Optical Coherence Tomography: Posterior Segment Applications

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Disclosure Statement: Nothing to Disclose
### ULTRASONOGRAPHY VS. OCT

#### Ultrasonography
- Utilizes transmission of sound waves to eye
  - Direct probe contact
  - Immersion of eye
- Reflection of sound wave echoes due to different structural borders
  - Structural borders
  - Micro-structural features
- Ultrasound imaging is a manifestation of the time delay for sound to be reflected from different intra-ocular structures
- Provides cross sectional images of the eye
  - Typical resolution ~150µm

#### Optical Coherence Tomography
- Utilizes specific wavelength of light
- Limited for measurement of structures which are optically accessible
- Does not require physical contact
- Light resolution provides higher spatial resolution
  - 10-5µm
  - 10-40x finer than ultrasound
## TOMOGRAPHY

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<th>Transverse</th>
<th>Longitudinal</th>
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<td>Retinal profile &amp; curvature</td>
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<td>Retinal pigment epithelium</td>
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<td>Bruch’s membrane</td>
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<td>Chorio-capillaris</td>
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Transmission

- Incident light is unaffected and proceeds to interact with deeper tissue.

**Normal Tissue**
- Vitreous
- Nuclear Layer

**Abnormal Tissue**
- Serous Fluid
- Edema
- Retinal hole
Absorption

The absorption of light by tissue can be due to various chromophores, such as hemoglobin and melanin, which are normal components of tissue.

### Normal Tissue
- **Tissue Chromophores** (Hemoglobin & Melanin)

### Abnormal Tissue
- Hemorrhages
- Hypertrophy of the RPE
- Choroidal Nevus

**removed from incident beam:** Absorption occurs due to tissue chromophores (absorption spectrum approximates that of incident light)
OPTICAL SCATTERING

- Property of heterogeneous media
- Microscopic spatial variations of the refractive index within tissues from sub-cellular structures (e.g., nuclei, cytoplasm, cell membranes, smaller structures, nerve fibers, or axons)
- Optical scattering causes incident light to be redirected in multiple directions
  - **Back-scattered light** – incident light completely reverses direction when scattered
  - **Back-reflection** – incident light falls at boundary between 2 homogenous materials that have different indices of refraction
OPTICAL SCATTERING

High Reflectivity
- Nerve fiber layer - NFL
- Outer plexiform layer or Henle’s fiber layer - OPL
- External limiting membrane - ELM
- Ellipsoid zone - EZ
- Interdigitation zone - IZ
- Retinal pigment epithelium band
  - Retinal pigment epithelium (RPE)
  - Burch’s membrane
  - Choroid and chorio-capillaris

Moderate Reflectivity
- Inner plexiform layer - IPL

Low Reflectivity
- Ganglion cell layers - GCL
- Inner nuclear layer - INL
- Outer nuclear layer - ONL
HYPER-REFLECTIVE STRUCTURES

- ELM – External Limiting Membrane
  - Boundary between cell bodies (nuclei) and IS photoreceptor
  - Junctional complexes between Müller cells & photoreceptors

- EZ – Ellipsoid Zone
  - Formerly - junction IS/OS
  - Mitochondria within ellipsoid layers of the outer portion of the IS
  - Distance from EZ to ELM < EZ to RPE

- IZ – Interdigitation Zone
  - RPE cell apices & outer segments
    - Formerly - Cone Outer Segment Tips (COST)
    - Formerly - Rod Outer Segment Tips (ROST)

- RPE - Retinal Pigment Epithelium Band
  - RPE & Bruch’s membrane
  - Indistinguishable in normal eyes
OPTICAL SCATTERING

- Highly reflective
- Increased attenuation of incident light
- Shadowing of deeper structures
- Reduces visualization of underlying structures

Abnormal clinical entities resulting in high backscattering:

- Hemorrhages
- Fibrosis / Disciform Scar
- Hard Exudates
- Detached RPE
VITREO-RETINAL INTERFACE
ABNORMAL VITREO-RETINAL INTERFACE

- **PVD**
  - Collagen fibrils of the posterior vitreal cortex are adherent to the macular ILM
  - Adhesion facilitated by proteoglycans
    - Laminin
    - Fibronectin
  - In PVD, vitreal liquification and weakening of adhesions occur

- Abnormal attachments between the vitreous and retina may result in alterations in retinal anatomy
  - Single or multiple retinal adhesions
  - Alteration of the retinal profile
VITREO-RETINAL ADHESIONS

Vitreo-macular adhesions (VMA)
- Adhesion of posterior hyaloid cortex involving the macular region

Vitreo-macular traction (VMT)
- Incomplete separation of the posterior vitreous
- Persistent macular attachment
- Incomplete posterior vitreal detachment
EPIRETINAL MEMBRANE

- OCT demonstrates:
  - Hyper-reflective band adherent to the internal limited membrane (ILM)
  - No retinal separation
  - Progression may result in:
    - Loss of foveal depression
    - Macular edema
ERM VS. VMTS / PVD

ERM

• Dense highly reflective band overlying ILM

VMTS

• Thin reflective band
• Band may appear patchy

PVD
OCT distinguishes between pseudo-holes and true holes

- Pseudo-holes
  - Deep & widened foveal pit contour
  - Foveal pit becomes steepened
  - Retinal tissue remains at the base of the pit
MACULAR LESIONS

- Macular cyst
  - Clear, signal-free area within the retina/fovea
- Lamellar hole
  - Partial thickness loss or separation of retinal tissue with a thin layer of persistent outer retina above the RPE
- Full-thickness macular hole
  - Complete loss of retinal tissue in the fovea extending to the RPE layer
GASS CLASSIFICATION OF MACULAR HOLES

Stage 1
- Loss of foveal depression
- Foveal cyst
- Posterior hyaloid tangential traction

Stage 2
- Intra-retinal cyst
- Partially adherent operculum

Stage 3
- Full-thickness hole
- Typically, operculum anterior to hole
- Margins demonstrate retinal edema
- No PVD

Stage 4
- Full-thickness hole
- Cystoid edema
- Hole margins rounded
- PVD
MACULA
DRUSEN

- Irregularity and/or disruption of the contour of hyper-reflective band representing RPE / Bruch’s membrane / chorio-capillaris complex
- Focal elevation of highly reflective RPE band
- Altered foveal contour
NEOVASCULAR AMD

- Irregular foveal contour
- Decreased reflectivity beneath neuro-sensory retina due to subretinal fluid accumulation from CNVM
- Thickened and/or irregular highly reflective external band
PIGMENT EPITHELIELIUM DETACHMENTS (PED)

- Serous Detachment
- Drusenoid Detachment
- Vascular Detachment
- Fibrovascular Detachment
GEOGRAPHIC ATROPHY

- Highly reflective signal from choroid in area corresponding to geographic atrophy
  - Enhanced penetration and reflection of signal from choroid due to attenuation of RPE / Bruch’s membrane / chorio-capillaris complex
- Overlying retina thinned with loss of layered structure of retina
CLINICAL APPLICATIONS OF OCT IN AMD

- Characterizing CNVM, especially early CNVM
- Response to therapy
  - Qualitative
  - Quantitative
- Detecting an early recurrence of CNVM
- Assessment of fluid-free zone with anti-VEGF treatment
- Essential in “Treat-And-Extend” (TAE) protocols
FUNDUS AUTOFLUORESCENCE

- FAF utilizes short-medium wavelength of light to detect lipofuscin accumulation
- Lipofuscin → Byproduct of phagocytized outer segment of photoreceptors
- Lipofuscin accumulates in RPE
- Lipofuscin represents a biomarker of
  - Normal aging
  - Chronic retinal disease
- Lipofuscin deposition in RPE may precede clinical / visual manifestations
- Normal ocular fundus
  - Normal RPE function
  - Mildly hyperfluorescent due to normal levels of lipofuscin in RPE cells
- ONH
  - Absence of RPE
  - Absence of lipofuscin
  - Hypofluorescent
- Retinal vasculature
  - Hypofluorescent
  - Signal absorption by blood
- Fovea
  - Hypofluorescent
  - Signal absorption by high density of macular luteal pigment
FAF → ABNORMAL

- RPE atrophy
- Retinal hemorrhages
- Exudation
- Pigmentation
- Hard drusen

- Increased Lipofuscin
  - Best
  - Stargardt
- Old hemorrhages
- Soft drusen
HYDROXYCHLOROQUINE (PLAQUENIL®)
AMERICAN ACADEMY OF OPHTHALMOLOGY GUIDELINES

2002
Dilated fundus exam
Automated VF 10-2
Color vision
Optional:
• mfERG
• FA

2011
Dilated fundus exam
Automated VF 10-2
1 of the following:
• SD-OCT
• mfERG
• FAF

2016
Considers risk of toxicity
Baseline
• Dilated fundus exam
At 5 years
• Annual screening:
  • Automated VF 10-2
  • SD-OCT
• Additional screening:
  • mfERG
  • FAF
Elevation / thickening of neuro-sensory retina due to fluid accumulation

Edematous fluid accumulation results in:
- Edema → optically transparent
- Decreased reflectivity

Superficial blood results in increased reflectivity
RETINAL ARTERY OCCLUSION EDEMA

- OCT
  - Acute
    - Inner retinal thickening
    - Shadowing of the outer retina
  - Chronic – Severe inner retinal thinning
GCA: GANGLION CELL ANALYSIS

- Ganglion Cell Complex
  - IFL: Inner Plexiform Layer (Dendrite)
  - GCL: Ganglion Cell Layer (Cell Body)
  - NFL: Nerve Fiber Layer (Axon)
DM MACULAR EDEMA

- Clinical presentation
  - Vascular endothelial compromise
  - Breakdown of blood retinal barrier
  - Increased vaso-permeability
- OCT demonstrates
  - Focal edema
  - Diffuse edema
    - Thickened retina
    - Small irregular cavities
- Macular schisis formation
PSEUDOPHAKIC CME

- CME (Irvine Gass Syndrome)
  - CME in 20% of individuals following uncomplicated phacoemulsification or extra capsular extraction
  - 1% develop significant decrease in VA
  - OCT may be equally effective as IV FA in establishing diagnosis of CME but less invasive

- Retinal thickening begins in the inner nuclear layer in the peri-foveal area
- Intra-retinal cavities of reduced reflectivity
- Central cysts expand to the entire thickness of the retina to the EZ/IZ
- Quantitative measurements of retinal thickness to evaluate therapeutic efficacy
OCT ANGIOGRAPHY

- OCT Fluorescein Angiography (FA)
- OCT Indocyanine Green Angiography (ICGA)
- OCT Angiography (OCTA)
  - Non-invasive and dye-less
  - Examines erythrocyte movement in blood vessels
  - Segmentation of tissue layers
OPTIC NERVE
DRUSEN VS. EDEMA

Optic Nerve Drusen

- Elevated optic nerve head
- Lumpy-bumpy appearance
- RNFL thinning nasally, thickening other sections
- Direct visualization of drusen on SD-OCT

Optic Nerve Edema

- Elevated optic nerve head
- Smooth internal contour and a lazy V pattern on TD-OCT
- Diffuse RNFL thickening in all sections of nerve
CHOROID
CHOROIDAL NEVI

Amelanotic

Pigmented Nevus
Increased pigment & choroidal reflectivity
CHOROIDAL MELANOMA

- OCT demonstrates:
  - Subretinal fluid
  - Increased reflectivity
Central serous choroidopathy
- Isolated RPE leakage
- Chronic diffuse retinal pigment epitheliopathy

Clinical presentation
- Choroidal fluid leakage
- Compromise or disturbance to RPE
- Serous retinal detachment
- Serous RPE detachment

OCT demonstrates
- Serous retinal detachment
- Serous PED
- Defect in RPE
- SD OCT ~800nm light wavelength fails to penetrate retinal pigment epithelium and photoreceptors in order to visualize the choroid optimally.
- 1050nm light wavelength permits deep penetrance to the scleral surface.
Unprecedented ultra-structural visualization -
- Vitreo-retinal interface
- Retina
- Optic Nerve
- Choroid

OCT permits -
- Quantification
- Qualification
- Diagnosis and serial management

CONCLUSION

- Advances
  - Wide field OCT
    - Visualize up to 200 degrees of retina
    - Project in retinal quadrants
    - Project into peripheral retina
  - Filters
    - Red → Enhance choroidal visualization
    - Green → Enhance retinal visualization
  - Enhanced depth imaging

- Functional OCT
  - Doppler OCT (Structure and blood flow)
  - Polarization-sensitive OCT

- Platforms
  - Handheld OCT
  - Intra-operative OCT

- No longer imagining, IMAGING!
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