Optical Coherence Tomography for Intracoronary Imaging

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Stephan Windecker

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Bern University Hospital, Switzerland
# OCT vs Other Imaging Modalities

<table>
<thead>
<tr>
<th></th>
<th>OCT</th>
<th>IVUS</th>
<th>CA</th>
<th>MSCT</th>
<th>MRI</th>
<th>Angioscopy</th>
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<tbody>
<tr>
<td>Resolution (µm)</td>
<td>5-20</td>
<td>80-150</td>
<td>200</td>
<td>300</td>
<td>300</td>
<td>200</td>
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<tr>
<td>Time aspect I</td>
<td>Real-time</td>
<td>Real-time</td>
<td>Real-time</td>
<td></td>
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<td>Real-time</td>
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<tr>
<td>Time aspect II</td>
<td>2-50 sec</td>
<td>20-50 sec</td>
<td></td>
<td></td>
<td></td>
<td>30 sec</td>
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<tr>
<td>Type of scan source</td>
<td>IR-light</td>
<td>Ultrasound</td>
<td>X-Ray</td>
<td>X-Ray</td>
<td>Magnetic res</td>
<td>Visible light</td>
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<td>Imaging target</td>
<td>Layer</td>
<td>Layer</td>
<td>Bloodflow</td>
<td>Density</td>
<td>Density</td>
<td>Surface</td>
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</tbody>
</table>
FD-OCT Imaging for In-Vivo Evaluation of Stent Healing

Templin C et al. *Eur Heart J* 2010

**Neointima Thickness**

**Strut Coverage**
Safety and Feasibility of FD-OCT Imaging

Imola F et al. *EuroIntervention* 2010;6:575-81

Success 99%

Duration 2.1±0.5 min

Contrast 49±19 ml

VT/VF 0%

MACE 0%
OCT for Intracoronary Imaging

**Atherosclerosis**
- Normal Vessel Wall
- Different Plaque Types
- Plaque Progression
- Plaque Rupture

**Stent Evaluation**
- Neointimal Hyperplasia
- Pattern of Restenosis
- Strut Coverage and Apposition
- Stent thrombosis
Tunica Intima

A1

B1

C1

A2

B2

C2
Value of Combined Assessment
Grayscale IVUS, IVUS-VH and OCT

Vulnerable Plaque characteristics

- Fibrous cap thickness
- Detailed surface morphology
- Visualization of entire plaques
- Plaque composition
- Differentiation lipid vs calcium

OCT

IVUS-VH

Thin cap fibroma-atheroma TCFA Detection Algorithm?
OCT/IVUS VH TCFA Detection Algorithm

AIT = adaptive intimal thickening
NC = necrotic core
FF = fibrofatty
DC = dense calcium
FC = fibrocalcic
FT = fibrotic
Ca FA = calcium fibroatheroma
FA = fibroatheroma
Ca TCFA = ca-thin-cap-fibroatheroma
TCFA = thin-cap-fibroatheroma

Plaque thickness >600 µm, >3 frames
Confluent NC >10% (VH)
Fibrous cap <65 microns by OCT

©Comfortable - IBIS 4

Courtesy: Hector Garcia
OCT/IVUS VH TCFA Detection Algorithm

- AIT = adaptive intimal thickening
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- FC = fibrocalcic
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©Comfortable

Courtesy: Hector Garcia
Fibrous plaque

Fibrocalcific plaque
Incidence of TCFA and Plaque Rupture Stratified by Lesion Severity

<table>
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<tr>
<th>AIT</th>
<th>FT</th>
<th>No</th>
<th>Yes</th>
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<tr>
<td>PIT</td>
<td>No</td>
<td>Yes</td>
<td></td>
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<td>FC</td>
<td>Ca FA</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>FT</td>
<td>FA</td>
<td></td>
<td></td>
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<tr>
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<td>Ca TCFA</td>
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</tr>
<tr>
<td>TCFA</td>
<td>= thin-cap-fibroatheroma</td>
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</table>
Screening of all incoming STEMI patients

Recanalisation, aspiration, intra- and extracoronary blood sampling

Imaging Candidate if
- Hemodynamic stable
- Creatinine Clearance > 50ml/min
- Age < 90
- OCT/IVUS feasible
- No stent at the site of infarct lesion

Comfy AMI IBIS 4 n=1100

IBIS 4 n=100

1:1

Principal Investigators
Lorenz Räber
Hector Garcia Garcia
Stephan Windecker

Participating sites
Bern (60)
Copenhagen (21)
Geneva (13)
Lugano (6)
Zurich (3)

Comfortable AMI IBIS 4 n=1100

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3 vessel imaging using IVUS Virtual Histology:
- Culprit vessel: Post-treatment imaging of the stented segment and distal segment
- Non-culprit vessel: >40 mm of proximal coronary artery
Comfortable – IBIS 4 study

3 vessel imaging using IVUS Virtual Histology:
- Culprit vessel: Post-treatment imaging of the stented segment and distal segment
- Non-culprit vessel: >40 mm of proximal coronary artery

Primary Objective: • To determine the effects of rosuvastatin on compositional measures of coronary plaque in a non-intervened coronary segment. Specifically, the change from baseline in Virtual Histology™ necrotic core volume at the end of week 52.
3 vessel imaging using OCT:

- Culprit vessel: Post-treatment imaging of the stented segment and distal segment
- Non-culprit vessel: >40 mm of proximal coronary artery
Comforatable – IBIS 4 study

3 vessel imaging using OCT:
- Culprit vessel: Post-treatment imaging of the stented segment and distal segment
- Non-culprit vessel: >40 mm of proximal coronary artery

Secondary Objective

• To determine the effects of rosuvastatin on fibrous cap thickness of coronary plaque in a non-intervened coronary segment. Specifically, the change from baseline in OCT cap thickness at the end of week 52.
Progression of Atherosclerosis

61 yo male

Cardiovascular risk factors
- Diabetes mellitus
- HTN
- Hypercholesterolemia

Acute STEMI Nov 2009 with occlusion of RCA
- Primary PCI of RCA
- Included into Comfortable AMI - IBIS 4 trial
  - 3 vessel baseline imaging: OCT/IVUS/IVUS VH
- Discontinuation of Rosuvastatin (40mg) after 2 months with change to Atorvastatin (20mg) during 11 months

- Invasive 3 vessel imaging @ 13 months follow-up
Ruptured TCFA in non-target vessel of STEMI Patient
Post PCI Result of Culprit Lesion in Proximal RCA
OCT for Intracoronary Imaging

**Atherosclerosis**
- Normal Vessel Wall
- Different Plaque Types
- Plaque Progression
- Plaque Rupture

**Stent Evaluation**
- Neointimal Hyperplasia
- Pattern of Restenosis
- Strut Coverage and Apposition
- Stent thrombosis
Neointimal Thickness Distribution in the OCT Substudy of the LEADERS Trial

Barlis et al. *Eur Heart J* 2010

![Graph showing neointimal thickness distribution with visualization by IVUS and missed by IVUS percentages.]

- Neointimal thickness visualised by IVUS: 27.65%
- Neointimal thickness missed by IVUS: 72.4%
Spectrum of Neointimal Response at Five Year Follow-up
SIRTAX LATE OCT Study
OCT Assessment of Neointimal Thickness At Various Time Points After DES Implantation

Mean Neointimal Thickness

3 Months

6 Months

9 Months

2 Years

- Mean Neointimal Thickness:
  - 3 Months: 29 μm (Takano 2007)
  - 6 Months: 57 μm (Matsumoto 2007)
  - 9 Months: 57 μm (Barlis 2009)
  - 2 Years: 86 μm (Kim 2009)
  - 71 μm (Xie 2008, Takano 2008)
Strut Coverage As Marker of Endothelialization

Finn A et al. *Circulation* 2007;115:2435-41

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DES Lesions With Thrombus (n=28)</th>
<th>DES Lesions Without Thrombus (n=34)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration, d</td>
<td>173 (66, 433)</td>
<td>127 (31, 400)</td>
<td>NS</td>
</tr>
<tr>
<td>External elastic lamina area, mm²</td>
<td>17.2±4.6</td>
<td>13.2±5.2</td>
<td>0.002</td>
</tr>
<tr>
<td>Stent area, mm²</td>
<td>7.5±2.0</td>
<td>6.7±3.2</td>
<td>0.02</td>
</tr>
<tr>
<td>Plaque area, mm²</td>
<td>9.7±3.9</td>
<td>6.5±3.7</td>
<td>0.003</td>
</tr>
<tr>
<td>Neointimal thickness, mm</td>
<td>0.074 (0.033, 0.129)</td>
<td>0.11 (0.071, 0.19)</td>
<td>0.05*</td>
</tr>
<tr>
<td>Fibrin score</td>
<td>2.4±1.3</td>
<td>1.2±1.1</td>
<td>0.002</td>
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<tr>
<td>Endothelialization, %</td>
<td>40.5±29.8</td>
<td>80.0±25.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Uncovered struts/section, n</td>
<td>5.0±2.7</td>
<td>2.0±2.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Stent length without neointima, mm</td>
<td>20.1±11.5</td>
<td>9.9±10.1</td>
<td>0.0004</td>
</tr>
<tr>
<td>Mean interstrut distance, mm</td>
<td>0.52±0.24</td>
<td>0.70±0.25</td>
<td>0.004</td>
</tr>
<tr>
<td>Uncovered struts/total struts per section</td>
<td>0.50±0.23</td>
<td>0.19±0.25</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

The morphometric parameter *uncovered struts/total struts* correlated best with histologic endothelialization.
Evaluation of Coverage and Apposition During Long-term Follow-up
SIRTAX LATE OCT Study

A Area Lumen: 10.91mm²
B Area Stent: 9.13mm²
C Area Helpline Lumen: 11.23mm²
D Thickness Protruding: 0.26mm
E Thickness: 0.13mm
F Thickness: 0.00mm
G Thickness ISA: -0.41mm
H Thickness ISA: -0.37mm
I Length: 0.14mm
J Thickness: 0.00mm
K Length: 0.14mm
L Thickness: 0.10mm

Covered Uncovered
Protruding
Malapposed
LEADERS - OCT Substudy

Barlis P et al. Eur Heart J 2010

Lesions With At Least 5% Uncovered Struts

Biolimus Stent

Sirolimus Stent

-45.5
(-76.9 to –14.3)

P<0.01

BioMatrix
N=29

CYPHER
N=35

29 Lesions

35 Lesions
# Importance of Healing Pattern

<table>
<thead>
<tr>
<th></th>
<th>Clustering</th>
<th>Homogenous</th>
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<tbody>
<tr>
<td>Total stent struts</td>
<td>320</td>
<td>350</td>
</tr>
<tr>
<td>Apposed</td>
<td>300 (93.75%)</td>
<td>330 (94.29%)</td>
</tr>
<tr>
<td>Malapposed / Protruding</td>
<td>20 (6.25%)</td>
<td>20 (5.71%)</td>
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</table>
Stent Strut Vessel Wall Interaction

Case report: 34 YO white man with an acute coronary syndrome in 2003

Subtotal proximal LAD stenosis
October 2003

Postprocedural result after SES 3.5x8mm implantation
Stent Strut Vessel Wall Interaction

Follow up 3 March 2009
SIRTAX LATE Angiography and OCT
Stent Strut Vessel Wall Interaction
24 May 2009
Definite stent thrombosis
Patient taking aspirin but not clopidogrel
B.Z., 07.02.1941

69 YO white male with several cardiac risk factors and complex history of CAD

**Anterior STEMI in 1991 s/p CABG**
- Left internal mammary artery to LAD
- Saphenous vein graft to RCA

**Recurrent STEMI in 1994**
- Occluded LIMA graft
- Primary PCI of mid-LAD with use of bare metal stent

**Inferior STEMI in 2003**
- Occluded SVG to RCA
- Primary PCI of native RCA with use of bare metal stent

**Anterior STEMI on July 28, 2008**
B.Z., 07.02.1941

Anterior STEMI on July 28, 2008

Complete thrombotic occlusion of proximal LAD

Primary PCI

Implantation of 2 everolimus-eluting stent
3.0x28mm + 3.5x10mm
• 20 months later….

• Onset of typical chest pain at 09:15 AM on April 2, 2010. Patient was on ASA 100mg qd on a regular basis

• Diagnosis of an acute anterior STEMI in referring hospital

• Administration of ASA 500mg iv, Clopidogrel 600mg po, UFH 5000 IE iv, and Morphine

• Arrival of a hemodynamically stable patient with modest chest pain in the cathlab at 11:30 AM
B.Z., 07.02.1941

Anterior STEMI on July 28, 2008

Complete thrombotic occlusion of proximal LAD

Primary PCI

Implantation of 2 everolimus-eluting stent
3.0x28mm + 3.5x10mm
• Delayed healing?
• Lack of endothelialization?
• Vessel remodelling?
• Malapposition?
• Restenosis?
EEM  Lumen  Stent  Thrombus
A) Aspirated platelet-fibrin rich thrombus
B) Numerous neutrophils interspersed with few chronic inflammatory cells in platelet rich region
C) Luna stain highlighting frequent eosinophils (15%)

Histological analysis by
Elena Ladich, MD
Renu Virmani, MD

CVPath Institute, Inc.
B.Z., 07.02.1941

Thrombus aspiration followed by balloon dilatation of the thrombosed segment

Balloon dilatation (3.5x20mm, 20atm)

Final angiographic result
OCT for Intracoronary Imaging

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