Overview

• OCT Technology: past, present and future
• Where we aren’t using OCT (yet)
• Where we might use OCT in the future – the new frontiers

Objectives:
• Interpret and apply new technology Optical Coherence Tomography (OCT) features for different retinal conditions
The earliest OCT devices started an underappreciated revolution

OCT Revolutionized the practice of ophthalmology by:
1. Providing unparalleled cross-sectional visualization of the retina
2. Making clinically-useful, quantitative measurements

So why was OCT underappreciated in the 1990’s?

- We wanted this

- But we got this

The measurements were unreliable. In fact, the first devices incorrectly measured retinal thickness by detecting the ellipsoid junction as the RPE.
OCT in the 1990's

**Famous regrettable quotes**

"I can see more with a contact lens exam than I can with OCT" – most retina specialists

"No one will need more than 640Kb of memory for a personal computer" – Bill Gates

OCT in the 2000's

- Higher resolution enabled better visualization of known tissue layers


OCT histologic correlations began to look more realistic

OCT in the 2000's

- "Wow I can see a lot with this OCT thing..." - many retina specialists

The Need for Speed

- **Time Domain OCT**
  - 6 Radial Line B-scans
  - ~8 seconds

- **Spectral Domain OCT**
  - 128 Raster Line B-scans
  - <3 seconds

By the End of the 2000's

- "Wow! I can't see patients without OCT!" - most retina specialists
The Revolution Roles on...

- Swept source OCT promises even better visualization of the posterior pole with improved lateral and axial imaging range

20 years ago...

Swept Source OCT (SS-OCT)

- Greater penetration

Swept Source OCT (SS-OCT)

- High speed also enables functional imaging
Other Types of OCT

- Full field OCT: uses a CCD chip (like a video camera) to capture full 2D OCT images
- Doppler OCT: can measure flow velocities and possibly even visualize leakage in the future

Doesn't everyone want OCT in their cell phone?

The Potential for OCT in Ophthalmology

"Pretty much everyone who needs an OCT machine already has one."
- anonymous

Is the OCT revolution in Ophthalmology reaching its peak or will it continue?
Clinical Activities

- What are the most commonly performed ophthalmic services?

Clinical Opportunities for OCT

- Could OCT play a bigger role in these services?

New Frontiers for OCT

- OCT angiography
- OCT biometry
- OCT fundus imaging
- Intraoperative OCT
- OCT biomicroscopy
OCT Angiography

- Doppler OCT: images blood flow by evaluating the phase differences between adjacent A-scans without using any injected dye.
  - Problems with blood vessel orientation and small blood vessels

- Current approaches:
  - Optical Microangiography (OMAG)
  - Doppler Variance OCT (DV-OCT)
  - Phase Variance OCT (PV-OCT)
  - Split-spectrum amplitude decorrelation (SSADA)

- Commercial systems:
  - Several companies are developing and/or selling OCT angiography systems

Phase Variance OCT

PV-OCT

Corresponding FA

Courtesy of Scott Fraser, Jeff Fingler, Dan Schwartz, Jack Werner
Phase Variance OCT

• Diabetic retinopathy
• PV-OCT
• PV-OCT (zoomed)

Con: Limited field of view
Pro: May be solved with wide-field OCT angiography

OCT Angiography - Advantages

• No dye injection
• Depth-resolved
OCT Angiography - Problems

- Motion artifact can impair image quality
  - Various techniques are being developed to mitigate this
- Limited field of view
  - Wide-field OCT may solve this
- Can montage images - but still time-consuming to acquire and compile
- Does not demonstrate leakage - only intraluminal blood flow
  - Research in phase variance OCT may enable this?

OCT-based Biometry

- Small study using SS-OCT (VCSEL light source @1065nm) showed good agreement between OCT-based biometry and commercial biometry systems
- Zeiss IOLMaster 700 uses SS-OCT
- Pros: use existing OCT devices?
- Cons: is cost warranted?

Grulkowski et al, Ophthalmology 2013;120:2184-2190

OCT-based Fundus Imaging

- Ultrafast OCT (millions of A-scans per second) can be used in conjunction with voxel summing to produce images such as these
- Pros: possible integration into existing OCT devices
- Cons: lack of color information, cost

Klein et al, Optics Express, Vol. 18, issue 4, pp. 3044-3062 (2011)
Intraoperative OCT

- **Microscope Mounted**
  - Impacts microscope-based surgeries
  - Primarily intraocular procedures

- **Handheld**
  - Intraocular
  - Extraocular

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Intraoperative OCT

Tano scraper with microscope-mounted OCT

Real-time AS-OCT in femtosecond laser surgical system

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Intraoperative OCT

**Studies**
- Several on-going studies looking at risks and benefits
- Some potential quality improvement
- Very few safety issues

**Challenges remain**
- When to use it?
- Does it improve surgical outcomes?
- Instrumentation
- Cost
OCT of the Whole Eye

Most clinicians associate the term 'OCT' with retinal imaging. But OCT is quite capable of imaging the vitreous... And the anterior segment.

The Growth of Anterior Segment OCT

PubMed publications listing OCT as keyword

Shifting the data back shows that glaucoma and anterior segment OCT publications are increasing at a rate similar to retinal OCT publications in 2005.

Swept Source OCT of Anterior Segment

Anterior Peripheral Imaging

Image courtesy of Heidelberg Engineering, Inc.

Optovue RTVue Zeiss Cirrus Tomey Casia

Schwalbe’s line Scleral spur

AS-OCT Findings and Measurements

a

Narrow Angle

b

Pupillary Block

c

AC Cell & Flare

d

Contact Lens Fitting

Contact Lens
**Intraocular Lenses**

Normal IOL Position

IOL rubbing the iris and causing secondary pigmentary glaucoma


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**Tube Shunt**


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**Clear Corneal Incision**

Images from Tufail et al. Wound architecture of clear corneal incision with or without stromal hydration observed with three-dimensional optical coherence tomography. Am J Ophthalmol. 2011;151:413–419.
Post-op Gaping and Descemet’s Tears

Complicated LASIK Flap


DSAEK

Normal flap

Flap dislocation
Keratoconus with ICRS


Granular Dystrophy


Thiel-Behnke dystrophy

Degenerations

Pellucid Marginal Degeneration
Spheroidal Degeneration

Other diseases

Cystinosis
LCAT Deficiency

Peters Anomaly

Images courtesy of Bioptigen, Inc
Microbulbous Keratopathy


Dry Eye


Tear Film Imaging

Bacterial Keratitis


Corneal Ulcer


Cataracts
The Angle

Existing OCT machines can already image almost all of the tissues we examine today with conventional slit lamp biomicroscopes. New deep-penetrating light sources may even make it possible to capture these data in a single 3D-OCT scan.

OCT Biomicroscopy

OCT is capable of showing magnified, 3D, cross-sectional views of transparent tissues in the eye and is the logical successor to the slit lamp microscope for the next century of Ophthalmology.

The Cornerstone of the Eye Exam

A century of slit lamp biomicroscopes...

… and not much has changed
The Cornerstone of the Eye Exam

• To me, the lack of change means either
  1. The current slit lamp is a perfect instrument
  2. The slit lamp has reached its maximum potential

Current trends in digital healthcare mean the time is right to move beyond slit lamp biomicroscopy to a more objective, quantitative, consistent and documented method of examining the eye.

The Evolution of Optical Instrumentation

- Optical instruments in several scientific disciplines have evolved through three strikingly similar stages over the last four centuries:

<table>
<thead>
<tr>
<th>Direct observation</th>
<th>Recorded observation</th>
<th>Remote observation</th>
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<tbody>
<tr>
<td>1600</td>
<td>1930</td>
<td>1950</td>
</tr>
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<td>Ophthalmology</td>
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- The earliest optical instruments transmitted light without recording thus providing only transient data.
- Expert observers were required to:
  - Operate instrument (variable)
  - Know what to look for (training-dependent)
  - Record observations (subjective)
  - Interpret observations (knowledge-dependent)

- The Galilean telescope
- The Galilean microscope
- The biomicroscope
The Evolution of Optical Instrumentation

- Optical instruments in several scientific disciplines have evolved through three strikingly similar stages over the last four centuries:

  - **1600**: Direct observation
  - **1930**: Recorded observation
  - **1950-2010**: Remote observation

### Direct Observation
- **Astronomy**: Galilean telescope
- **Microscopy**: Galilean microscope
- **Ophthalmology**: Slit lamp camera

### Recorded Observation
- **Astronomy**: Schmidt camera
- **Microscopy**: Microphotography
- **Ophthalmology**: Fundus camera

### Remote Observation
- **Astronomy**: Radio telescopes
- **Microscopy**: Electron microscopy
- **Ophthalmology**: Angiography

Incorporation of film photography into instruments in 1930 enabled observations to be recorded and subsequently reviewed and measured.

Development of non-visible modalities forced the observer away from the instrument.

The Evolution of Optical Instrumentation

- The convergence of digital imaging and computer technology caused another shift to real-time, recorded observations.

### Astronomers
- Astronomers are now able to make objective observations and measurements without looking through a telescope eyepiece.

### Microscopists
- It is now possible for microscopists to review, measure and compare gigapixel-sized images anytime, anywhere.

### Ophthalmologists
- Even though we use FA, OCT, etc. for remote imaging, the cornerstone of our exam is still based on transient light transmission.

The Model for Ophthalmology

- In 2011, the Nobel Prize in Physics was given to three astrophysicists who demonstrated that the universe is expanding at an ever-increasing rate.

- They did this with conventional optical telescopes that had been around for decades.

- To make their tremendous discovery, they applied three simple techniques:
  1. They consistently and efficiently stored useful images of the sky.
  2. They compared images from different time points to detect the appearance of new supernovae.
  3. They made quantitative measurements of the supernova's redshift to determine that they were further away than they should have been.
OCT Biomicroscopy

- I believe that OCT can play a central role in every eye exam by substantially replacing slit lamp biomicroscopy.
- Compared to the slit lamp, OCT is more:
  - consistent
  - efficient
  - objective
  - useful
  - quantitative

Consistency

What NLs did: Acquired images in the same regions of the sky night after night.
What MDs do: Try to look at all eye tissues every time.
The reality: Eye doctors all perform slit lamp exams differently. To detect a new finding, we must have examined every region previously and documented the absence of the finding.
The solution: Scanning protocols consistently cover tissue, every time, everywhere. Consistent imaging of the human body can be accomplished anywhere in the world with MRI and CT.

Efficiency

What NLs did: Captured images remotely (since it would have been impossible for them to sit at every telescope every night).
What MDs do: Sit at our slit lamp biomicroscopes day after day!
The reality: Eye doctors use technicians to collect exam data, and automated collection of slit lamp data could save us time that we could then spend with patients doing procedures.

**Store and Compare**

**What NLs did:** Stored images that they could review after a supernova appeared (since they didn’t know where they would appear).

**What MDs do:** To monitor changes in lesions over time, we use our memories and the subjective findings that we chose to record in the past which typically focus more on positive/present findings than negative/absent findings.

**The reality:** Since we don’t know where future findings will appear, storing objective exam data documents both positive and negative findings (e.g. absence of thinning or thickening) for later comparisons.

**The solution:** Longitudinal data storage enables head-to-head comparisons of findings between visits and a better understanding of the natural history of most eye diseases (we already do this with retinal OCT).

**Useful Data**

**What NLs did:** Their images contained all of the information they needed to measure the speed of these supernovae.

**What MDs do:** Slit lamps provide magnified, 3D, cross-sectional views of transparent tissues in the eye.

**The reality:** Stereoscopic planar imaging isn’t as good as tomography at showing 3D information since it requires very high resolution.

**The solution:** 3D tomograms (i.e. 3D-OCT) provide the best of both worlds – good en face visualization plus detailed cross-sectional visualization.

**Measure**

**What NLs did:** Measured changes in light intensity that showed that the supernovae were moving away faster than expected.

**What MDs do:** Qualitative or pseudo-quantitative slit lamp assessments.

**The reality:** Our subjective, categorical metrics (i.e. 1+, 2+, 3+ and mild, moderate or severe) may not be accurate or consistent enough to detect subtle changes in lesions over time.

**The solution:** Quantitative, machine-based measurements can be precise enough to identify even small changes and corrected if they are wrong.
Limitations of OCT Biomicroscopy

OCT has important limitations that need to be studied:

- **Consistency:** Exam will not necessarily focus on specific areas of interest.
- **Useful Data:** OCT does not provide a color image or show hemorrhage, does not examine the adnexa or palpebral conjunctiva, and presents information cross-sectionally instead of en face.
- **Store and Compare:** Requires digital access and large datasets.
- **Measurements:** Subject to segmentation errors.
- **Efficiency:** Lose physical interaction with patient required with slit lamp.

But for those who choose to use it...

...a Nobel Prize may be waiting!

Summary

- OCT angiography and OCT-based biometry have the potential to continue to increase utilization of OCT as an ancillary diagnostic modality.
- Intraoperative OCT is a new, exciting realm for OCT.
- Widespread adoption of OCT biomicroscopy as the cornerstone of the ophthalmic exam could increase OCT utilization by an order of magnitude.
- Ultimately, I believe that OCT utilization in the field of Ophthalmology is still in its infancy with many new exciting applications still to come!

Thank you!