Basics and Techniques

Optical Coherence Tomography

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What is OCT?

• Optical Coherence Tomography (OCT) is a high-resolution imaging technology that employs near-infrared light (1.3 µM) to probe micrometer-scale structures inside biological tissues.

Near-infrared light
0.77-3µm, biologically safe
Property of particle and wave
• Goes straightly
• Reflection, refraction, interference, diffraction
• Doppler effect
When the back-reflected optical intensities of the sample and reference are measured and compared, the optical properties of the tissue is deduced.
Why Use OCT?

1. Real time image for intravascular structure
2. High Resolution
3. Tissue characterization

- OCT range
  - 0.1 µm
  - 1 µm
  - 10 µm
  - 100 µm
  - 1 mm

- Blood vessels
- Duct
- Gland
- Cell layer
- Cell
- Cell Nuclei
- Nucleoli, Mitochondria, other large organelles
- Large proteins, Nucleotides & Ribosomes

Renu Virmani, MD, Erik Mont, MD AFIP
Comparison of IVUS and OCT

<table>
<thead>
<tr>
<th>Feature</th>
<th>IVUS</th>
<th>OCT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resolution</strong></td>
<td>(axial) 100 - 150 µm</td>
<td>10 - 20 µm</td>
</tr>
<tr>
<td></td>
<td>(lateral) 150 - 300 µm</td>
<td>25 - 40 µm</td>
</tr>
<tr>
<td><strong>Dynamic range</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Frame rate</strong></td>
<td>30 frames/s</td>
<td>15 frames/s</td>
</tr>
<tr>
<td><strong>Scan area</strong></td>
<td>10 - 15 mm</td>
<td>7.0 mm</td>
</tr>
<tr>
<td><strong>Max. depth of penetration</strong></td>
<td>1 – 1.5 mm</td>
<td></td>
</tr>
<tr>
<td><strong>Imaging core size</strong></td>
<td>0.8 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td><strong>Blood clearing</strong></td>
<td>not required</td>
<td>requires blood clearing</td>
</tr>
<tr>
<td><strong>Scan area</strong></td>
<td>is smaller and penetration depth is more shallow</td>
<td>Requiring blood clearing to avoid the attenuation</td>
</tr>
</tbody>
</table>

Higher resolution almost 10 times more
Imaging core size is a half of that in IVUS

“First-in-man OCT”
Jang et al. JACC, 2002
### Plaque Characterization by OCT

**Ex Vivo Study**

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fibrous</strong></td>
<td>0.87</td>
<td>0.97</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>Calcific</strong></td>
<td>0.95</td>
<td>1.0</td>
<td>1.0</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>Lipid pool</strong></td>
<td>0.92</td>
<td>0.94</td>
<td>0.81</td>
<td>0.97</td>
</tr>
</tbody>
</table>

**Accuracy Statistics:**
- Interobserver $k=0.88$
- Intraobserver $k=0.91$

Presented by IK Jang in 2002 TCT*
Plaque Characterization by OCT

Three Types of Plaque

**Fibrous**
- High reflectivity
- Homogenous
- Finely textured

**Lipid-rich**
- Low reflectivity
- Homogenous
- Diffuse margins

**Calcified**
- Low reflectivity
- Inhomogeneous
- Sharp margins
- Isolated, strong reflections in dark background

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Vulnerable Plaque

OCT may provide better understand the natural progression of coronary artery disease and the answers longstanding questions about the relationship between vulnerable plaque and the risk of heart attack.

Therapeutic Guidance
Evaluation of Therapeutic Results

The technique is poised to play an important role in the guidance of therapeutic interventions and assessment of the results of medical and interventional treatment.
The vulnerable plaque characterized by thin fibrous cap, extensive macrophage infiltration, and large lipid core.

**Major criteria**
- Active inflammation (monocyte/macrophage and T-cell infiltration)
- Thin cap with large lipid core
- Endothelial denudation with superficial platelet aggregation
- Fissured plaque
- **Stenosis 90%**

**Minor criteria**
- Superficial calcified nodule
- Glistening yellow
- Intraplaque hemorrhage
- Endothelial dysfunction
- Outward (positive) remodeling

Based on previously presented autopsy study

*Circulation.* 2003;108:1664-1672
Detection of VP in OCT

Macrophage Accumulation

There was a high degree of positive correlation between OCT and histological measurements of fibrous MQ density $r=0.84$, $p<0.0001$.

Thin-cap fibroatheroma was more frequently observed in patients with AMI or ACS than SAP.

Intimal Tear

Plaque rupture

Detection of VP in OCT

Superficial Lesion of Plaque

PJK M/43 UA

PDS M/46 NSTEMI

LPK M/38 STEMI

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Detection of VP in OCT

Thrombus

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The Major and Minor Criteria for Vulnerable Plaque

**Detection of VP in OCT**

**IVUS vs. VH-IVUS vs. OCT**

* The Major and Minor Criteria for Vulnerable Plaque

- 48 Patients (48 lesions) were enrolled and categorized according to their clinical presentation into SAP (n=15) and ACS (n=33).

**Major Criteria**

- Thin Cap
- Lipid Core
- Thrombus
- Rupture/Fissure
- AS≥90%

**Minor Criteria**

- Positive Remodeling
- SCN

* p<0.05 among 3 modalities, †p<0.05 between GS vs. OCT, ‡p<0.05 between VH-IVUS vs. OCT

*Choi et al, TCT 2008*
### Case

#### LCS 065699 56/M NSTEMI
- **Mixed Plaque**
  - Eccentric PB
  - Remodeling (+)
  - > 3/4 Lipid core
  - FC <65
  - NC 5%
  - FF 20%
  - TCFA(-)

#### SJW 0247337 59/F UA
- **Soft Plaque**
  - Remodeling (-)
  - > 2/4 Lipid core
  - Erosion
  - FC <65
  - NC 2%
  - FF 37%
  - TCFA(-)

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*Ajou University Medical Center*
Vulnerable Plaque
OCT may provide better understand the natural progression of coronary artery disease and the answers longstanding questions about the relationship between vulnerable plaque and the risk of heart attack.

Therapeutic Guidance
Evaluation of Therapeutic Results
The technique can play an important role in the guidance of therapeutic interventions and assessment of the results of medical and interventional treatment.
OCT as a Tool for PCI
Understanding PCI Mechanism

After Cutting Balloon

LJ. Diaz-Sandoval, IK Jang et al.
Cath Cardio Interv. 2005:65:492-6

After DCA

Suzuki
Toyohashi Heart Center, Japan
OCT as a Tool for PCI

Immediate Results after PCI

Well-apposed stent

Mal-apposed stent

Minor prolapse of plaque after stenting

BJK M/48

Cypher 4.0 x 23 mm
Ajou University Medical Center

Cypher 3.5 x 28 mm
Suzuki, Japan

Cypher 4.0 x 23 mm
Ajou University Medical Center
Evaluation of Therapeutic Results

Long-term Results after PCI

Complete Tissue Coverage

Cypher
HDH M/44 C3533 LAD

Taxus
SWS F/67 T3528 LAD

Incomplete Tissue Coverage

SJS M/70 C3533 LAD

LYJ M/46 T3020 LAD

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Evaluation of Therapeutic Results

Incomplete Tissue Coverage

1936 Cross Sectional Images from 57 patients

Age 56±11, 43 males (51 Cypher, 21 Taxus)
Average follow up period: 13.4±1.1 months

The uncovered strut index (USI) of total observed stent strut was 0.13±0.12.
The USI of Cypher stent was significantly increased than Taxus stent (Cypher 0.15±0.04, Taxus 0.04±0.03, p=0.034).

Choi et al, TCT 2008
Evaluation of Therapeutic Results

OCT in Complex Lesion
F/U after Crushing with DESs in Bifurcation

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**OCT and PCI**

<table>
<thead>
<tr>
<th>Preinterventional lesion assessment</th>
<th>IVUS</th>
<th>OCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of severity and clinical impact</td>
<td>😌</td>
<td>😞</td>
</tr>
<tr>
<td>Detect Vulnerable Plaque</td>
<td>😞</td>
<td>😊</td>
</tr>
</tbody>
</table>

**During intervention**

| Device sizing | 😊 |
| Decision of strategies for the lesion | 😞 |
| Understanding mechanism of intervention | 😊 |
| Decision of ending of procedure | 😊 |
| Recognition of complications | 😊 |

**Serial follow-up**

| Understanding for atherosclerosis | 😊 |
| Mechanisms, prevention and Tx of restenosis | 😊 |
| Assessment for long-term complication | 😊 |

OCT could be used as a tool for PCI by providing useful information in detecting VP and assessing PCI result and complication and evaluating long-term outcomes.
Limitation of OCT

1. OCT imaging needs blood free zone to avoid attenuation by blood flow.

2. OCT devices has some technical limitation in some lesions including left main disease, ostial disease, very tortuous lesion and so on.

3. Penetration through the arterial wall is in the range of 2–3 mm. The entire plaque cannot be imaged and only superficial anatomic information is obtained.

4. OCT could not detect lipid pools or calcium behind thick fibrous caps, and by an inability to distinguish calcium deposits from lipid pools or the opposite.
Complications of OCT

Experience in Ajou University Medical Center

Total 117 patients (male 73, age 57 ± 9), 126 lesions
Successful image acquisition: 121 lesions (96%)
(3 wire passage failure, 2 incomplete occlusion)

<table>
<thead>
<tr>
<th>Complication</th>
<th>number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air embolization</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transient ischemia: ECG change with pain</td>
<td>57</td>
<td>49</td>
</tr>
<tr>
<td>Pulmonary edema due to volume overloading</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ventricular arrhythmia</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Post PCI Infarction</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Death</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Limitation of OCT

1. OCT imaging is attenuated by blood and needs to create blood free zone.

2. OCT devices has some technical limitation, so there are some limited lesions including left main disease, ostial disease, very tortuous lesion and so on.

3. Penetration through the arterial wall is in the range of 2–3 mm. Sometimes, the entire plaque cannot be obtained.

4. OCT could not detect lipid pools or calcium behind thick fibrous caps, and by an inability to distinguish calcium deposits from lipid pools or the opposite.
Currently Evolving OCT

**STRUCTURE**
- Necrotic core
- Thin cap
- Macrophage
- Superficial Ca

**COMPOSITION**
- Lipid content
- Cholesterol ester
- Collagen component
- Macrophages
- Proteoglycans

**BIOMECHANICS**
- Cap stiffness
- Core stiffness
- Shear stress

**MOLECULAR**
- Inflammation
- Oxidative stress
- Endothelial dysfunction
- Angiogenesis
- Apoptosis

**FUNCTION**
- LSI, OCE
- OCT, OFDI
- LSI
- Raman
- PS-OFDI
- Fluorescence
- EEM, Lifetimes
- Raman
- PS-OFDI
- COMPOSITION
- Lipid content
- Cholesterol ester
- Collagen component
- Macrophages
- Proteoglycans

G Tearney, TCT 2008
The design of delivery catheters with improved blood-clearing efficiency is going on clinical trials.

Fourier-Domain OCT (FD-OCT)
Swept-Source OCT (SS-OCT)
Frequency-Domain OCT (FD-OCT)
Spectral-Domain OCT (SD-OCT)
Scanning Laser OCT (SL-OCT)
Optical Frequency Domain Imaging (OFDI)

Currently Evolving OCT
Toward easy practice with OCT

Time-Domain OCT
M3 system (Light Lab)

Frequency Domain OCT
M4 Prototype (Light Lab)

From GOODMAN Co.Ltd
OCT Imaging Systems
The First Generation

MGH OCT system

- 3.2F OCT imaging catheter
- Intermittent saline flush (6 to 10 mL)
- Spot image

LightLab system

- 1.4F OCT image wire
- Over-the-wire soft occlusion balloon catheter.
- Pullback image through continuous saline infusion
- in speed of 0.5ml/sec.

Optical source: Broadband light
Frame rate: 10-20/ s
Pullback speed: 1.5~3 mm/ s
Ranging of depth: 4-6 mm
OCT Imaging Systems
The Second Generation

MGH OCT system

- 2.6 F OD rapid exchange
- Helical scanning inner core
- 7 μm axial, 30 μm transverse resolutions
- 2-fold larger (5-6 mm) imaging range
- 100 fps; 512 A-lines/image

From GOODMAN Co.Ltd

LightLab system

- Guide flush and local flush designs
- R_x delivery
- Torque-wire based
- compatible with 6F guide

G Tearney, TCT 2008

Optical wavelength: Swept-frequency
Frame rate: 100-200/s
Pullback speed: 5~20 mm/s
Ranging of depth: 7-8 mm
Next generation OCT has imaging acquisition speeds of 10 times faster and resolution 3 times greater. It does not require occlusion of the patient’s blood flow during procedure.
Case

First in human FD-OCT
Imaging conducted at Lahey Clinic (S. Waxman)

68 y/o male
Risk factors: hypertension, dyslipidemia
Chest pain on exertion
Positive stress test showing ST elevation in two leads
Prox. LAD stented with DES

G Tearney, TCT 2008
Currently Evolving OCT

Toward complete lesion characterization with OCT

New platform modality and combine with other modality

<table>
<thead>
<tr>
<th>Morphological</th>
<th>Lesion size</th>
<th>Backscatter/Gray Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lesion shape</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% stenosis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cap thickness</td>
<td></td>
</tr>
</tbody>
</table>

| Biochemical composition | Lipid, collagen, proteoglycans, calcium | Spectroscopy Polarization |

<table>
<thead>
<tr>
<th>Physiological</th>
<th>Flow disturbances</th>
<th>Doppler</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CFR, FFR</td>
<td></td>
</tr>
</tbody>
</table>

| Mechanical          | Plaque stiffness  | Elastography |

Renu Virmani, MD; Erik Mont, MD AFIP
OCT is feasible as an intravascular imaging tool and it could be conducted safely in cath Lab.

OCT has a high resolution, it could assess the tissue characterization more accurately than IVUS.

OCT has a potential benefit to identify vulnerable plaques and also provides superficial information of the vessel during and after PCI.

OCT has major limitations in need of blood clear zone and low penetrating depth. Evolving OCT image moves closer to becoming a powerful diagnostic tool that will provide new insights into the etiology and treatment of coronary artery disease.