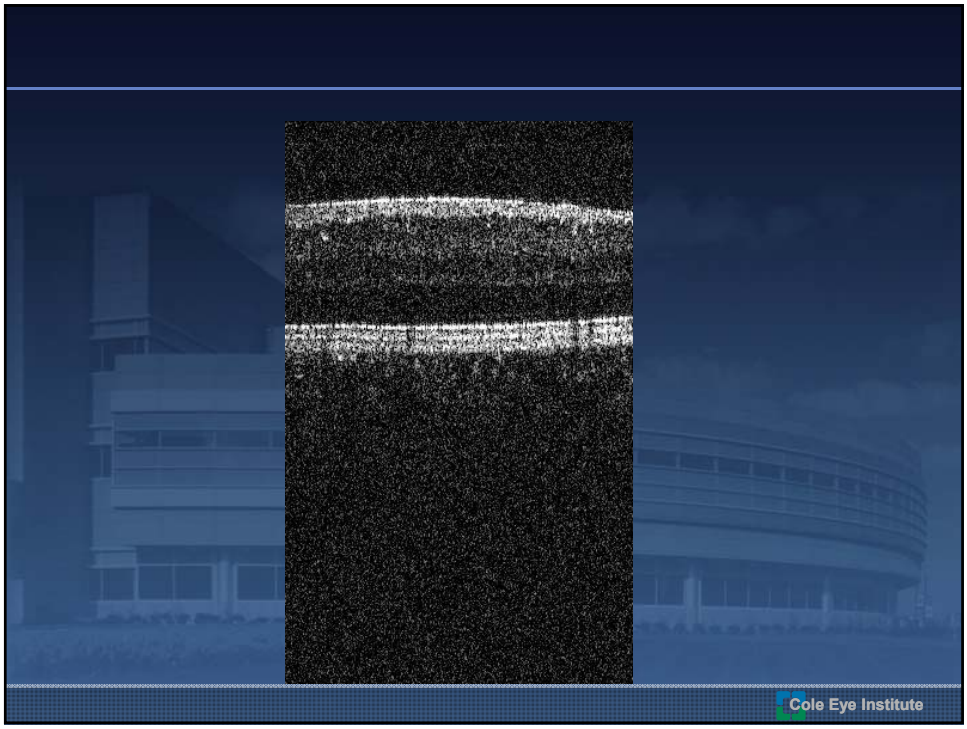
OCT Angiography

- Uses motion of red blood cells against static background to identify retinal vessels
- Requires high speed OCT, motion correction, lots of math and enface imaging
- No leakage, but structural components now visible into choroid

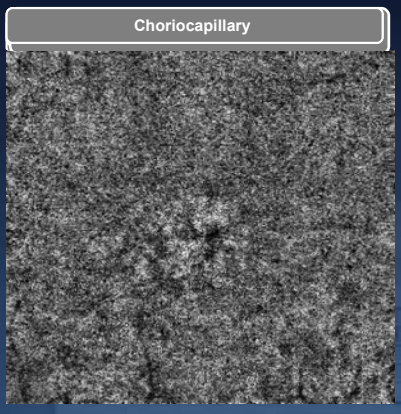
Cole Eye Institute

www.youtube.com/watch?v=U6Ubp7ILIaM

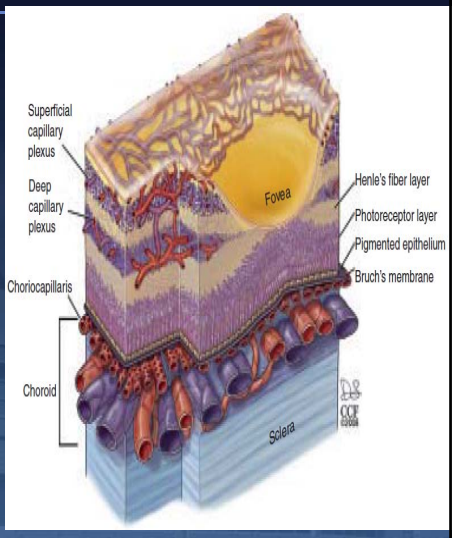
Cole Eye Institute

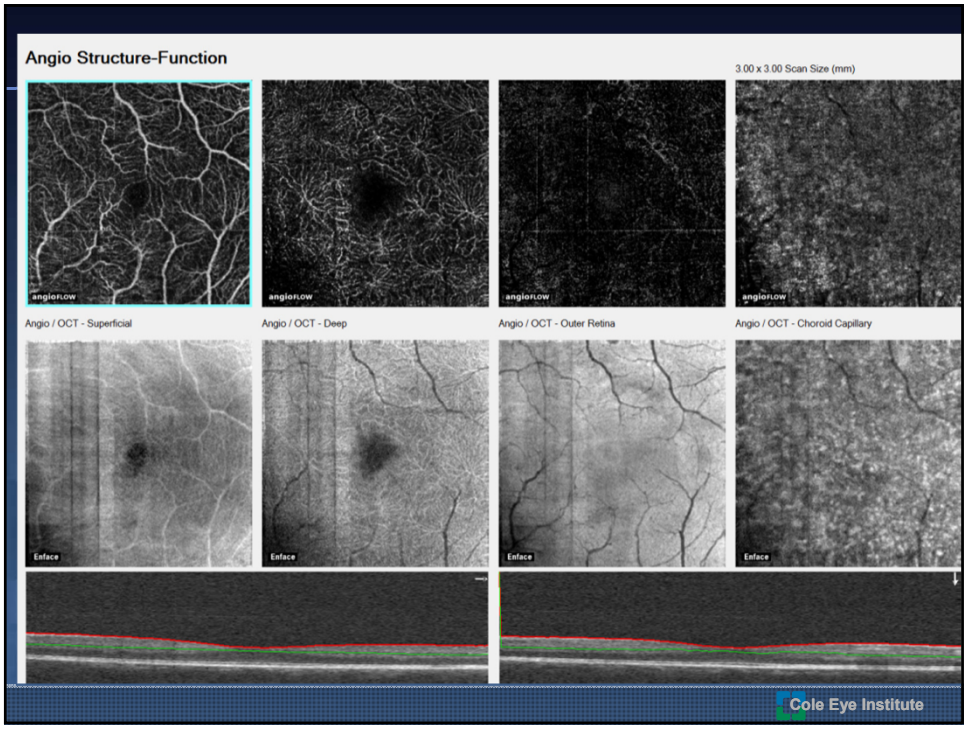


En Face Visualization



En Face Visualization of layers based on retinal anatomy





Potential Advantages

- Advantages
  - No injection
  - High magnification of macular flow characteristics
  - With Enface technology – can analyze flow anatomy in a specific layer
- Disadvantage
  - No information about leakage
  - Limited quantitative tools (for now)
  - Subject to imaging artifacts

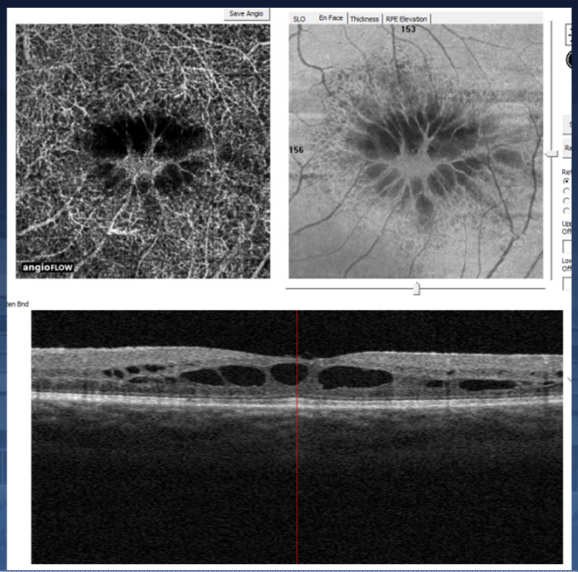
Cole Eye Institute

OCTA in Retinal Diseases

- AMD
- DME
- PDR
- RVO
- CME

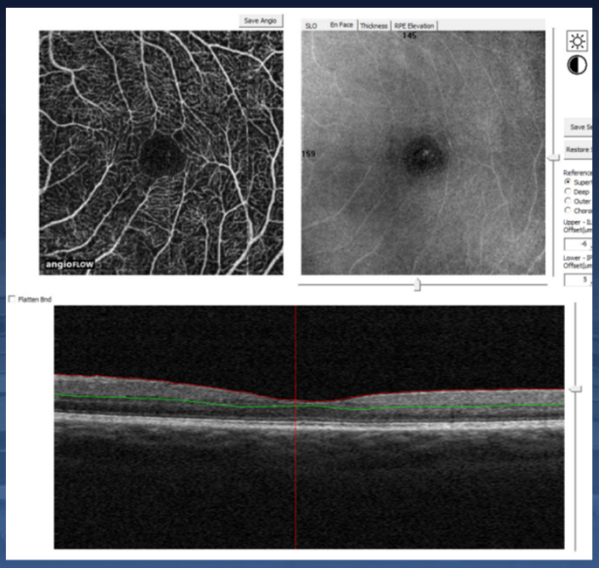
Cole Eye Institute

OCTA in Uveitis Patient with CME



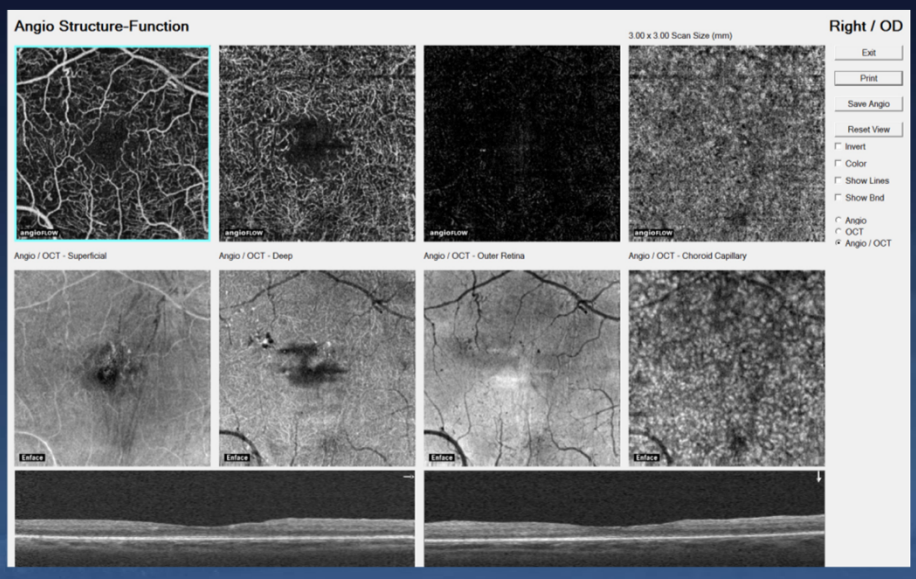
Cole Eye Institute

OCTA in Uveitis Patient with CME



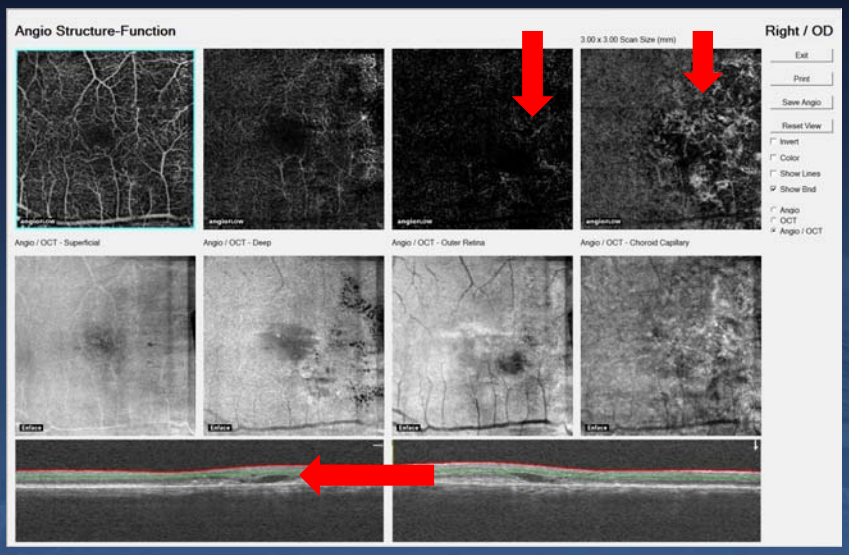
Cole Eye Institute

OCTA in Diabetic Retinopathy



Cole Eye Institute

OCTA – CNVM Formation in Uveitis



Cole Eye Institute

Patients

- 65 people with uveitis were enrolled
- 103 imaging sessions
- 86% of patients had posterior uveitis or panuveitis
- 66.7% were female

Cole Eye Institute

Choroidal Neovascularization

Cole Eye Institute

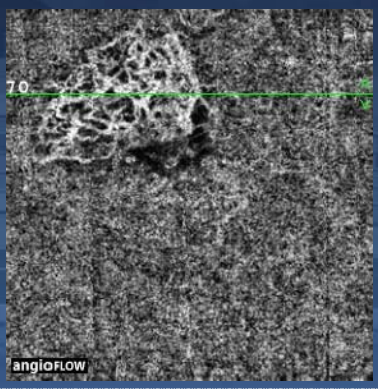
Patients with CNV

- 8 patients with PIC
- 6 patients with MCP
- 1 patient with AZOOR
- 1 patient with VKH
- 15/16 had been previously treated with bevacizumab for choroidal neovascularization

Cole Eye Institute

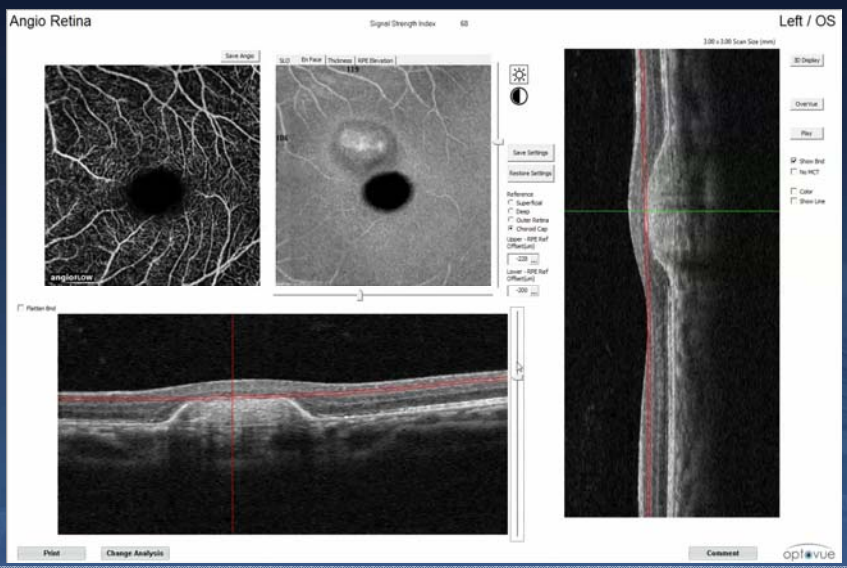
Findings in patients with inflammatory CNV

- In the 16 patients suspected of having CNV, OCTA identified CNV in 15 patients.
- A network of hyperreflective vessels seen at the level of the choriocapillaris, sometimes extending into the outer retina.



Cole Eye Institute

Video of Native Screen



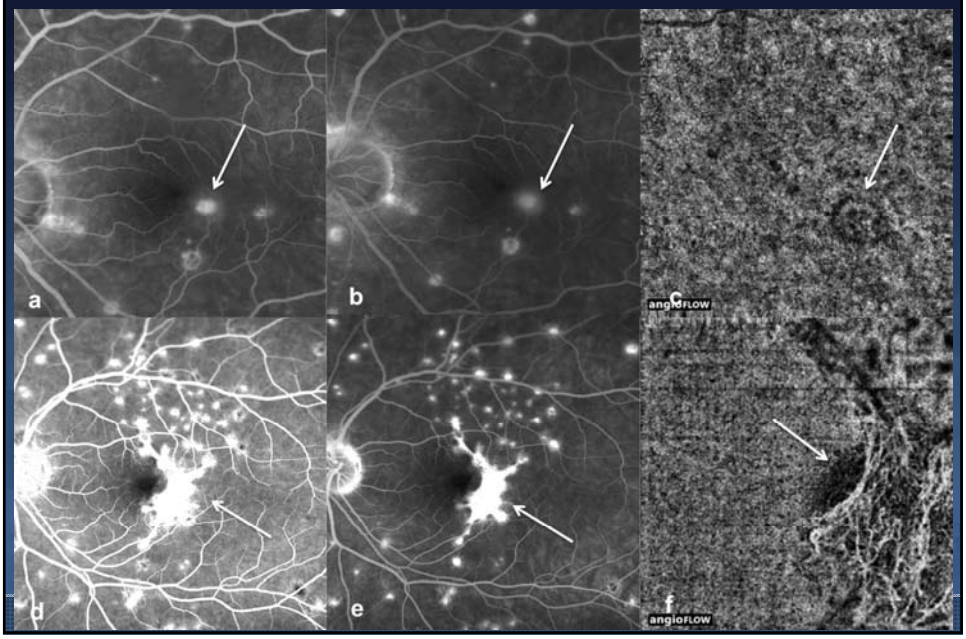
Cole Eye Institute

OCTA vs. FA

- Corresponding FA was available for 8 patients.
  - In 4 of 8 patients FA suggested presence of CNV
  - In 4 of the 8 patients it was difficult to distinguish leakage from staining of inflammatory lesions.
  - CNV was identified on OCTA in all 8 patients

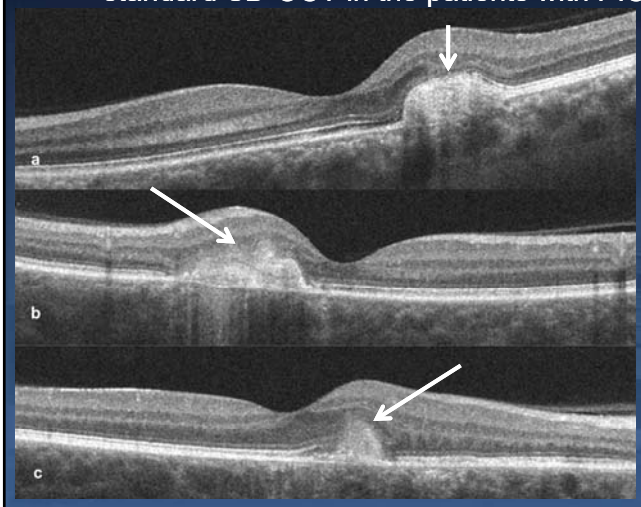
Cole Eye Institute

FA vs. OCTA



SD-OCT Findings in PIC/MCP Patients

- Three different types of outer retinal lesions were seen on standard SD-OCT in the patients with PIC/MCP/VKH



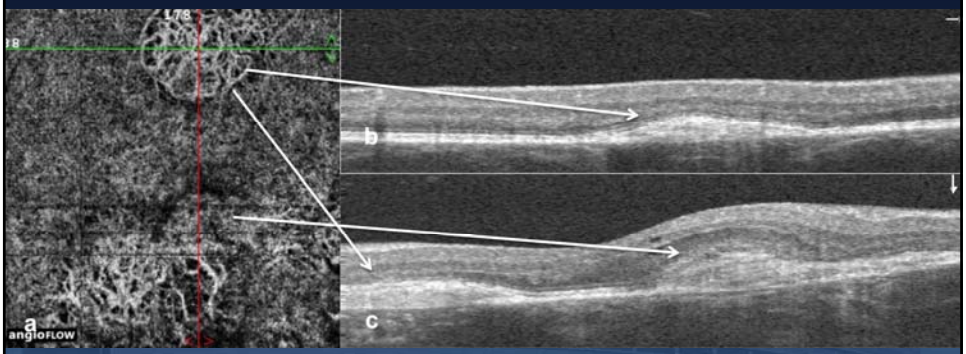
OCTA revealed mature vascular formations consistent with a CNV.

The vessels of the CNV tended to be less distinct.

CNV formation in only some eyes

Cole Eye Institute

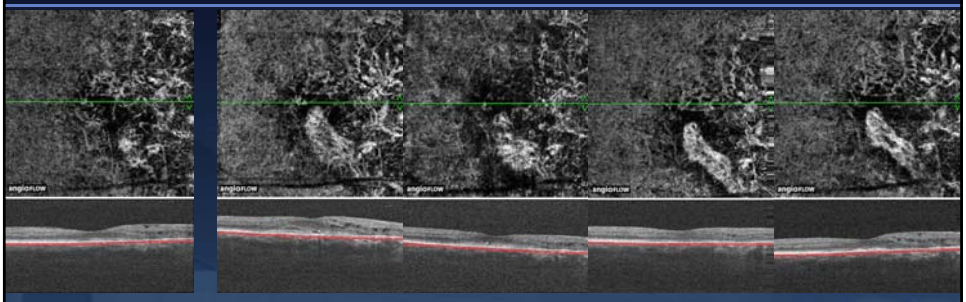
OCTA vs OCT



- Multiple PEDs and CNVMs seen on OCTA
  - In regions with concern for activity the OCTA showed less distinct vessels while there was stability of vessels in the regions that did not appear clinically active.

Cole Eye Institute

Change in CNV Over Time



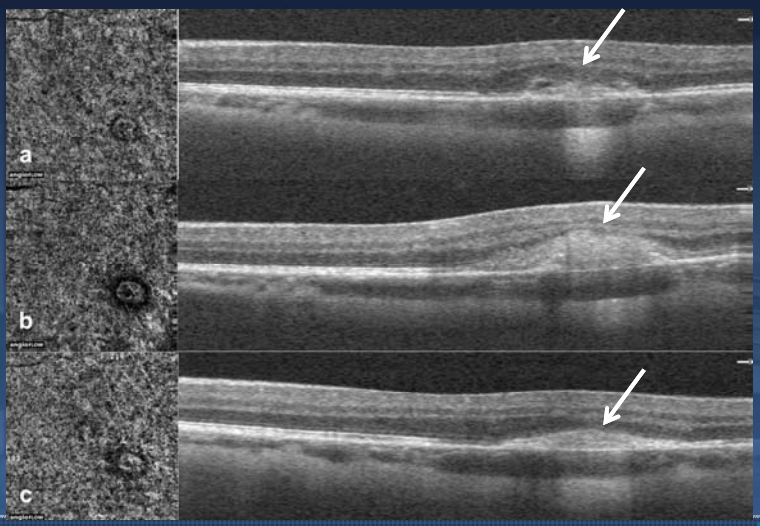
- Initially intraretinal fluid on OCT but no obvious CNV seen clinically or on FA. OCTA shows evidence of early CNV formation.
- OCTA images at subsequent 4 week to 7 week visits after treatment with bevacizumab
- Note the progressive change of the CNV, with small, finer vessel apparent in the earlier images with larger, more distinct vessels in the later images as she is treated with bevacizumab.

Levison et al. OCT Angiography Identification of Choroidal Neovascularization Secondary to Acute Zonal Occult Outer Retinopathy. OSLI Retina. (In Press)

Cole Eye Institute

OCTA Change Over Time

- 35 year old with MCP



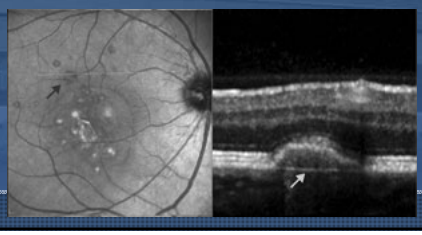
s/p triamciniolone

s/p bevacizumab

Cole Eye Institute

CNV in PIC

- Rate of CNV in PIC is up to 77%
- Channa et al previously published a case series describing the OCT findings in patients with PIC thought to have isolated inflammatory lesions without underlying CNV.
  - Lesions had elevation of the retinal pigment epithelium and loss of photoreceptors
  - Our study may suggest that those patients did in fact have underlying CNV that could not be appreciated on FA.



Channa et al. Characterization of macular lesions in punctate inner choroidopathy with spectral domain optical coherence tomography. J Ophthalmic Inflamm Infect 2012;2(3):113-20.

Cole Eye Institute

Retinal Vasculitis

Cole Eye Institute

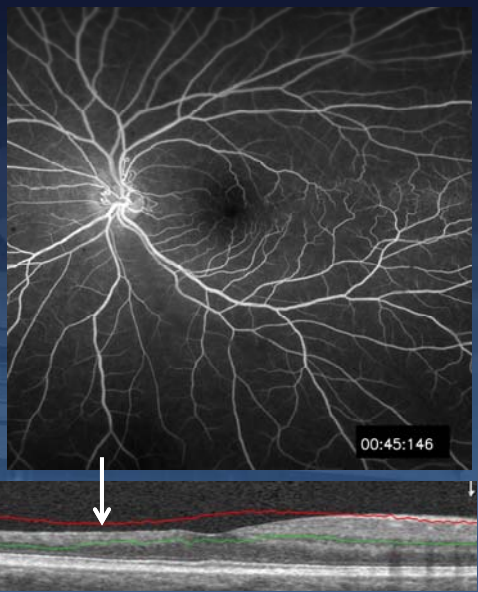
Retinal Vasculitis Patients

- 19 total patients
  - 9 patients with Susac Syndrome
  - 4 with Behcets' Syndrome
  - 3 with idiopathic retinal vasculitis
  - 1 with retinal vasculitis associated with PMR
  - 1 with retinal vasculitis associated with anti-synthetase syndrome
  - 1 with intermediate uveitis

Cole Eye Institute

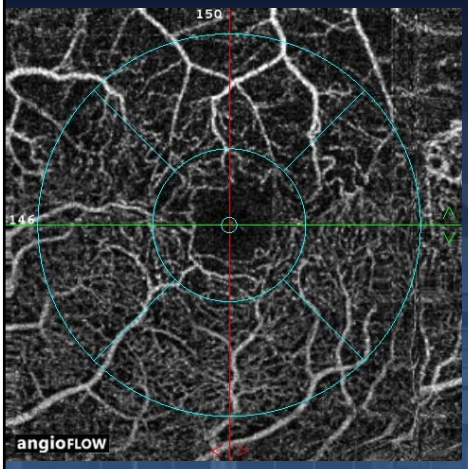
Vasculitis with Obvious RAO on OCT

- 44 year old female with Susac syndrome who has had a BRAO in the left eye
- FA shows temporal microvascular remottling but normal perfusion
- OCT shows thinning in region of RAO

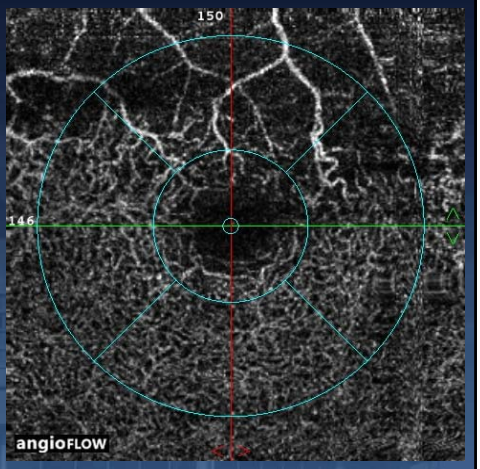


Cole Eye Institute

Superficial/Deep Capillary Plexus



Superficial

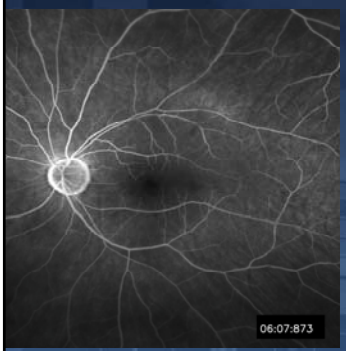


Deep

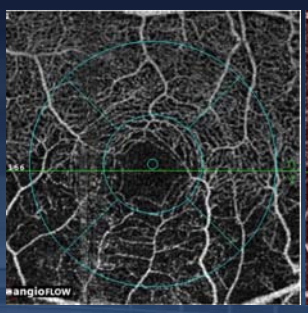
Cole Eye Institute

Retinal Vasculitis

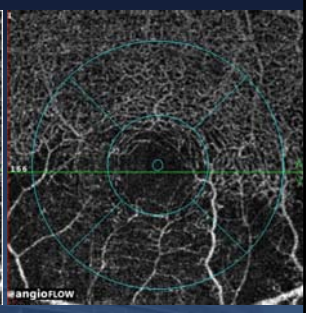
- 50 year old female with Susac Syndrome



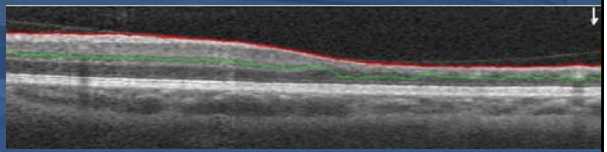
FA appears normal



Superficial



Deep



Cole Eye Institute

Vasculitis without thinning on follow up OCT

- 48 year old male with Behcets'

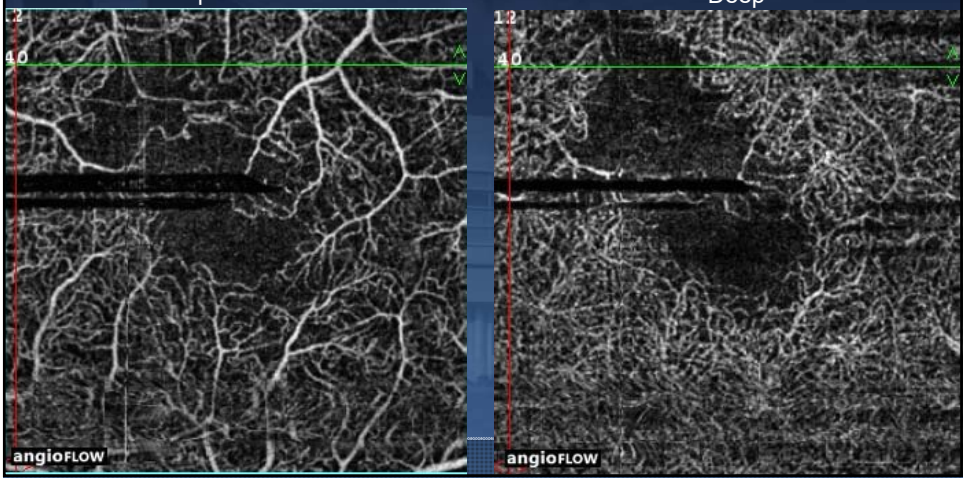
CF vision | 20/30 with scotoma

Cole Eye Institute

Vasculitis without obvious RAO on final OCT

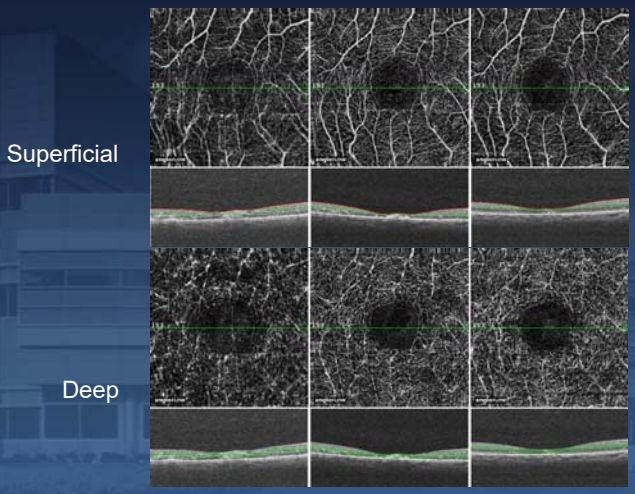
- At follow up VA 20/30 and FA with normal appearing perfusion

Superficial | Deep



Vasculitis without change to perfusion

- 32 yo with retinal vasculitis from anti-synthetase syndrome



Cole Eye Institute

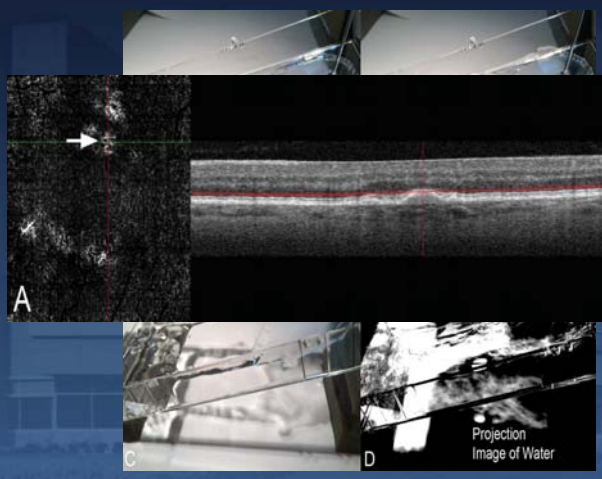
Limitations

- Small number of patients enrolled
- No control
- Not masked
- Many do not have corresponding FA, none have ICG
- Our analysis of OCTA at this point
  - Qualitative
  - Rudimentary
  - ? Artifact

Cole Eye Institute

Artifacts in OCTA

Artifact 1: PROJECTION ARTIFACT

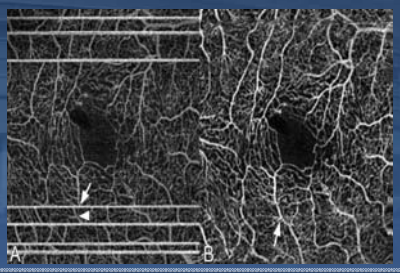


Light that passes through moving blood encounters tissue below blood vessels. If it hits bumps in the RPE, the RPE will seem to have the pattern of overlying retinal vessels

Artifact 2: MOTION ARTIFACT

AXIAL MOTION: pulsation of retina and choroid due to caridac cycle

TRANSVERSE MOTION: from saccades

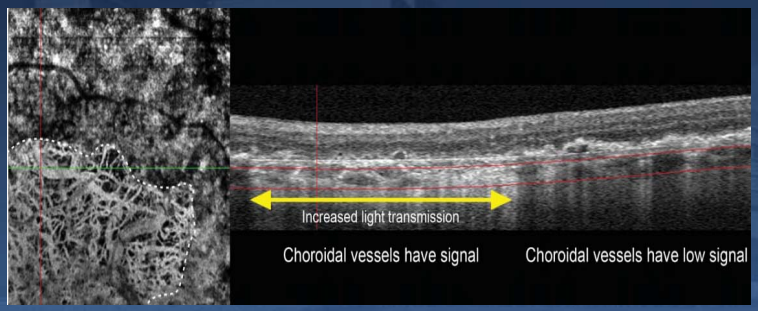


Cole Eye Institute

Artifact 3: THRESHOLDING

OCTa only processes structures with a strong flow signal ➔ the choroid has a low signal if the RPE and CC are intact

In areas of atrophy of RPE or CC, choridal vessels will seem to have flow



Cole Eye Institute

How about the OR?

Cole Eye Institute

Intraoperative OCT (iOCT): Premise

- High resolution anatomic information is a natural complement to the operating room theater.
- Visualization of the acute impact of surgical maneuvers on the ultrastructure of the eye.
- Provides immediate feedback and guidance to the surgeon.
- Allows assessment of surgical goal completion.
- In essence – with greater visualization, more information, can we become even better surgeons?

Cole Eye Institute

Why Perform iOCT?

- Would you like histology-level visualization of tissue during surgery?
- Would you like immediate feedback to know if surgical goals are accomplished?
  - Have I removed the membrane?
  - Is the retina attached?
  - Is the traction relieved?

Cole Eye Institute

iOCT: How to use it currently?

- Handheld SDOCT Probes
  - Portable
  - Allows for versatile imaging in multiple situations
  - Limited scan repeatability
  - Lack of eye tracking
  - User dependent
  - Bioptigen, Optovue

Cole Eye Institute

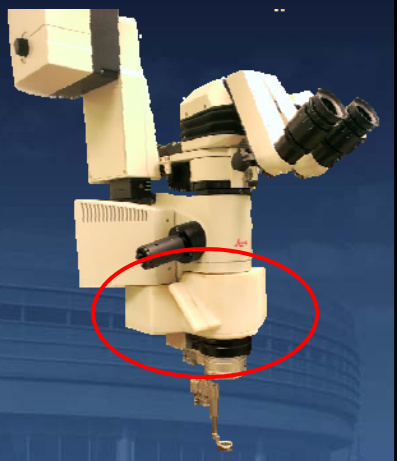
iOCT: How to use it currently?

- Microscope mounted portable system

Cole Eye Institute

iOCT: Microscope Integrated OCT Systems

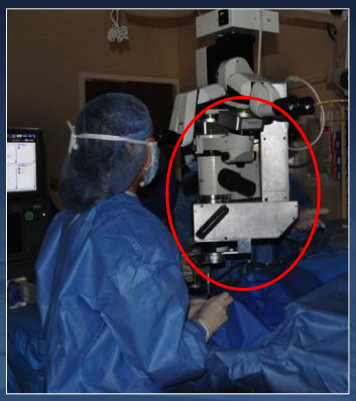
- Current Systems:
  - Cole Eye Institute/Cleveland Clinic
  - Duke University
  - Carl Zeiss Meditec
    - External Cirrus System
    - Rescan 700
  - Haag-Streit *i*OCT and Moller-Wedel System (outside US)
  - Bioptigen/Leica



Cole Eye Institute

iOCT: Microscope Integrated OCT Systems

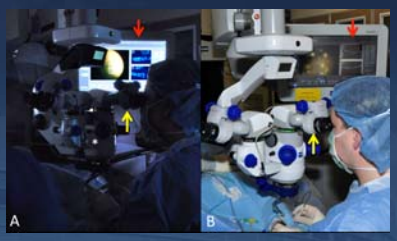
- Current Systems:
  - Cole Eye Institute/Cleveland Clinic
  - Duke University
  - Carl Zeiss Meditec
    - External Cirrus System
    - Rescan 700
  - Haag-Streit *i*OCT and Moller-Wedel System
  - Bioptigen/Leica



Cole Eye Institute

iOCT: Microscope Integrated OCT Systems

- Current Systems:
  - Cole Eye Institute/Cleveland Clinic
  - Duke University
  - Carl Zeiss Meditec
    - External Cirrus System
    - Rescan 700
  - Haag-Streit *i*OCT and Moller-Wedel System
  - Bioptigen/Leica



Ehlers JP, Kaiser PK, Srivastava SK, BJO 2014

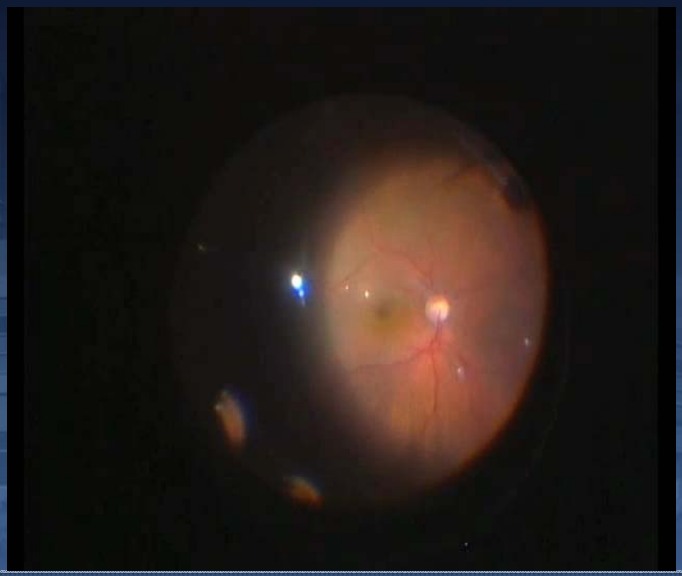
Cole Eye Institute

Before I buy a system, is it useful?

- What information can be gained?
- How does it impact patient care?
- Reality – in times of cost containment – we have to prove why its worth the cost and time

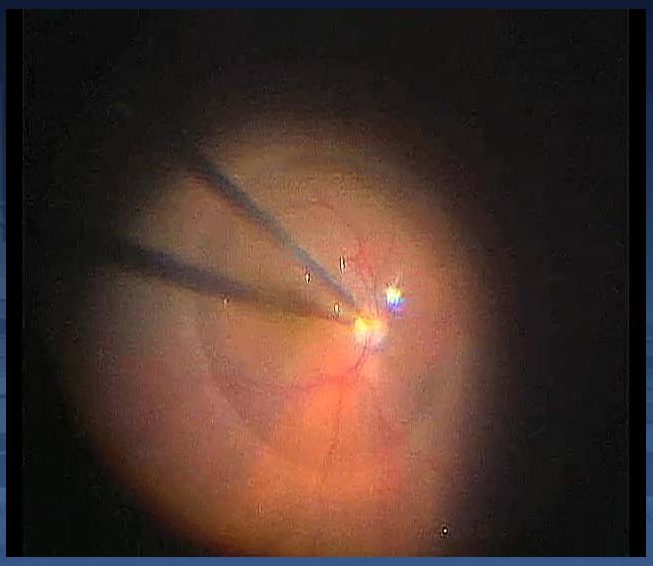
Cole Eye Institute

Could this be useful?



Cole Eye Institute

Could this be useful?



Cole Eye Institute

Clinical Feasibility and Utility:

PIONEER Study

Cole Eye Institute

iOCT: Purpose

- PIONEER Study
  - To assess the feasibility and utility of intraoperative and perioperative OCT in the management of surgical ophthalmic diseases
    - Anterior segment surgery
    - Vitreoretinal surgery

Ehlers JP, Dupps WJ, Kaiser PK, Goshe J, Singh R, Petskovek D, Srivastava SK. "The **P**rospective **I**ntraoperative and Perioperative **O**phthalmic Imagi**N**g with Optical Coher**E**nc**E** Tomog**R**aphy (PIONEER) Study**:** 2-year Results." Am J Ophthal. 2014.

Cole Eye Institute

iOCT: PIONEER

- PIONEER Study
  - Cole Eye Institute Ophthalmic Imaging Center
  - IRB-approved prospective single-center multi-surgeon study for use of *i*OCT across ophthalmic surgery.
  - Includes:
    - 6 VR surgeons, 5 anterior segment surgeons
    - *i*OCT research coordinators
  - Standardized imaging protocol

Cole Eye Institute

iOCT: PIONEER

- PIONEER Study
  - Microscope-mounted handheld SD-OCT probe (Bioptigen SDOIS)
  - Surgeon feedback questionnaire administered for select cases to better identify areas of utility

Cole Eye Institute

iOCT: 24-Month PIONEER Overall Results

	Anterior		Posterior	
Enrollment	275		256	
Most Common Preoperative Diagnosis	Fuchs Cataract Bullous Keratopathy Failed DSAEK Keratoconus Other	82 (30%) 66 (24%) 32 (12%) 23 (8%) 16 (6%) 56 (20%)	ERM Macular hole Retinal detachment PDR Other	90 (35%) 58 (23%) 44 (17%) 32 (13%) 32 (12%)
Most Common Procedures	DSAEK CE/IOL Femto CE/IOL DALK	135 29 37 19	PPV PPV/SB Other	253 15 3

Cole Eye Institute

PIONEER 24 Month Results: Time

- Average duration surgery paused per scan session:
  - Posterior Segment: 3.4 minutes
  - Anterior Segment: 1.9 minutes
- Total time surgery paused:
  - Posterior segment: 6 minutes
  - Anterior Segment: 3.2 minutes

Cole Eye Institute

iOCT: 24-Month PIONEER Overall Results

	Anterior	Posterior
Scan Sessions	2 (1-4)	2 (1-5)
Total Scans	4 (1-14)	10 (1-24)
Total Duration Surgery Paused	3.2 (0.4-17.8)	6.6 (1.0-26.7)
Duration surgery paused per scan session	1.9 minutes	3.4 minutes

Cole Eye Institute

iOCT: PIONEER Adverse Events and Safety

	Anterior	Posterior
Serious Adverse Events		
Endophthalmitis	1	0
Other Adverse Events:		
Epithelial defect	34	33
Elevated IOP	6	39
Hypotony	0	8
Fibrin	1	11
Hyphema	1	1
Vitreous hemorrhage	3	6

Cole Eye Institute

Impact on Decision Making

- Membrane Peeling (146 cases)
  - 43% of cases *i*OCT impacted the surgeon's understanding of the anatomy and decision making.

Ehlers JP, Dupps WJ, Kaiser PK, Goshe J, Singh R, Petskovek D, Srivastava SK. "The **P**rospective **I**ntraoperative and Perioperative **O**phthalmic Imagi**N**g with Optical Coher**E**nc**E** Tomog**R**aphy (PIONEER) Study**:** 2-year Results." Am J Ophthal. 2014. *In press.*

Cole Eye Institute

Membrane Peeling

- Peel membrane (146 cases)
- I think I am done: (91/146 cases) 62%
- I think there is more to peel: (5/146 cases) 3%
- I am not sure: (51/146 cases) 35%

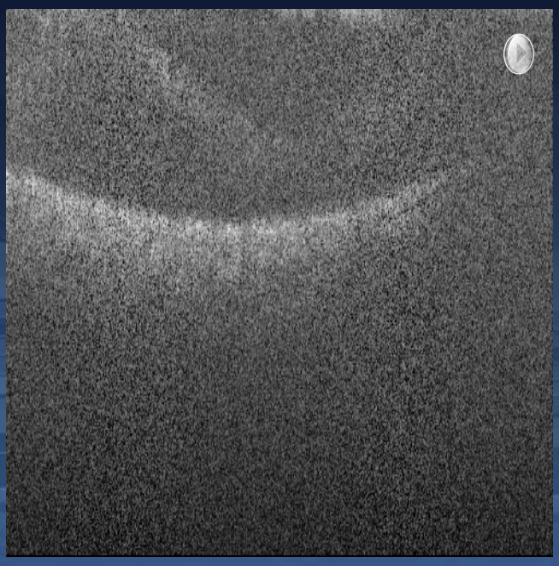
Cole Eye Institute

*Membrane Peel – i*OCT Answer

- Peel membrane
- I think I am done
  - 13% of cases additional membrane peeling required
- I think there is more to peel
  - 40% of cases no additional peeling required
- I am not sure
  - 94% of cases, *i*OCT gave definitive answer

Cole Eye Institute

Clinical Examples – "I am not sure"

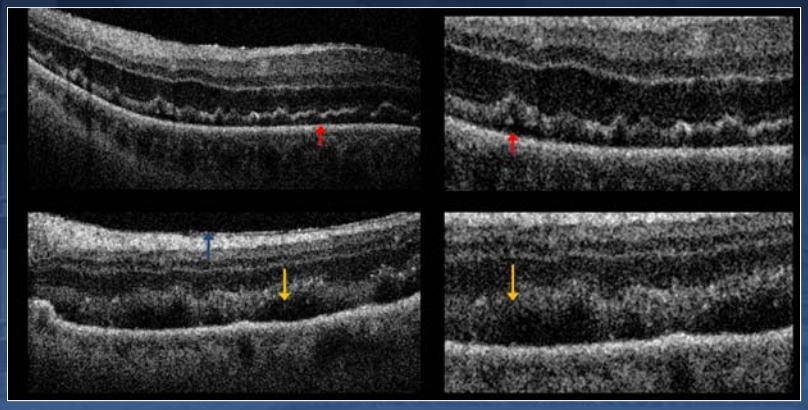


Cole Eye Institute

JPE4

iOCT: Surgical Insights in RD

- New discoveries in RD
  - 100% eyes had persistent submacular fluid under PFO



Cole Eye Institute

Slide 146

JPE4

Garbo for vitreous schisis
VMT for butler
Parsley for macula involving RD

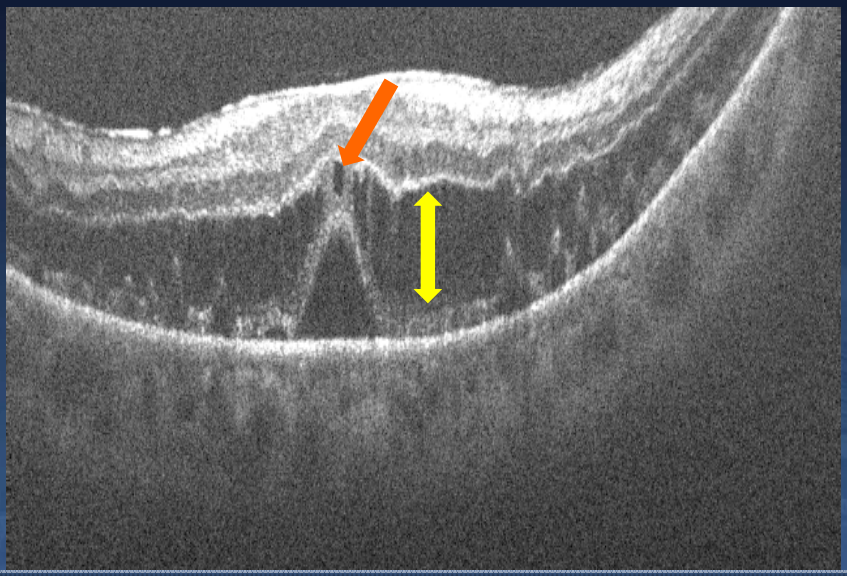
Justis P. EHlers, 10/16/2011

Can iOCT findings predict postop vision?

- Retinal detachment cases
- Mean retinal thickness under perfluoron– 410 um
  - In eyes with good visual acuity - 389 um vs. 489 um in eyes with poor visual acuity (p< .02)
- Outer retinal thickness (distance from outer plexiform layer to IS/OS (inner ellipsoid)
  - In eyes with good visual acuity – 94 um vs. 173 um in poor visual acuity eyes (p <.004)

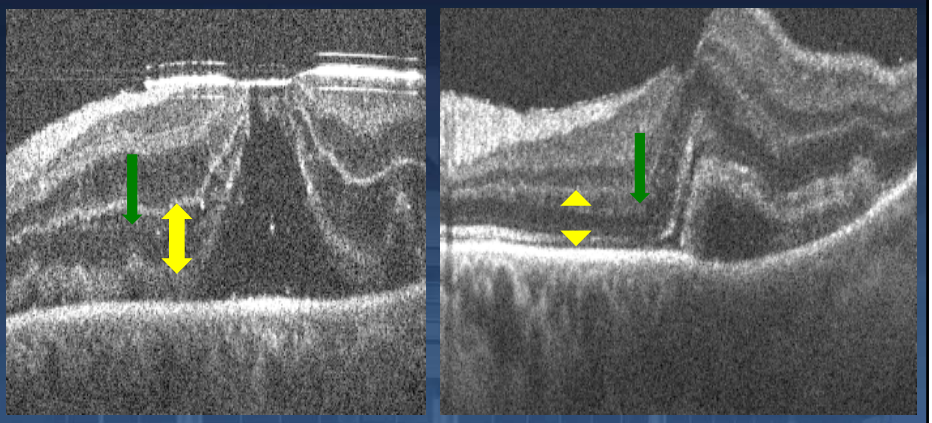
Cole Eye Institute

Clinical Examples – Post-op Vision CF



Cole Eye Institute

Clinical Examples – Post-op Vision 20/40



Cole Eye Institute

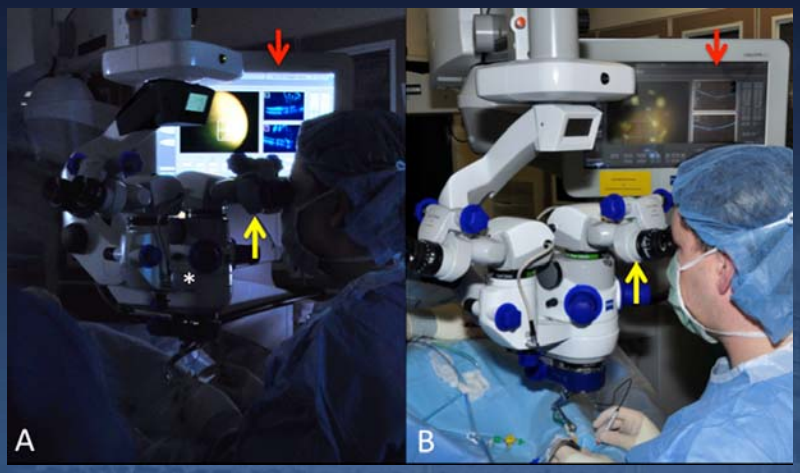
iOCT, the move to true integration

- Advantages of Integrated *i*OCT systems
  - Provides visualization of instrument-tissue interaction for true "real-time" *i*OCT.
  - Parfocal with surgeon view
  - Rapid scan localization to area of interest
  - Seamless integration of OCT into the surgical procedure
  - Minimal to no increase in surgical time
  - "heads-up" display

Ehlers JP, Tao YK, Farsiu S, Maldonado R, Izatt JA, and Toth CA. "Visualization of real-time intraoperative maneuvers with spectral domain optical coherence tomography system." Retina. 2013 Jan; 33(1): 232-6

Cole Eye Institute

Rescan 700



Ehlers JP, Kaiser PK, Srivastava SK, BJO 2014

Cole Eye Institute

Now that we have an integrated system- should I buy one

- Lets ask the same questions again
- Does it help?
- Change decisions?

Cole Eye Institute

DISCOVER Purpose

- DISCOVER Study
  - To evaluate the feasibility and utility of real-time intraoperative OCT (*i*OCT) with a microscope-integrated prototype with a heads-up display surgeon feedback system.
    - Anterior segment surgery
    - Vitreoretinal surgery

Cole Eye Institute

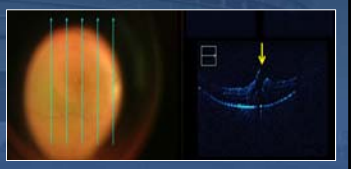
Rescan 700: 1 year results

- 227 eyes enrolled
- 121 woman, 106 men
- Average age: 62
- Successful imaging obtained in 99% (224/227)
- Anterior Segment Arm: 91 eyes
- Posterior Segment Arm: 136 eyes

Cole Eye Institute

DISCOVER: Overall Integrated System Feedback

- Provided valuable feedback: 71% (97/136)
  - Identified membrane edge
  - Lamellar vs full-thickness hole after peeling
  - Confirmation of peel completion
- Altered surgical procedure: 36% (49/136)
  - Aborted need for ICG staining
  - Less surgery/peeling
  - FTMH Identified
  - Placement of drainage retinotomy



Cole Eye Institute

DISCOVER: Impact on Surgical Decision-Making

- How does integrated *i*OCT change surgical approach membrane peeling?
  - *i*OCT revealed residual membrane requiring peeling in 22% of cases (9/41) where surgeon believed peeling was complete.
  - *i*OCT confirmed complete membrane peel in 14% of cases (4/26) where surgeon thought additional peeling was needed.
  - *i*OCT was discordant with surgeon observation in 19% of membrane peeling cases

Cole Eye Institute

DISCOVER: Overall Integrated System Feedback

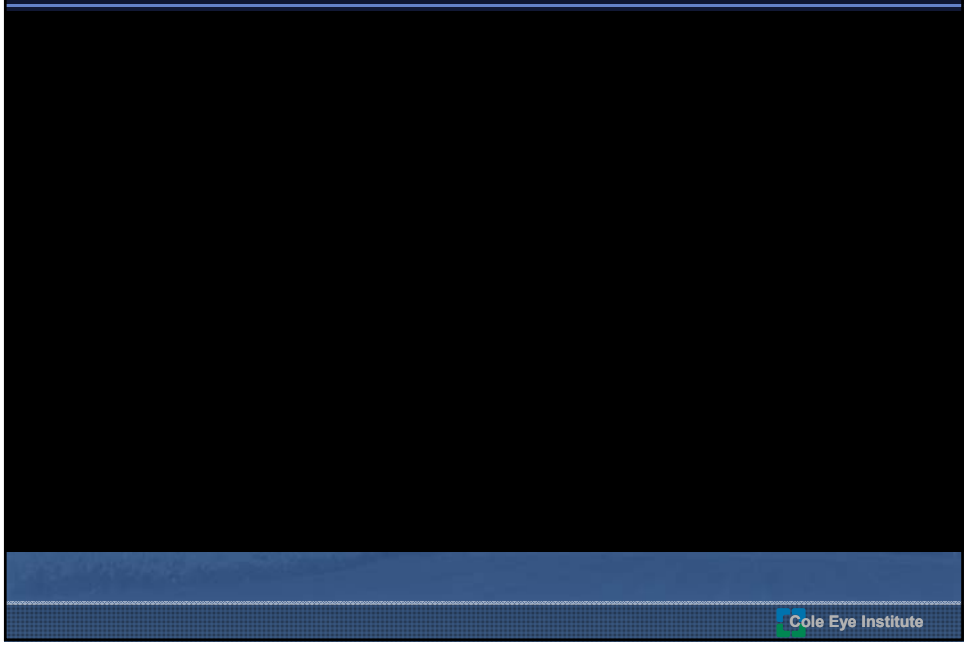
- Preferred Heads-up Display: 79% (179/227)
- Preferred Real-time vs Static Feedback: 65% (148/227)
- Potentially Interfere with Case: 3% (7/227)
  - Reasons:
    - Rebooting microscope
    - Lack of foot pedal response

Cole Eye Institute

Clinical Examples from DISCOVER Study

Cole Eye Institute

Membrane Peel with Forceps



Cole Eye Institute

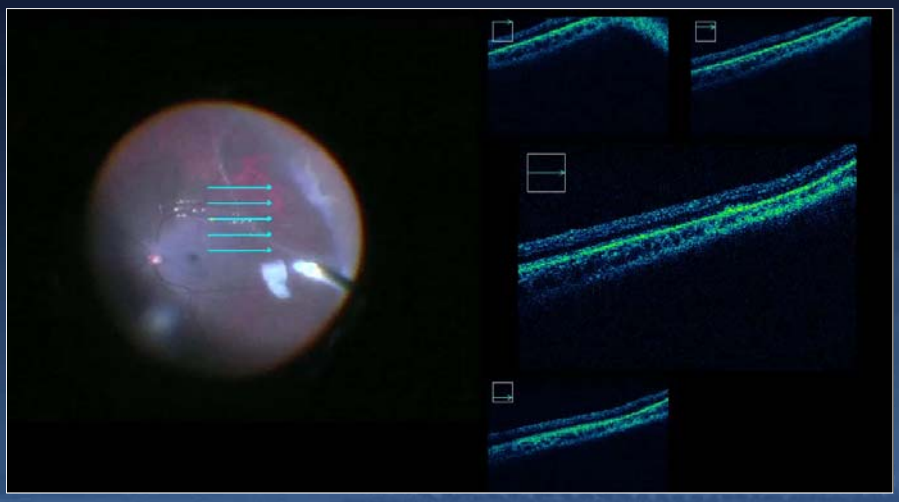
Dense Membranes

Cole Eye Institute

Membrane Identification

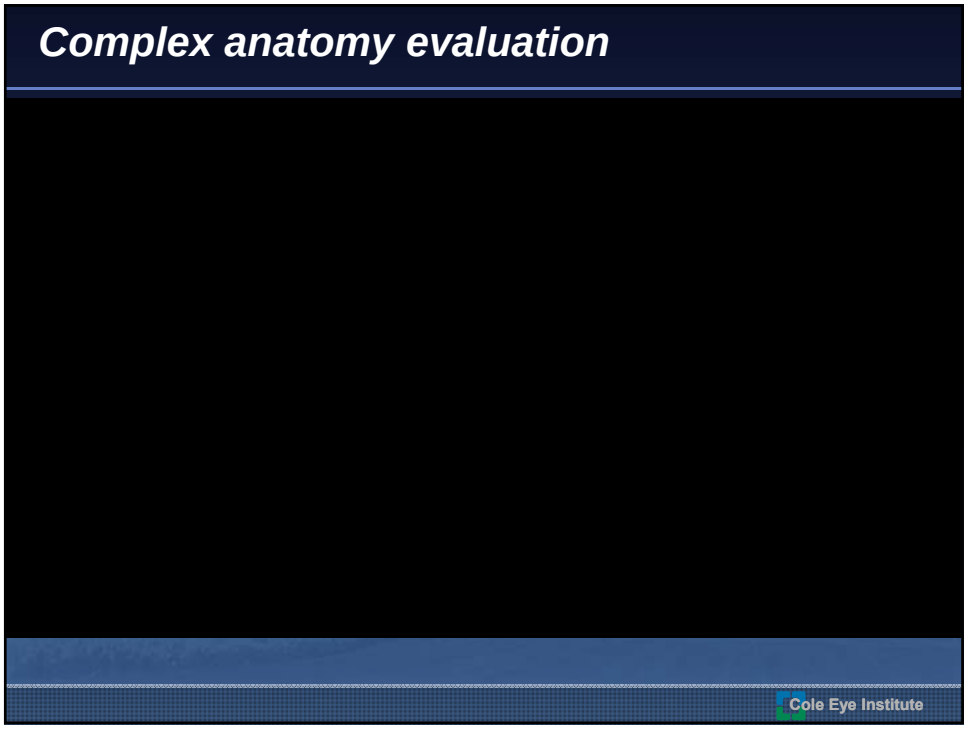
Cole Eye Institute

OCT-guided Fluid Evaluation



Cole Eye Institute

Complex anatomy evaluation

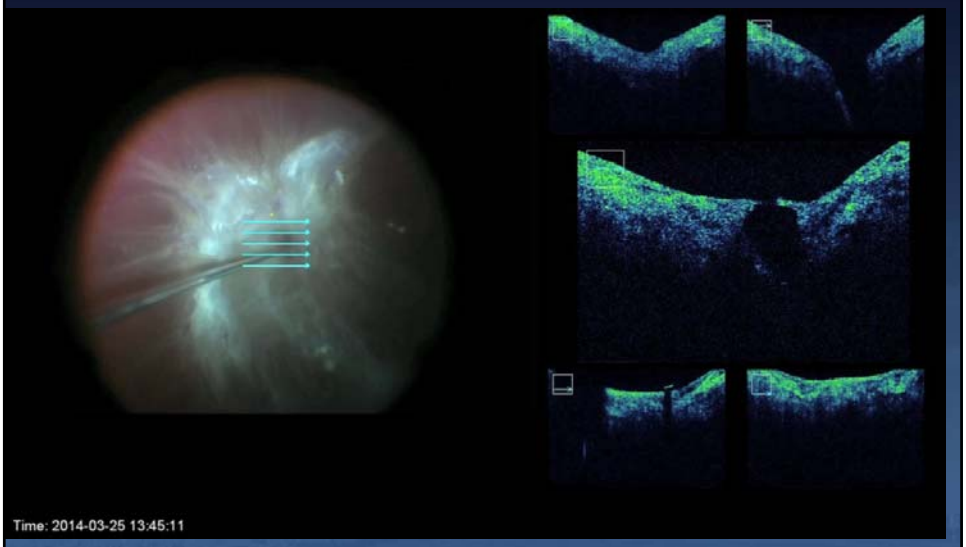


Cole Eye Institute

Complex Anatomy

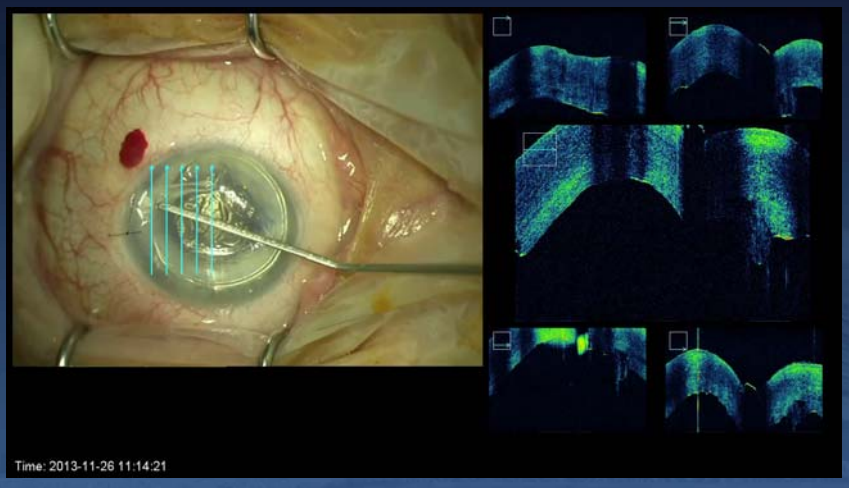
Cole Eye Institute

Complex Anatomy- Viscodissection



Cole Eye Institute

DSAEK Case



Courtesy Prof. Oliver Findl – Vienna, Austria

Cole Eye Institute

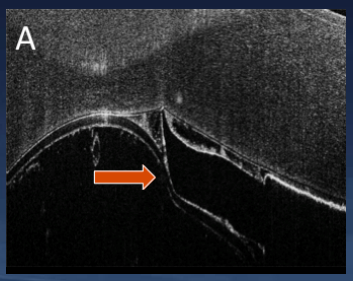
Is that all?

- With current spectral domain platforms – great information
- To do real-time OCT guided surgery we need some additional enhancements.

Cole Eye Institute

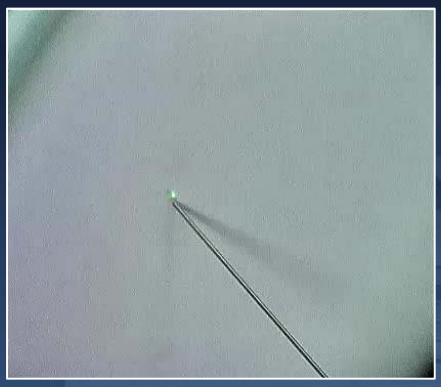
Next Generation OCT-Friendly Instrumentation

- Prototypes

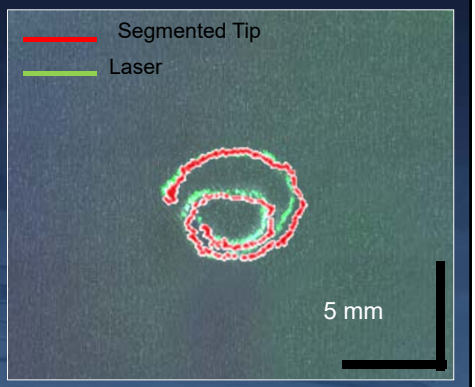


Cole Eye Institute

Real-Time Tracking and Accuracy



Real-Time Instrument Tracking

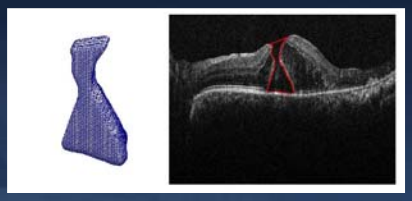


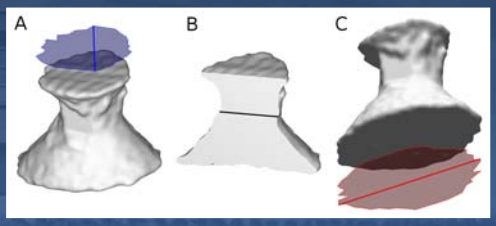
Collapsed Frames

Cole Eye Institute

Software Analysis Algorithms

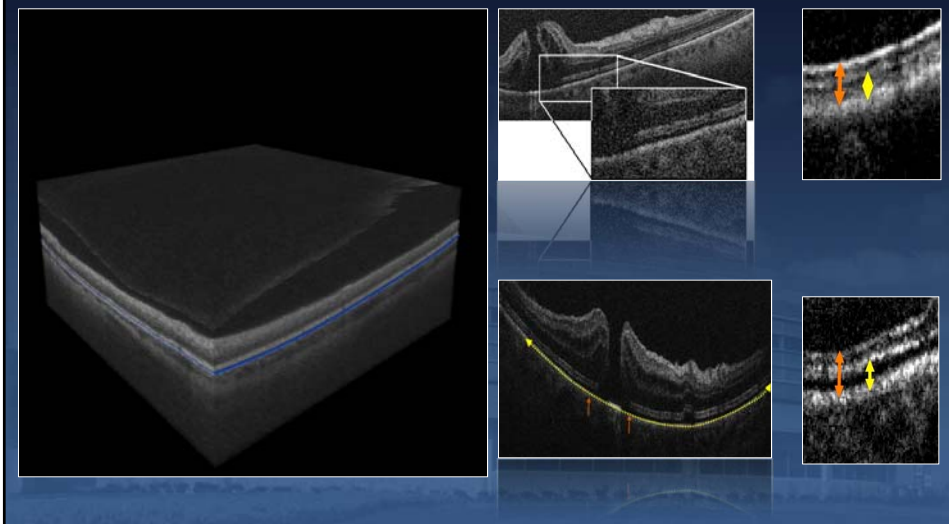
- Pathology-oriented segmentation algorithms:
  - Allow for pre- and post-analysis of changes associated with surgical manipulation
  - May provide input for surgical decision-making
  - Possible information regarding prognosis





Cole Eye Institute

OCT: Automated Ellipsoid Zone and Pathology Analysis

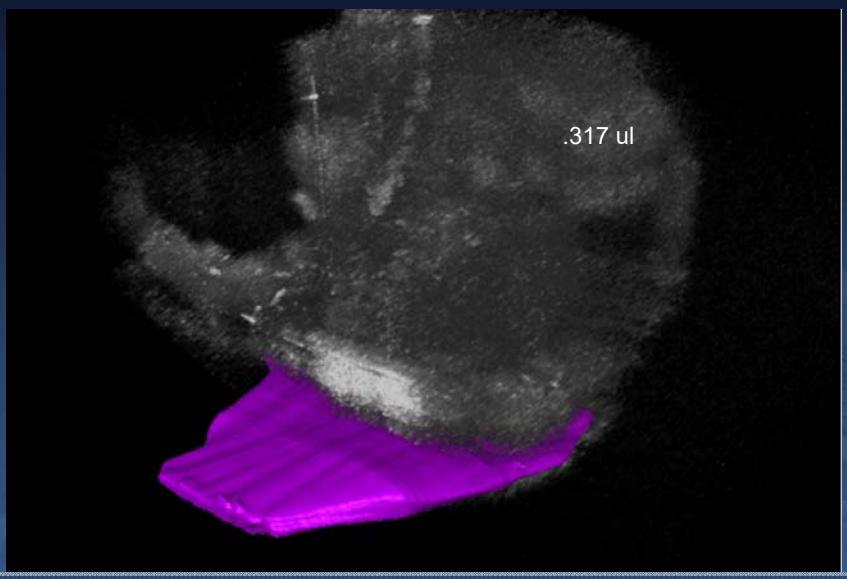


Cole Eye Institute

Instrument refinement

Cole Eye Institute

Subretinal injection

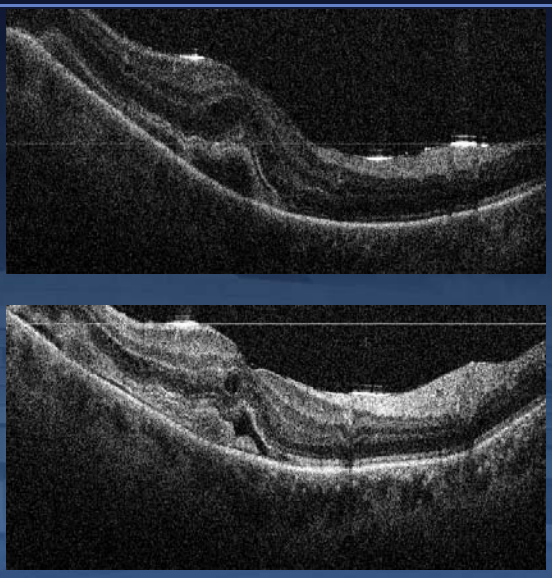


Cole Eye Institute

Future for VR surgery?

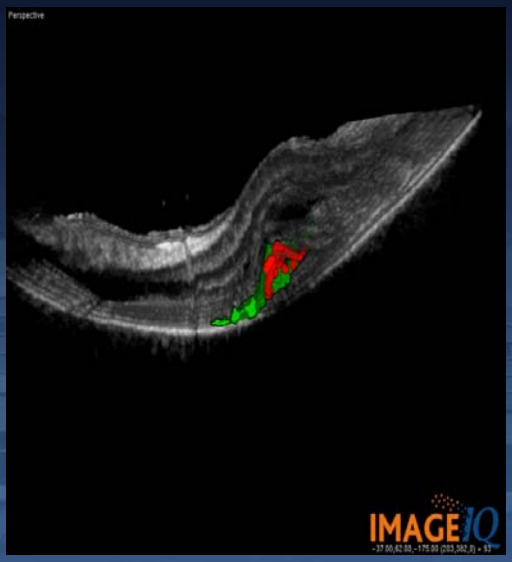
Cole Eye Institute

Accomplish Surgical Goals



Cole Eye Institute

Vitreo-retinal specific software



Cole Eye Institute

Acknowledgments

- Cole Eye Institute Ophthalmic Imaging Center
  - Justis P. Ehlers, MD
  - Yuankai "Kenny" Tao, PhD
  - Daniel F. Martin, MD
  - Jamie L. Reese, RN
  - Peter K. Kaiser, MD
  - Rishi P. Singh, MD
  - Kimberly Baynes
  - Carmen Calabrise
- Duke University Eye Center
  - Cynthia Toth, MD
  - Joseph Izatt, PhD

Cole Eye Institute