Physiological Assessment and Intra-Coronary Imaging in the Cath Lab

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Why does the angiogram fail?

Severe narrowings?
Angiography Has Major Limitations in Assessing Complicated Lesions

Limitations of Coronary Angiography

• Coronary angiography does not reliably detect the hemodynamic significance of coronary stenosis
• Coronary angiography does not reliably delineate the anatomy of coronary lesions
IC Imaging: ANATOMY

Functional assessment: PHYSIOLOGY
Improved Assessment of Coronary Lesions

- Fractional Flow Reserve (FFR):
  - Accurate assessment of hemodynamic significance
- Intravascular imaging (IVUS/OCT):
  - Precise visualization of intracoronary anatomy
Anatomy Vs. Physiology

Two clinical settings:
1. Is PCI indicated?
2. Technical aspects of PCI:
   - Characterization of lesion
   - Is the PCI result optimal?
   - ....
FFR = P dist / P prox
## Fractional Flow Reserve (FFR)

<table>
<thead>
<tr>
<th>FFR Condition</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR &gt; 0.8</td>
<td>Normal</td>
</tr>
<tr>
<td>FFR: 0.75-0.8</td>
<td>?</td>
</tr>
<tr>
<td>FFR &lt; 0.75</td>
<td>Ischemia</td>
</tr>
</tbody>
</table>
ComboWire 1.5 cm offset

Modular Plug for Pressure

Connects to Pimmette of ComboMap model 6800

Included torque device

ComboWire 0.0 cm offset

Row Sensor

RADIOPAQUE COIL

Pressure Sensor

Flow Sensor

4.7cm

155cm Blue PTFE Coating

Soft Tip 29cm JET Coating

185cm Working Length

ComboWire Configuration

Proximal End

Contacts

0.014" Diameter

ComboWire Shaft

Flexible Coil

Radiopaque Coil

Tip
Microvascular hyperemia: Adenosine

- Adenosine: 6mg/500cc NS (12mcg/cc)
- IC boluses:
  - 60 mcg (5 cc)
  - 96 mcg (8 cc)
  - 120 mcg (10 cc)
- IV drip 140 mcg/Kg/Min
A: FFR=1.00
B: FFR=0.65
FAME study

1005 patients with stenosis >50% randomized: PCI or FFR (PCI if FFR<0.8)

<table>
<thead>
<tr>
<th></th>
<th>PCI</th>
<th>FFR</th>
<th># stents</th>
<th>P</th>
<th>PCI</th>
<th>FFR</th>
<th>1-yr D/MI/TVR</th>
<th>P</th>
<th>PCI</th>
<th>FFR</th>
<th>1-yr angina-free</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td># stents</td>
<td>2.7</td>
<td>1.9</td>
<td></td>
<td>&lt;0.001</td>
<td>18.3</td>
<td>13.2</td>
<td></td>
<td>&lt;0.02</td>
<td>78</td>
<td>81</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>1-yr D/MI/TVR</td>
<td></td>
<td></td>
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FAME NEJM 2009;360:213-24
LDCMC Analysis:
First 20 FFR Cases in Intermediate Lesions

• Mean FFR = 0.85±0.08 (range: 0.71-1.00)
• FFR<0.80 was measured in only 5 stenoses (25%)
• Comparison of FFR to opinion of 2 experienced cardiologists
The graph shows the percentage of patients with FFR<0.8 and MD-1. The percentage of patients with FFR<0.8 is 25% and the percentage of patients with MD-1 is 60%.
The bar chart shows the percentage of different conditions:

- FFR < 0.8:
  - 25%

- MD-1:
  - 60%

- MD-2:
  - 95%
FFR = 0.84
Potential Limitations of FFR

• False negative: ACS, Microvascular disease, Elevated RAP
• LMCA / CABG graft lesions - excluded from FAME
• Assessment of optimal PCI result
IVUS / OCT

- Accurate visualization of coronary anatomy
- Analysis of plaque composition & distribution, vessel and lumen geometry
- Identify dissections, stent apposition etc...
- Virtual histology
IVUS Transducers

A: Mechanical rotating transducer
B: Electronic phased array
Measurement and Analysis
Calculating - Area and % Stenosis

D(mm) = 0.0
A1 = 5.9mm²
Calculating - Area and % Stenosis

D(mm) = 0.0
Al = 5.9mm²
A2 = 15.3mm²
%Sten = 82.9
%Dia = 38.9

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Lumen Diameter Measurements
Vessel Diameter Measurements
Angiography Cannot Account for Coronary Remodeling
Angiography Masks Complicated Lesions
IVUS GUIDED STENT DEPLOYMENT
IVUS GUIDED STENT DEPLOYMENT

A: 3.5 mm balloon, 6 atm
B: 4.0 mm balloon, 18 atm
C: 4.0 mm balloon, 23 atm
Calcified plaque (continued)

180° arc of eccentric superficial calcified plaque

270° arc of superficial calcified plaque
How many previous stents have been placed in this lesion?

1) 1
2) 2
3) 3
How many previous stents have been placed in this lesion?

2) 2

Reflection of the stent as the sound wave bounces between stent and catheter (reverb)
The most likely cause of this image is:

1) Inadequate flushing
2) Bend in catheter
3) Calcified Plaque
4) Wrong Frequency
The most likely cause of this image is:

2) Bend in catheter

A bend in a mechanical IVUS catheter may cause unnecessary friction and generate Non-Uniform Rotational Distortion (NURD), which results in a smeared image. This effect can be minimized by removing bends in the catheter and checking the tension on the Y-adaptor. NURD can also occur when imaging in tortuous anatomy.
What is the present diameter of the stent?

1) 2.0mm
2) 2.5mm
3) 3.0mm
4) 4.5mm
5) 4.0mm
What is the present diameter of the stent?

2) 2.5 mm

Since each division is 1 mm, the diameter is approximately 2.5 mm.
What size balloon should be used to adequately deploy this stent?

1) 3.0 mm
2) 4.0 mm
3) 5.0 mm
What size balloon should be used to adequately deploy this stent?

2) 4.0mm

The external elastic lamina (EEL) appears to be 4.0 mm and the lesion is primarily fibrofatty plaque. Therefore, a 4.0 mm balloon should produce the desired result.
**IVUS**

- Threshold for PCI (vs FFR/CFR)
  - LMCA: CSA=6 mm$^2$
  - Prox vessels: CSA=4 mm$^2$
- Missing: Robust outcome data
- IVUS less specific than FFR for ischemia
- “If you want PCI then IVUS, if not-then FFR”
• 48-year old woman
• Extensive anterior STEMI with RBBB
• Cardiogenic shock
• Cardiac arrest-2.5 hours CPR with 20 DC shock
• Finally located and stented an anomalous origin LMCA
Same Lumen Size: Different Atheromas

Thin Cap With Lipid Core

Thick Stable Fibrotic Cap
**Fibrous**
Densely packed bundles of collagen fibers with no evidence of intra-fiber lipid accumulation. No evidence of macrophage infiltration. Appears dark yellow on Movat stained section.

**Fibrous tissue**

**Lipid Core**
Highly lipidic necrotic region with remnants of foam cells and dead lymphocytes present. No collagen fibers are visible and mechanical integrity is poor. Cholesterol clefts and micro calcifications are visible.

**Lipid Core**

**Fibro-lipidic**
Loosely packed bundles of collagen fibers with regions of lipid deposition present. These areas are cellular and no cholesterol clefts or necrosis are present. Some macrophage infiltration. Increase in extracellular matrix. Appears turquoise on Movat stained section.

**Fibro-lipidic region**

**Calcium**
Focal area of dense calcium. Appears purple on Movat. Usually falls out section, but calcium crystals are evident at borders.

**Calcium**

Kern SCAI 2006
intimal thickening

thick-cap fibroatheroma

Maehara Circ Cardiovasc Intervent. 2009;2:482-490
IVUS vs. OCT

IVUS Resolution = 150 microns
OCT Resolution = 10 microns
<table>
<thead>
<tr>
<th></th>
<th>OCT</th>
<th>IVUS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resolution</strong></td>
<td>15 µm</td>
<td>100 µm</td>
</tr>
<tr>
<td><strong>Penetration</strong>*</td>
<td>2 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td><strong>Penetration requires blood clearance</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
The Future?
• 51 year-old diabetic woman
• Atypical angina
• ? Positive exercise test

Angiography:
≈ 50% stenosis in ostial LAD
CSA = 4.1 MM²
CSA = 4.1 mm$^2$
Plaque volume 59 mm$^3$
• Decision not to perform PCI

• Medical therapy: Lipitor and Aspirin

• Follow-up CTA after 1 year
CSA = 6.3 mm$^2$
Plaque volume 32 mm$^3$
Conclusions
Conclusions

• IVUS/OCT and FFR are complementary techniques
• “Is PCI indicated?”
  – Shift from anatomic revasc to physiological revasc-FFR more applicable
  – IVUS has a role in LMCA and prox LAD

• “Is PCI result optimal?”
  – IVUS preferred
Thank-you
FAME study

1005 patients with stenosis > 50% randomized: PCI or FFR (PCI if FFR < 0.8)

# stents

- P < 0.001

D/MI/TVR

- P < 0.02

No angina

- P = NS

FAME NEJM 2009;360:213-24
For a 30-40 MHz IVUS transducer:
Axial resolution = 80-100 µ
Lateral resolution = 200-250 µ

\[ a = \text{Axial Resolution} \]
\[ l = \text{Lateral Resolution} \]
Case A: non-STR case

Percentage of each plaque component at the MLA site
- Plaque area: 12.2 mm²
- Lumen area: 3.7 mm²
- fibrous: 73.8 %
- necrotic core: 3.5 %
- fibro-lipid: 14.8 %
- dense-calcium: 7.8 %

Each plaque component volume
- Total volume: 131.1 mm³
- fibrous: 79.2 mm³
- necrotic core: 3.9 mm³
- fibro-lipid: 41.8 mm³
- dense-calcium: 6.2 mm³

Case B: STR case

Percentage of each plaque component at the MLA site
- Plaque area: 9.8 mm²
- Lumen area: 3.7 mm²
- fibrous: 46.0 %
- necrotic core: 36.7 %
- fibro-lipid: 5.1 %
- dense-calcium: 12.2 %

Each plaque component volume
- Total volume: 112.8 mm³
- fibrous: 59.4 mm³
- necrotic core: 37.1 mm³
- fibro-lipid: 7.1 mm³
- dense-calcium: 9.2 mm³
Fractional Flow Reserve (FFR)

- FFR = Distal coronary / Aortic pressure during maximal hyperemia
- Normal FFR = 1.0
- FFR < 0.75 accurately identifies stenosis associated with inducible ischemia
- FFR 0.75-0.80: Grey zone