Intravascular Imaging in the Cath Lab

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Nothing to disclose
Intravascular Imaging in the Cath Lab

- Coronary angiography has been the most important imaging method to guide PCI
- We incorporate several advanced intravascular imaging modalities to allow operators to improve their performance and patient safety
Intravascular ultrasound (IVUS)

• catheter-based imaging technology

• uses reflected acoustic energy to generate high resolution, tomographic images of vascular structures in vivo

• 2 well defined ultrasound reflection interfaces can be observed in most of the vessels

Normal coronary artery
Plaque morphology by IVUS

- Soft (echolucent)
- Fibrous
- Calcific plaque
Quantitative measurements

Stenosis

- Lumen area
- Min diameter
- Max diameter
- EEM/vessel area
- Atheroma area
- Plaque burden

Reference segment

- Lumen area (LA)
- EEM area
- Atheroma area
- Plaque burden (PB)
Post-stent quantitative measurements

Distal reference lumen area

Minimum stent area (MSA)

Proximal reference lumen area

Stent expansion = $\frac{\text{MSA}}{\text{Average reference lumen area}} \times 100$

Maehara et al. JACC Cardiov Interv 2015
Post-intervention MSA was the strongest independent predictor of angiographic ISR (TAXUS)

Table 2. Univariate and Multivariate Predictors of ISR in TAXUS-Treated Patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>Odds Ratio (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Univariate analysis</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Pre-RVD (mm)</td>
<td>-0.9945</td>
<td>0.2455</td>
<td>0.37 (0.23–0.60)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Post-intervention IVUS MSA (mm²)</td>
<td>-0.2597</td>
<td>0.0688</td>
<td>0.77 (0.67–0.88)</td>
<td>0.0002</td>
</tr>
<tr>
<td>Sex</td>
<td>0.6088</td>
<td>0.2219</td>
<td>1.84 (1.19–2.84)</td>
<td>0.0061</td>
</tr>
<tr>
<td>Multiple study stents Implanted</td>
<td>0.5898</td>
<td>0.2464</td>
<td>1.80 (1.11–2.92)</td>
<td>0.0167</td>
</tr>
<tr>
<td>Multivariate analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-intervention IVUS MSA (mm²)</td>
<td>-0.2597</td>
<td>0.0703</td>
<td>0.77 (0.67–0.89)</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Doi et al. JACC Cardiov Interv 2009
MSA after PCI can predict early stent thrombosis and restenosis (SES, SIRIUS IVUS)

<table>
<thead>
<tr>
<th>Optimal Threshold</th>
<th>PPV</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SES (n = 72)</td>
<td>5.0 mm²</td>
<td>90%</td>
<td>76%</td>
<td>83%</td>
</tr>
<tr>
<td>BMS (n = 50)</td>
<td>6.5 mm²</td>
<td>56%</td>
<td>63%</td>
<td>78%</td>
</tr>
</tbody>
</table>

BMS = bare metal stents; PPV = positive predictive value; SES = sirolimus-eluting stents.
## MACE reduction in IVUS-guided PCI
(meta –analysis of DES randomized trials)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Incidence IVUS-Guided, % /Angiography-Guided, %</th>
<th>Model</th>
<th>OR*</th>
<th>95% CI</th>
<th>P Value</th>
<th>I²%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MACE</td>
<td>6.5/10.3</td>
<td>Peto</td>
<td>0.60</td>
<td>0.46–0.77</td>
<td>&lt;0.0001</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DL</td>
<td>0.65</td>
<td>0.52–0.82</td>
<td>&lt;0.0001</td>
<td>0</td>
</tr>
<tr>
<td>Cardiovascular mortality</td>
<td>0.5/1.2</td>
<td>Peto</td>
<td>0.46</td>
<td>0.21–1.00</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DL</td>
<td>0.51</td>
<td>0.24–1.12</td>
<td>0.09</td>
<td>0</td>
</tr>
<tr>
<td>MI</td>
<td>0.8/1.5</td>
<td>Peto</td>
<td>0.52</td>
<td>0.26–1.02</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DL</td>
<td>0.60</td>
<td>0.31–1.17</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>TLR</td>
<td>4.1/6.6</td>
<td>Peto</td>
<td>0.60</td>
<td>0.43–0.84</td>
<td>0.003</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DL</td>
<td>0.62</td>
<td>0.45–0.86</td>
<td>0.004</td>
<td>0</td>
</tr>
<tr>
<td>TVR</td>
<td>5.5/8.7</td>
<td>Peto</td>
<td>0.61</td>
<td>0.41–0.91</td>
<td>0.02</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DL</td>
<td>0.63</td>
<td>0.43–0.92</td>
<td>0.02</td>
<td>0</td>
</tr>
<tr>
<td>Stent thrombosis</td>
<td>0.6/1.3</td>
<td>Peto</td>
<td>0.49</td>
<td>0.24–0.99</td>
<td>0.04</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DL</td>
<td>0.57</td>
<td>0.26–1.23</td>
<td>0.15</td>
<td>0</td>
</tr>
</tbody>
</table>

Assessment of intermediate LM coronary lesions

(2011 ACCF/AHA/SCAI guidelines)

Class IIa
1. IVUS is reasonable for the assessment of angiographically indeterminant left main CAD.\(^{489-491}\)
   (Level of Evidence: B)

\[
\text{Angiographic 30-60\% Diameter Stenosis} \\
\quad \downarrow \\
\begin{align*}
\text{MLA < 6.0 mm}^2 & \quad \text{MLA \geq 6.0 mm}^2 \\
\quad \downarrow & \quad \downarrow \\
\text{FFR or Non-invasive Stress Test} & \quad \text{Defer Revascularization}
\end{align*}
\]
Assessment of intermediate non–LM coronary lesions

Class IIb
1. IVUS may be reasonable for the assessment of non–left main coronary arteries with angiographically intermediate coronary stenoses (50% to 70% diameter stenosis).489,496,497 (Level of Evidence: B)

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McDaniel et al. JACC Cardiov Interv 2011
Near-infrared spectroscopy (NIRS)

- Characterizes lipid content of plaques
- Chemogram displays low probability of lipid as red and high probability as yellow
- The lipid core burden index (LCBI) indicates the amount of lipid on a 0 to 1000 scale
• Rapid detection of large Lipid Rich Plaques (LRP)
• MaxLCBI4mm ≥ 500 was associated with a high risk of peri-procedural MI (Goldstein 2011)
• MaxLCBI4mm > 400 was a signature of plaques causing STEMI (Madder 2013).
## Optical Coherence Tomography (OCT)

Optical Coherence Tomography (OCT) uses near-infrared light reflectance to produce high-resolution *in vivo* images of vessel anatomy, tissue microstructure and stents.

<table>
<thead>
<tr>
<th></th>
<th>OCT</th>
<th>IVUS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Axial Resolution</strong></td>
<td>10 – 15 µm</td>
<td>100 – 200 µm</td>
</tr>
<tr>
<td><strong>Frame Rate</strong></td>
<td>180 frames/s</td>
<td>30 frames/s</td>
</tr>
<tr>
<td><strong>Pullback Speed</strong></td>
<td>36 or 16 mm/s</td>
<td>0.5 - 1 mm/s</td>
</tr>
<tr>
<td><strong>Max. Scan Diameter</strong></td>
<td>10 mm</td>
<td>15 mm</td>
</tr>
<tr>
<td><strong>Tissue Penetration</strong></td>
<td>1.5 - 3.0 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td><strong>Blood Clearing</strong></td>
<td>Required</td>
<td>Not Required</td>
</tr>
</tbody>
</table>
Pre-PCI lesion assessment

Minimal lumen area (MLA), distal and proximal reference diameter/areas, lesion length, and diameter stenosis (DS)
Normal coronary artery wall by OCT

3-layered structure:
• signal-rich intima
• low backscattering/signal-poor media
• heterogeneous and frequently highly backscattering adventitia
Plaque morphology by OCT

Signal-rich, relatively homogeneous
- **Fibrous**
  - Visible media layer
  - Invisible media layer

Signal-poor area
- Poorly delineated diffuse border
  - **Lipid**
    - Thin-cap fibroatheroma (TCFA)
    - Thick-cap fibroatheroma
  - Calcification
    - Visible luminal & abluminal border
    - Invisible abluminal border
Red thrombus

- red blood cell-rich
- high signal attenuation
- resulting in shadowing

White thrombus

- platelet-rich thrombus
- little signal attenuation
- underlying vessel structure can be easily visualized
ACS culprit lesion assessment with OCT

Plaque rupture (PR)
ACS culprit lesion assessment with OCT

Plaque erosion (PE)
ACS culprit lesion assessment with OCT

Calcific nodule (CN)

(Jia et al. JACC 2013)
Incidence of plaque rupture, plaque erosion and calcific nodule

- PR is the most common underlying mechanism responsible for ACS
- OCT-Erosion patients are youngest; most often present with NSTEMI; have lower frequency of lipid plaques and the least severe luminal stenosis
- OCT-CN patients were oldest

“...it is conceivable that patients with OCT-erosion might be stabilized by effective antithrombotic treatment without stent implantation. “

Jia et al. JACC 2013
Post-stent quantitative measurements by OCT

Distal reference lumen area: 4.86 mm²
Minimum stent area (MSA): 4.77 mm²
Proximal reference lumen area: 6.10 mm²

Stent expansion = MSA/Average reference lumen area*100
OCT findings after stent implantation

- Malapposition
- In-stent dissection
- Thrombus
- Plaque protrusion
- Stent underexpansion
- Edge dissection

MSA = 1.6 mm²
Thrombus

Protrusion

Instent dissection
Clinical impact of OCT findings after PCI (CLI-OPCI II)
(1000 lesions, 1 year follow-up)

<table>
<thead>
<tr>
<th>Predictors of MACE</th>
<th>HR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-stent minimum lumen area &lt;4.5 mm²</td>
<td>1.64 (1.1-2.6)</td>
<td>0.040</td>
</tr>
<tr>
<td>Distal dissection &gt;200 μm</td>
<td>2.54 (1.3-4.8)</td>
<td>0.004</td>
</tr>
<tr>
<td>Proximal dissection &gt;200 μm</td>
<td>0.83 (0.4-1.9)</td>
<td>0.65</td>
</tr>
<tr>
<td>In-stent lumen underexpansion*</td>
<td>1.21 (0.7-1.9)</td>
<td>0.45</td>
</tr>
<tr>
<td>Malapposition &gt;200 μm</td>
<td>1.15 (0.8-1.7)</td>
<td>0.52</td>
</tr>
<tr>
<td>Intrastent plaque/thrombus protrusion &gt;500 μm</td>
<td>1.00 (0.6-1.6)</td>
<td>0.99</td>
</tr>
<tr>
<td>Distal reference narrowing†</td>
<td>4.65 (2.5-8.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Proximal reference narrowing†</td>
<td>5.73 (2.2-14.6)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Distal edge dissection > 200 μm
MLA < 4.5 mm²
REF LA < 4.5 mm² in the presence of significant plaque

Prati et al. JACC Cardiov Imaging 2015
OCT Compared to IVUS and Angiography to Guide Coronary Stent Implantation (ILUMIEN II)

- Limited penetration depth of OCT prevents detection of the vessel size (EEM)

- Does routine OCT guidance result in a similar stent expansion compared to IVUS?

- The degree of stent expansion was not significantly different between OCT and IVUS guided PCI

**Table 3: Quantitative Intravascular Imaging in the Propensity-Matched Groups**

<table>
<thead>
<tr>
<th>Stent measurements</th>
<th>OCT (N = 286)</th>
<th>IVUS (N = 286)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expansion, %</td>
<td>72.8 (63.3, 81.3)</td>
<td>70.6 (62.3, 78.8)</td>
<td>0.29</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>259 (90.6)</td>
<td>266 (93.0)</td>
<td>0.26</td>
</tr>
<tr>
<td>&lt;60%</td>
<td>50 (17.5)</td>
<td>54 (18.9)</td>
<td>0.66</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>22 (7.7)</td>
<td>14 (4.9)</td>
<td>0.18</td>
</tr>
<tr>
<td>Lumen expansion, %</td>
<td>71.1 (62.1, 80.4)</td>
<td>70.0 (61.9, 78.7)</td>
<td>0.40</td>
</tr>
<tr>
<td>Mean stent expansion, %</td>
<td>89.6 (79.7, 98.1)</td>
<td>86.2 (76.6, 94.1)</td>
<td>0.17</td>
</tr>
<tr>
<td>Mean lumen expansion, %</td>
<td>91.8 (80.9, 99.9)</td>
<td>86.0 (76.9, 93.9)</td>
<td>0.001</td>
</tr>
<tr>
<td>Minimal stent CSA, mm²</td>
<td>5.0 (3.9, 6.4)</td>
<td>5.5 (4.4, 7.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Minimal lumen CSA, mm²</td>
<td>5.0 (4.0, 6.3)</td>
<td>5.5 (4.4, 6.9)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean stent CSA, mm²/mm</td>
<td>6.4 (5.1, 7.8)</td>
<td>6.7 (5.5, 8.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean lumen CSA, mm²/mm</td>
<td>6.5 (5.3, 7.9)</td>
<td>6.7 (5.5, 8.3)</td>
<td>0.002</td>
</tr>
<tr>
<td>Reference measurements, mm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximal reference largest lumen CSA</td>
<td>8.3 (6.2, 10.7)</td>
<td>8.8 (7.1, 11.2)</td>
<td>0.02</td>
</tr>
<tr>
<td>Proximal reference minimum lumen CSA</td>
<td>5.6 (4.3, 7.5)</td>
<td>7.4 (5.8, 9.5)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Distal reference largest lumen CSA</td>
<td>6.1 (4.7, 7.7)</td>
<td>6.9 (5.3, 9.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Distal reference minimal lumen CSA</td>
<td>3.9 (2.9, 5.4)</td>
<td>5.8 (4.4, 7.5)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Values are median (first, third quartiles) or n (%). CSA = cross-sectional area; other abbreviations as in Table 1.
Randomization 1:1:1

Patients undergoing PCI

Angiography Guidance

IVUS Guidance

OCT Guidance

Primary End Point: Post-PCI MSA

OCT Compared to IVUS and Angiography to Guide Coronary Stent Implantation (ILUMIEN III)
IVUS vs. OCT

• IVUS can measure stenosis severity, plaque burden, calcification, and remodeling

• IVUS can identify lesions in which revascularization can be safely deferred, guide PCI and stent placement

• OCT provides several advantages over IVUS in lesion characterization, detection of post-PCI complications and PCI optimization

• Data from properly powered, randomized trials are needed to further refine the role and clinical utility of OCT
Multimodality Intravascular Imaging to Evaluate Sex Differences in Plaque Morphology in Stable CAD

Plaque Morphology Predictors of Side Branch Occlusion after Main Vessel Stenting in Coronary Bifurcation Lesions
Optical Coherence Tomography Imaging Study

Basic Science Review
Optical Coherence Tomography Assessment of the Mechanistic Effects of Rotational and Orbital Atherectomy in Severely Calcified Coronary Lesions
Aggressive statin therapy resulted in significant reduction in the lipid content of coronary plaques by NIRS in a short time frame.
Aim: to assess the changes in plaque morphology using multimodality intravascular imaging, in HDL functionality (cholesterol efflux capacity) and inflammatory cell activity (microarray) after high-dose statin treatment.
Aim: to identify the predictors of side branch ostial stenosis (SBOS) developed after main vessel (MV) stenting using OCT

Patients: 30 patients with bifurcation lesions not involving the SB ostium, (1,1,0), (1,0,0), or (0,1,0), were included

SBOS > 50% by 3D-QCA was observed in 10 (33%) patients.

Maximal lipid arc by OCT and the presence of contralateral lipid were independent predictors of SBOS > 50% by multivariable statistical analysis.
ORBID representative case

**ORBID-FFR**

**PRE**

- SBOS - 23%

**POST**

- SBOS - 65%
- 1.64 mm²
- 0.66 mm² (60% reduction)

*Kini et al. CCI 2016*
Thank you!!!