IVUS and OCT

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Associate Professor of Medicine
Medical Director, IVUS/Angiography Core Laboratory
Within the past 12 months, I or my spouse/partner have had a financial interest, arrangement, or affiliation with the organization(s) listed below:

<table>
<thead>
<tr>
<th>Affiliation/Financial Relationship</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grant/Research Support</td>
<td>N/A</td>
</tr>
<tr>
<td>Consulting Fees/Honoraria</td>
<td>Medtronic, Amgen, Sanofi</td>
</tr>
<tr>
<td>Stock Shareholder/Equity</td>
<td>Centerline Biomedical</td>
</tr>
<tr>
<td>Royalty Income</td>
<td>N/A</td>
</tr>
<tr>
<td>Ownership/Founder</td>
<td>N/A</td>
</tr>
<tr>
<td>Intellectual Property Rights</td>
<td>N/A</td>
</tr>
<tr>
<td>Other Financial Benefit</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Expanding world of invasive plaque imaging

Puri R. et al Nat Rev Cardiol 2011
Why do we use IVUS…? To Study the Vessel Wall
IVUS Measurements of Atheroma Volume

Puri R. et al. Int J Cardiol 2013
What Have We Learned From Serial IVUS Trials

**BENEFICIAL IMPACT**

- High-intensity statin therapy
- Blood pressure lowering
- Pioglitazone in diabetes
- Evolocumab

**NO BENEFIT**

- ACAT inhibition
- Torcetrapib, ?CETP inhibition
- Rimonabant
- Lp-PLA2 inhibition
- ApoA-1 Milano
- RVX 208
- CER-001
Intravascular Ultrasound: Principles

IVUS transducer rotates and pulls back through an area of interest and emits sound waves. Multiple pullback speeds are available.

Sound waves are reflected or pass through structures dependent on their density or acoustic impedance.

The electrical pulses are analyzed and processed by a complex computerized imaging system and displayed on a screen.

**Mechanical Transducer (40-60 MHz)**
- Single transducer rotates on a drive shaft, 1800 rpm

**Synthetic Phased Array / Solid State Transducer (20 MHz)**
- Multiple (64) stationary transducers

Higher resolution

Lower resolution
Recent more recent developments in conventional rotational IVUS

OPTICROSS™ Imaging Catheter 40 MHz

OPTICROSS™ HD Imaging Catheter 60 MHz
IVUS Image Interpretation

Normal vessel

- Pink is IVUS catheter
- Green is lumen
- Orange is EEM
- Dark band = media
Eccentric mixed plaque

- Pink are sidebranches
- Green is lumen
- Orange is acoustic shadowing (Ca)
IVUS Image Interpretation

Concentric mixed plaque

- Circumferential plaque distribution
  - Varying echogenicity
    - Fibrocalcific
  - Acoustic shadow (blue lines)
IVUS Image Interpretation

Calcified plaque
- Bright areas (blue) with acoustic shadowing (orange)
  - Reverberation artifact (pink)

Underexpanded stent
- Stent struts are bright
  - Significant plaque burden behind stent (pink arrow)
IVUS Image Interpretation

**Malapposed stent**

- Blood speckle behind stent struts
- Area of malapposition (pink)

**Intraluminal thrombus**

- Usually circular and non-stationary
- Can inject contrast to highlight contours
IVUS Image Interpretation

Dissection

False lumen
Optical Coherence Tomography: Principles

Analogous to IVUS, but uses NIR light instead of sound to measure optical reflections

High-resolution imaging technology employing NIR light to probe micrometer-scale structures inside biological tissues

1300 nm wavelength light

Dragon Fly catheter

2.7 Fr

75 mm pullback/2.5 secs

Clear lumen with contrast

10-20 micron axial resolution
OCT Image Interpretation: Plaque, Device & Complications

Fibrous
High reflectivity, diffuse margins

Lipidic
Low reflectivity, diffuse margins

Calcified
Low reflectivity, sharp margins

White thrombus

Red thrombus

Struts malapposed

ISR
IVUS and OCT Image Interpretation

Train Your Eyes!
Slightly larger stent diameters with IVUS

What is the vessel size??

Where OCT images to

Where IVUS images to
IVUS vs. OCT

CENTRAL ILLUSTRATION: IVUS and OCT: Similarities and Differences

<table>
<thead>
<tr>
<th>Pre-PCI</th>
<th>Post-PCI</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCT</td>
<td>IVUS</td>
<td></td>
</tr>
<tr>
<td>Very good</td>
<td>Good</td>
<td>Feasible</td>
</tr>
<tr>
<td>Severe of calcium</td>
<td>Prediction of slow flow</td>
<td>Stent sizing by vessel wall</td>
</tr>
<tr>
<td>Stent length to cover normal to normal</td>
<td>Stent expansion</td>
<td>Tissue protrusion through strut</td>
</tr>
<tr>
<td>Stent malaposition</td>
<td>Stent deformation (frequently at aorto-ostium)</td>
<td>Stent edge dissection</td>
</tr>
<tr>
<td>Residual disease at stent edge</td>
<td>Old stent expansion</td>
<td>Tissue coverage</td>
</tr>
<tr>
<td>Neointimal hyperplasia</td>
<td>Stent fracture</td>
<td>Stent malaposition</td>
</tr>
<tr>
<td>Positive remodeling of vessel wall</td>
<td>Neoatherosclerosis</td>
<td></td>
</tr>
</tbody>
</table>

IVUS vs. OCT

<table>
<thead>
<tr>
<th>Severe Calcification</th>
<th>CTO</th>
<th>LMCA</th>
<th>Ostial Disease</th>
<th>Advanced CKD</th>
</tr>
</thead>
<tbody>
<tr>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
</tr>
</tbody>
</table>
Intravascular Imaging Improving Stent/Patient Outcomes

Mela-analyses


Registries


IVUS Improves PCI Outcomes: Some Evidence (1)

Witzenbichler B et al. Circulation 2014
IVUS Improves PCI Outcomes: Some Evidence (2)

Zhang J et al. JACC 2018

ULTIMATE TRIAL
IVUS Improves PCI Outcomes: Some Evidence (3)

Hong SJ et al. JAMA 2014

IVUS-XPL TRIAL

HR, 0.48 (95% CI, 0.28-0.83)
Log-rank $P = .007$

Angiography-guidance

IVUS-guidance

No. at risk
Angiography arm 700 673 660 643 624
IVUS arm 700 671 665 654 641
IVUS Improves PCI Outcomes: Meta-analysis

Raber L et al. Eur Heart J 2018
**ILUMIEN III**

**Inclusion:**
- Single native vessel
- One or more target lesions
- RVD 2.25mm - 3.50mm
- Length < 40mm

**Exclusion:**
- Left main
- Ostial RCA
- CTO
- Planned bifurcation
- eGFR < 30ml/min

**Randomization:**
Randomization to OCT-, IVUS- or angiography-guided PCI

- **Pre-PCI OCT**
  - OCT Stent Sizing Guidance, per study protocol
  - OCT guided Optimization per study protocol
  - Post-PCI OCT

- **Pre-PCI IVUS**
  - IVUS guided PCI, per “local standard practice”
  - IVUS guided optimization, per “local standard practice”
  - Post-PCI OCT, blinded to investigator

- **Angiography**
  - Angiography guided PCI, per “local standard practice”
  - Angiographic optimization, per “local standard practice”
  - Post-PCI OCT, blinded to investigator

**Procedure Complete**

**OCT** 5.79 mm² [4.54, 7.34]  
**IVUS** 5.89 mm² [4.67, 7.80]  
97.5% one-sided CI: [-0.70, -]

**Pnoninferiority** = 0.001
ILUMIEN IV

2556-3568 pts with high-risk clinical or angiographic features undergoing PCI at 125 centers in the US, Canada, Western Europe, and Asia-Pacific

Randomize 1:1

OCT-guided* PCI
(modified ILUMIEN III protocol)

Angiography-guided PCI

Final OCT (blinded in angiography arm)

Follow-up: Minimum 1 year, maximum 2 years

Primary endpoints:
1) Minimal stent area (MSA) by OCT (powered for superiority)
2) Target vessel failure (event-driven, powered for superiority)

Principal Investigators: Ziad Ali and Ulf Landmesser
Study Chair: Gregg W. Stone

Sponsor: Abbott

HR clinical:
- Diabetes

HR angio:
- Troponin+ ACS culprit
- Stent length ≥28 mm
- 2-stent bifurcation
- Severe calcification
- CTO
- Diffuse/MF ISR

*ESRD not excluded
Safety of optical coherence tomography in daily practice: a comparison with intravascular ultrasound

Johannes N. van der Sijde1, Antonios Karanasos3, Nienke S. van Ditzhuijzen1,

3618 consecutive coronary imaging procedures: MACE 0%

Invasive imaging complications after adjudication

<table>
<thead>
<tr>
<th></th>
<th>OCT</th>
<th>IVUS</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient ST-elevation</td>
<td>3 (0.26)</td>
<td>2 (0.08)</td>
<td>0.2</td>
</tr>
<tr>
<td>Bradycardia</td>
<td>2 (0.18)</td>
<td>1 (0.04)</td>
<td>0.2</td>
</tr>
<tr>
<td>Coronary spasm</td>
<td>1 (0.09)</td>
<td>1 (0.04)</td>
<td>0.6</td>
</tr>
<tr>
<td>Thrombus formation</td>
<td>1 (0.09)</td>
<td>4 (0.16)</td>
<td>0.6</td>
</tr>
<tr>
<td>Dissection</td>
<td>0 (0.00)</td>
<td>3 (0.12)</td>
<td>0.2</td>
</tr>
<tr>
<td>Stent deformation</td>
<td>0 (0.00)</td>
<td>1 (0.04)</td>
<td>0.5</td>
</tr>
<tr>
<td>Major adverse events</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Values in n (%).

Van der Sijde et al. EHJ CV Img 2017
Intravascular Imaging Guided-PCI: Practical Strategy

- **Intravascular Imaging**
  - **Pre-Intervention Assessment**
    1. Assess plaque composition
    2. Identify reference segments
    3. Choose stent size
  - **Stent Deployment**
    4. Deploy normal-to-normal
    5. Determine expansion/MSA
  - **Complication and Post Procedural Assessments**
    6. Identify stent problems
       - Malapposition
       - Tissue Protrusion
    7. Identify edge problems
       - Edge dissection
       - Reference Segment Disease
Stent Expansion Criteria (non Left Main lesions)

<table>
<thead>
<tr>
<th>Study</th>
<th>Target</th>
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<tbody>
<tr>
<td>IVUS-XPL</td>
<td>MSA ≥ distal reference lumen area</td>
</tr>
<tr>
<td>CTO-IVUS</td>
<td>MSA ≥ distal reference lumen area &gt; than 5mm² at CTO</td>
</tr>
<tr>
<td>HOME DES</td>
<td>MSA &gt; than 5mm² or MSA ≥ 80% distal reference lumen area for small vessel</td>
</tr>
<tr>
<td>AVID</td>
<td>MSA ≥ 90% of distal reference lumen area</td>
</tr>
<tr>
<td>TULIP</td>
<td>MLD ≥ 80% of mean reference lumen diameters</td>
</tr>
<tr>
<td></td>
<td>MSA ≥ distal reference lumen area</td>
</tr>
<tr>
<td>OPTICUS</td>
<td>MSA ≥ 90% of mean reference lumen area or ≥ 100% of the reference with lowest lumen area</td>
</tr>
<tr>
<td>SIPS</td>
<td>MSA ≥ 90% of mean reference lumen area or ≥ 100% of the reference with lowest lumen area</td>
</tr>
<tr>
<td>RESIST</td>
<td>MSA ≥ 80% of mean reference lumen area</td>
</tr>
<tr>
<td>ILUMIEN 3</td>
<td>MSA ≥ 90% in proximal and distal reference segments relative to closest reference</td>
</tr>
<tr>
<td>OPINION</td>
<td>MSA ≥ 90% of average reference lumen area</td>
</tr>
<tr>
<td>DOCTORS OCTACS</td>
<td>MSA ≥ 80% of average reference lumen area</td>
</tr>
<tr>
<td></td>
<td>MSA ≥ 90% of average reference lumen area</td>
</tr>
</tbody>
</table>

Consensus Document

- MSA ≥ 80% of mean reference lumen area
- MSA > 5mm² by IVUS and 4.5mm² by OCT.

GET THE STENT MSA AS BIG AS YOU REASONABLY CAN
OCT Stent Sizing Algorithm

Pre-PCI OCT

Measure the EEL at both proximal and distal reference segments, if possible.

Can the EEL be identified at the distal reference segment to allow vessel diameter measurement?

Yes

Stent diameter decided by OCT measurement of mean EEL to EEL diameter rounded down to nearest stent size

Stent length determined by OCT automation adjusted for Xience DES

No

Stent diameter decided by OCT measurement of mean lumen diameter rounded up to nearest stent size

Adapted from slide by Ziad Ali
EXCEL trial
1095 with unprotected LMCAD randomized to CABG vs. PCI

IVUS sub-study (n=504)

Unpublished, courtesy Gary Mintz

Kang et al. Circ CV Intv 2011

Stent Expansion Criteria (Left Main lesions)

EXCEL trial
1095 with unprotected LMCAD randomized to CABG vs. PCI

IVUS sub-study (n=504)

Unpublished, courtesy Gary Mintz

Kang et al. Circ CV Intv 2011

Add 0.5 mm² for non-Asian or larger BSA patients
IVUS to Evaluate & Guide LM Lesion Severity/Revascularization

**LITRO trial**
354 patients, 22 Spanish centers
IVUS MLA <6mm² → revasc, ≤6mm² → defer

de la Torre Hernandez JM et al. JACC 2011
20% of ACS patients developed MACE within 3-years

12% of MACE were non-culprit lesion-related MACE

VH-IVUS defined TCFA encompassing 70% PB and an MLA ≤ 4 mm² harbored the highest (18%) 3.4-year per lesion chance of MACE

Stone G et al. NEJM 2011
Plaque compositional imaging: NIRS-IVUS

Light + tissue → absorb, scatter, emit
NIR wavelength is 780-2,500 nm
Chemical composition of tissue
Ideal for specific lipid detection in tissue
Near-Infrared Spectroscopy In STEMI

LCBI max ≥400 ≈ STEMI culprit

Madder R et al. JACC CV Intv 2013; Madder R et al. ATVB 2016
Case 1: Indeterminate left main and significant LAD disease (1)

60 yo obese diabetic male, ACS (TnT +ve), cath at OSH interpreted as significant LMCA + OM1 + prox-mid LAD, anti-phospholipid syndrome on Coumadin for recurrent DVT/PE. Sent for CABG.

IVUS LM: MLA >6mm²; iFR OM1 0.92-0.95, IVUS-guided PCI to LAD with 3 x 28 mm Synergy, PD with 3.5 mm NC balloon at 22A.
Case 1: Indeterminate left main and significant LAD disease (2)
Case 2: Stenting ‘cute’ into an LAD aneurysm

IVUS:
- Aneurysm neck: 6-6.5 mm
- LAD 4 mm

Rationale:
- Size stent for LAD and position stent 2-3 mm into neck of aneurysm and flare with PD balloon

4 x 16 mm Synergy, post-dilated with a 6.0mm Emerge balloon at 22A
Some Recent Developments in IVUS

HD-IVUS

Courtesy Dr A Fleischman
Irrespective of your preference/bias between IVUS and OCT…

→ ANY USE OF INTRAVASCULAR IMAGING IS STRONGLY RECOMMENDED DURING YOUR PCIs, supported by a wealth of evidence

→ learn how to use/interpret the images you take
Thank you!  purir@ccf.org