Intravascular ultrasound (IVUS), VH-IVUS and OCT for interventional procedures

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Krakow, Poland
Angiography

2 dimensional

Planar

Shadow of lumen

Wall structures not imaged

Vessel is seen for a very short time during contrast injection

QCA analysis with mistakes
## Angiography vs. IVUS

<table>
<thead>
<tr>
<th>Angiography</th>
<th>IVUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 dimensional</td>
<td>360° view</td>
</tr>
<tr>
<td>Planar</td>
<td>Tomographic and sagittal</td>
</tr>
<tr>
<td>Shadow of lumen</td>
<td>Visualization of shape and location</td>
</tr>
<tr>
<td>Wall structures not imaged</td>
<td>Visualization of inner wall structures</td>
</tr>
<tr>
<td>Vessel is seen for a very short time during</td>
<td>and morphology</td>
</tr>
<tr>
<td>contrast injection</td>
<td>Confluent imaging (whole length of vessel is imaged)</td>
</tr>
<tr>
<td>QCA analysis with mistakes</td>
<td>Spatial imaging</td>
</tr>
<tr>
<td></td>
<td>Precise assessment</td>
</tr>
</tbody>
</table>
ANGIO vs. IVUS

Courtesy of S. Nissen
ANGIO vs. IVUS

Courtesy of S. Nissen
ANGIO vs. IVUS

Courtesy of S. Nissen
Intravascular ultrasound (IVUS)
Intravascular ultrasound (IVUS)

Use in everyday practice

- Assessment of borderline coronary lesions
- Diagnosis of vulnerable plaque
- Optimization of PCI during complex interventions
- Optimization of PCI during MI
- Diagnosis and treatment of ISR
- Assessment of plaque regression/progression – new drugs
Intravascular ultrasound (IVUS)

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Borderline left main assessment

DS = 47%
# Borderline left main assessment

## FFR assessment of borderline LMCA stenosis

<table>
<thead>
<tr>
<th>Author</th>
<th>Reference</th>
<th>n=</th>
<th>QCA DS (%)</th>
<th>FFR&gt;0,75</th>
<th>FFR&lt;0,75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindstaedt M, et al</td>
<td>American Heart Journal 2006;152:156e1-e9</td>
<td>41</td>
<td></td>
<td>44</td>
<td>45</td>
</tr>
</tbody>
</table>

* FFR>0,8  **FFR<0,8
Borderline left main assessment

$L-\text{CSA}_{\text{min}} = 4.9\text{mm}^2$

$\text{DS}=47\%$
Borderline left main assessment

**ICUS cut-off values for FFR = 0.75:**

- \( \text{MLD} = 2.8 \text{ mm} \)
- \( \text{L-CSA}_{\text{min}} = 5.9 \text{ mm}^2 \)

- i.c. bolus of adenosine (42 – 52 \( \mu \)g) instead of i.v. infusion
- Patients with >70% lesion in LAD or CX included into the study

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*Jasti V, et al.. Circulation 2004;110:2831-2836*
Non left main intermediate stenosis IVUS assessment

MLA ≤4,0 mm² proximal segments of LAD / CX / RCA

- Death/MI/TLR @ (mean) 13 mos = 8% overall (2% death/MI and 6% TLR)
- Death/MI/TLR @ (mean) 13 mos = 4.4% in lesions with MLA >4.0mm²
- Only independent predictor of death/MI/TLR was IVUS MLA (p=0.0041)
- Independent predictors of TLR were DM (p=0.0493) and IVUS MLA (p=0.0042)
Non left main intermediate stenosis IVUS assessment

IVUS – FFR correlation (non left main lesions)

4 mm^2
Intravascular ultrasound (IVUS)

Use in everyday practice

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Grey-Scale IVUS

Type of plaques and other common findings in vessel

- Soft plaque
- Mixed plaque
- Calcified plaque
- Plaque rupture
- Intraluminal thrombus
Virtual histology (VH-IVUS)

RF Signal (Sound) returns from tissue, each scan line is analyzed with the use of moving window parameters

Software used to outline borders

Classification tree determines the plaque type assigned to the sample in the window

Power spectra are calculated within the window - spectral parameters
Virtual histology (VH-IVUS)

- **Fibrous - F**
- **Fibrofatty - FF**
- **Necrotic Core – NC**
- **Dense Calcium – DC**

<table>
<thead>
<tr>
<th>CaTCFA</th>
<th>TCFA</th>
<th>CaFA</th>
<th>FA</th>
<th>PIT</th>
<th>FCa</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcifid TCFA</td>
<td>ThinCapFibroAtheroma</td>
<td>Calcified Fibroatheroma</td>
<td>Fibrotheroma</td>
<td>Pathological Intima Thickening</td>
<td>FibroCalcific Plaque</td>
<td>Fibrous Tissue</td>
</tr>
</tbody>
</table>
### IVUS and VH-IVUS assessment of vulnerable plaque

#### PROSPECT: Correlates of Non Culprit Lesion Related Events

Lesion level events (51 events from 2709 lesions in 601 pts at median 3.4 yrs)

### Virtual Histology Plaque Type

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rate (n)</th>
<th>HR [95% CI]</th>
<th>HR [95% CI]</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH-TCFA (n=595)</td>
<td>4.4% (26)</td>
<td>3.90 [2.25, 6.76]</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Not VH-TCFA (n=2114)</td>
<td>1.2% (25)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ThCFA (n=1005)</td>
<td>1.8% (18)</td>
<td>0.92 [0.52, 1.63]</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Not ThCFA (n=1704)</td>
<td>1.9% (33)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIT (n=1005)</td>
<td>0.6% (6)</td>
<td>0.22 [0.09, 0.51]</td>
<td>0.0005</td>
<td></td>
</tr>
<tr>
<td>Not PIT (n=1704)</td>
<td>2.6% (45)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibrotic (n=71)</td>
<td>0% (0)</td>
<td></td>
<td></td>
<td>0.99</td>
</tr>
<tr>
<td>Not Fibrotic (n=2638)</td>
<td>1.9% (51)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibrocalcific (n=33)</td>
<td>3.0% (1)</td>
<td>1.56 [0.22, 11.30]</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Not fibrocalcific (n=2676)</td>
<td>1.9% (50)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TCFA = thin cap fibroatheroma; ThCFA = thick cap fibroatheroma; PIT = pathologic intimal thickening. Univariate, unadjusted.
<table>
<thead>
<tr>
<th>Variable</th>
<th>OR [95% CI]</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLA ≤ 4.0 mm²</td>
<td>5.38 [2.72, 10.64]</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MLA ≥ 11.2 mm²</td>
<td>3.07 [1.71, 5.49]</td>
<td>0.0002</td>
</tr>
<tr>
<td>EEMLA ≤ 14.1 mm²</td>
<td>2.55 [1.22, 5.33]</td>
<td>0.08</td>
</tr>
<tr>
<td>PBMLA ≥ 70%</td>
<td>1.95 [0.93, 4.12]</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Independent predictors of lesion level events by logistic regression analysis.
IVUS and VH-IVUS assessment of vulnerable plaque

**PROSPECT: VH-TCFA and Non Culprit Lesion Related Events**

<table>
<thead>
<tr>
<th>Lesion Type</th>
<th>Median 3.4 Yr MACE Rate per Isn (%)</th>
<th>Lesion HR P value</th>
<th>Prevalence*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCFA</td>
<td>4.4 (1.2)</td>
<td>3.90 &lt;0.0001</td>
<td>46.7%</td>
</tr>
<tr>
<td>TCFA + MLA ≤4.0mm²</td>
<td>9.2 (1.5)</td>
<td>6.55 &lt;0.0001</td>
<td>15.9%</td>
</tr>
<tr>
<td>TCFA + PB ≥70%</td>
<td>15.1 (1.5)</td>
<td>10.83 &lt;0.0001</td>
<td>10.1%</td>
</tr>
<tr>
<td>TCFA + PB ≥70% + MLA ≤4mm²</td>
<td>17.2 (1.7)</td>
<td>11.05 &lt;0.0001</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

*Likelihood of one or more such lesions being present per patient. PB = plaque burden at the MLA.

Presented by Gregg Stone, CCT 2010
VH-IVUS Defined Thin Cap Fibroatheroma (VH-TCFA)

High risk TCFA; most often found as a cause of the sudden coronary death
- Confluent NC>20%
- No evidence of fibrotic cap
- Calcium >5%
- Positive Remodeling (index >1.05)
- >50% cross sectional area luminal narrowing by IVUS
Optical Coherence Tomography – principle

Optical coherence tomography (OCT) is a light-based modality of intravascular imaging with higher spatial resolution than IVUS (15 vs. 100 µm). Its penetration is lower than IVUS but it provides detailed imaging of the endoluminal borders.
Optical Coherence Tomography — versus IVUS

**Resolution** (axiale)
- 100 - 150 μm
- 150 - 300 μm

(laterale)
- 10 - 20 μm
- 25 - 40 μm

**Wire diameters**
- 1,1 mm
- 0,4 mm

**Frequency**
- 30 /s
- 15 /s

**Exam Area**
- 10 - 15 mm
- 7,0 mm

**Signal penetration**
- 4 - 8 mm
- 1 - 1,5 mm
NSTEmI
Intravascular ultrasound (IVUS)

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IVUS guided stenting

Długość zwężenia = 12 mm
Pomiar możliwy tylko przy stosowaniu automatycznej wyciągarki (pull-back device)

LA min STENT > 90% (LA REF prox + LA REF dist) / 2
[>80%, gdy LA min STENT > 9,0 mm² (MUSIC criteria)]
Target Stent Segment IVUS

Incomplete Apposition

Incomplete Expansion

Edge Tear

Courtesy of P. Fitzgerald
IVUS guided stenting

Does IVUS usage improve of procedural outcomes? Trials with BMS

<table>
<thead>
<tr>
<th>Study (10)</th>
<th>Angio Better</th>
<th>IVUS Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choi et al (AHJ 2001;142:112-8)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>CENIC (JACC 2002;39:54A)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>CRUISE (Circulation 2000;102:523-30)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>DIPOL (Am Heart J. 2007;154:669-75)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>AVID (Circulation CV Interv 2009;2:113-123)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>RESIST (JACC 1998;32:320-8)</td>
<td></td>
<td>?</td>
</tr>
<tr>
<td>TULIP (Circulation 2003;107:62-7)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>BEST (Circulation 2003;107:545-551)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>OPTICUS (Circulation. 2001;104:1343-9)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>PRESTO (Am Heart J. 2004;148:501-6)</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
IVUS guided stenting

Randomized Comparison of Coronary Stent Implantation Under Ultrasound or Angiographic Guidance to Reduce Stent Restenosis (OPTICUS Study)

Harald Mudra, MD; Carlo di Mario, MD; Peter de Jaegere, MD; Hans Reiner Figulla, MD; Carlos Macaya, MD; Ralf Zahn, MD; Bertil Wennerblom, MD; Wolfgang Rutsch, MD; Vasilj Voudris, MD; Evelyn Regar, MD; Karl-Heinz Henneke, MD; Volker Schachinger, MD; Andreas Zeiher, MD;

for the OPTICUS (OPTimization with ICUS to reduce stent restenosis) Study Investigators

"... The extensive experience with intracoronary ultrasound of the investigators participated in the present study may have affected the way the stents have been implanted under angiographic guidance. ..."
Late Stent Thrombosis – frequency

Early and late coronary stent thrombosis of sirolimus-eluting and paclitaxel-eluting stents in routine clinical practice: data from a large two-institutional cohort study

Joost Daemen, Peter Wenaweser, Keiichi Tsuchida, Linda Abrecht, Sophia Vaina, Cyrill Morger, Neville Kukreja, Peter Jüni, Georgios Sianos, Gerrit Hellige, Ron T van Domburg, Otto M Hess, Eric Boersma, Bernhard Meier, Stephan Windecker, Patrick W Serruys

0,6% / year
2,575 patients were treated with 4,722 Cypher stents.
21 (0.8%) had stent thrombosis of whom 15 had IVUS
12/15 SES thrombosis lesions has stent CSA <5.0mm² (vs 13/45 controls)
For DES, it was recently shown that
the threshold of stent expansion
predictive of late events including
restenosis and stent thrombosis is
lower than for BMS (5.0–5.5 mm²)
First generation drug-eluting stents – delayed healing

Pathological Correlates of Late Drug-Eluting Stent Thrombosis
Strut Coverage as a Marker of Endothelialization

Aloke V. Finn, MD*; Michael Joner, MD*; Gaku Nakazawa, MD; Frank Kolodgie, PhD; John Newell, AB; Mike C. John, MPH; Herman K. Gold, MD; Renu Virmani, MD
Mild neointima formation
0.12 mm
IVUS guided stenting

Impact on clinical outcomes in the DES era

<table>
<thead>
<tr>
<th></th>
<th>IVUS-guided</th>
<th>Angio-guided</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>30 day</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MACE</td>
<td>2.8%</td>
<td>5.2%</td>
<td>0.01</td>
</tr>
<tr>
<td>Stent thrombosis</td>
<td>0.5%</td>
<td>1.4%</td>
<td>0.045</td>
</tr>
<tr>
<td>TLR</td>
<td>0.7%</td>
<td>1.7%</td>
<td>0.045</td>
</tr>
<tr>
<td><strong>1 year</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MACE</td>
<td>14.5%</td>
<td>16.2%</td>
<td>0.3</td>
</tr>
<tr>
<td>Definite stent thrombosis</td>
<td>0.7%</td>
<td>2.0%</td>
<td>0.014</td>
</tr>
<tr>
<td>Probably stent thrombosis</td>
<td>4.0%</td>
<td>5.8%</td>
<td>0.08</td>
</tr>
<tr>
<td>TLR</td>
<td>5.1%</td>
<td>7.2%</td>
<td>0.06</td>
</tr>
<tr>
<td>Late definite stent thrombosis</td>
<td>0.2%</td>
<td>0.7%</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Conclusions—Elective stenting with IVUS guidance, especially in the placement of drug-eluting stent, may reduce the long-term mortality rate for unprotected left main coronary artery stenosis when compared with conventional angiography guidance. (*Circ Cardiovasc Intervent. 2009;2:167-177.*)
Guidelines on myocardial revascularization

The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS)

Developed with the special contribution of the European Association

- IVUS-guided stent implantation may be considered for unprotected left main PCI.
Intravascular ultrasound (IVUS)

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- Optimization of PCI during MI
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- Assessment of plaque regression/progression – new drugs
Impact of Intravascular Ultrasound Guidance in Patients with Acute Myocardial Infarction Undergoing Percutaneous Coronary Intervention

Gabriel Maluenda, MD, Gilles Lemesle, MD, Itsik Ben-Dor, MD, Sara D. Collins, MD, Asmir I. Syed, MD, Rebecca Torguson, MPH, Kimberly Kaneshige, BS, Zhenyi Xue, MS, William O. Suddath, MD, Lowell F. Satler, MD, Kenneth M. Kent, MD, PhD, Joseph Lindsay, MD, Augusto D. Pichard, MD, and Ron Waksman,* MD

Fig. 1. Kaplan-Meier curves illustrating freedom from MACE over 12 months (P = 0.98).
Acute coronary syndromes
The Culprit of the Culprit Concept

Acute coronary syndromes
Rupture of an Eccentric TCFA and the Thrombotic Tails

Fall Out of the problem Layers of distal Thrombotic Tail (Red cell rich)

Blood Flow

Site of min LD

(Angiographic culprit)

(Ruptured TCFA – true culprit)

Site of the problem
Plaque rupture and layers of healed plaque ruptures
Acute coronary syndromes
The Culprit of the Culprit Concept

IVUS-VH ACS Study in Poland

Primary Investigated Outcome – STEMI kohort (n=20)

Uncovered TCFA not present in 10 mm long proximal and distal reference segment

50%

Uncovered TCFA present in 10 mm long proximal reference segment

35%

Uncovered TCFA present in 10 mm long proximal and distal reference segment

15%

Legutko et al. Eur Heart J 2009;30 (Suppl 1):A100
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Treatment of in-stent restenosis

IVUS assessment

Mechanisms of ISR:

- Not optimal stent deployment
- Geographic miss (too short stent)
- Neointimal hiperplasia
- Stent fracture

Finding the mechanizm allows to use an accurate type of treatment (POBA, DES, DEB, CABG)
**Intravascular ultrasound (IVUS)**

**Use in everyday practice**

- Assessment of borderline coronary lesions
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- Optimization of PCI during MI
- Diagnosis and treatment of ISR
- Assessment of plaque regression/progression – new drugs
Assessment of atheroma progression / regression
Trials with new drugs

IVUS assessment of the plaque volume changes in time

Nissen S. JAMA 2004,291,1071-1080
Assessment of atheroma progression / regression
Trials with new drugs

Randomization

Standard therapy
Pravastatin 40mg/d

Intensive therapy
Atorvastatin 80mg/d

LDL-CHOL mean 110 mg%

ΔAV = + 5.1 mm²

LDL-CHOL mean 79 mg%

ΔAV = - 0.4 mm²

ASTEROID
(Rosuvastatyna)

Nissen S. JAMA 2004, 291, 1071-1080

Nissen S. ACC 2006

Regression
Progression
**Guidelines on myocardial revascularization**

The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS)

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IVUS is a valuable adjunct to angiography, providing further insights into both diagnosis and therapy, including stent implantation.

Interventional cardiologists have learnt much from IVUS, but it has been difficult to demonstrate that this knowledge acquired routinely translates into reduced MACE.

In a retrospective analysis of a multicentre registry comparing PCI with surgery for unprotected LM, IVUS-guided stent implantation was associated with a significant mortality reduction at 3 years (IIbC).

No properly designed RCT has compared the clinical value of IVUS-guided stent implantation in the DES era.
Guidelines on myocardial revascularization

The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS)

The analysis of plaque composition based on radiofrequency backscatter, so-called ‘virtual histology’, characterizes plaques as fibrotic, fibrofatty with or without a necrotic core, or calcific.

Although the PROSPECT trial provided new insights regarding indications for stent implantation, the role of tissue characterization for everyday practice remains to be established.

Optical coherence tomography (OCT) is a light-based modality of intravascular imaging with higher spatial resolution than IVUS (15 vs. 100 mm). Its penetration is lower than IVUS but it provides detailed imaging of the endoluminal borders. At present, OCT is a valuable research tool.
IVUS-guided PCI – the Krakow experience

1. IVUS is useful tool for optimal stenting in difficult cases (left main disease, ostial LAD, bifurcation, last remaining vessel)
2. Pre-intervention IVUS is useful for selection of stenting strategy or additional mechanical devices
3. IVUS experience is important for more “aggressive” ANGIO-guided stenting
4. IVUS is necessary when stent troubles or doubts occurs (whenever stent underexpansion/malapposition or severe edge problems are suspected)

**IVUS is not routinely used for stent optimization in every case !!!**

But...

**IVUS experience is very important in all cases and may influence the results !!!**