Assessment of vulnerable plaque by OCT

Comparison among Intravascular Imaging Modalities

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Disclosure Statement of Financial Interest

I (Takashi Akasaka) do not have a financial interest/arrangement or affiliation with one or more organizations that could be perceived as a real or apparent conflict of interest in the context of the subject of this presentation.
Pathohistology of vulnerable plaque (HE stain)

- Thin fibrous cap
- Large lipid core
- Advanced atherosclerosis

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Pathohistological characteristics of vulnerable plaque

- Positive remodeling
- Eccentric plaques
- Lipid-rich plaques (necrotic core)
- Thin fibrous cap (< 65 μm)
- Rupture (60%) or ulceration (30~40%) of fibrous caps
- Thrombus formation
- Macrophage accumulation
Identification of vulnerable plaque

- Plaque prone to rupture
  - Rupture (-)
  - Rupture (+)
    - Event (-)
      - UAP
      - AMI
    - Event (+)
      - Sudden cardiac death

in vivo

in vitro
Study Population

Inclusion criteria

Acute Myocardial Infarction

- continuous chest pain lasted > 30 minutes,
- arrival within 6 hours from the onset of chest pain
- ST elevation $\geq 0.1 \text{ mV}$ in 2 or more contiguous leads
- culprit lesion with diameter stenosis $\geq 75$
- TIMI flow $\leq 2$ identified by CAG

Exclusion criteria

- left bundle-branch block
- pacemaker rhythm
- a culprit lesion in the left main coronary artery
- history of prior MI
- cardiogenic shock
- unsuccessful reperfusion < TIMI III flow by thrombectomy
Study Design

Oral aspirin (162 mg) and intravenous heparin (100 U/kg) were administered before PCI.

Cardiac catheterization was performed by the femoral approach, using a 7F sheath and catheters.

- **Thrombectomy**  *(Export catheter ® Medtronic Japan)*
  - TIMI grade III
  - **IVUS**  *(Atlantis SR Pro® 2.5F, 40-MHz; Boston Scientific, Natick, MA, USA)*
  - **CAS**  *(Angioscope MC-800E and the optic fiber AS-003, Nihon Kohden)*
  - **OCT**  *(ImageWire®; LightLab Imaging, Westford, MA, USA)*
OCT system (LightLab Co.)
Optical Coherence Tomography (OCT)
OCT vs histology

Fibrous: Homogeneous, Signal-rich
Lipid pool: Echolucent, Diffuse Borders
Calcific: Echolucent, Sharp Borders

Yabushita et al. Circulation, 2002
### Tissue characterization by OCT and IVUS


<table>
<thead>
<tr>
<th>Pathohistological Diagnosis</th>
<th>OCT image</th>
<th>IVUS image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous (n=43)</td>
<td>Sensitivity 79 Specificity 99</td>
<td>Sensitivity 88 Specificity 86</td>
</tr>
<tr>
<td>Fibrocalcific (n=82)</td>
<td>Sensitivity 96 Specificity 88</td>
<td>Sensitivity 98 Specificity 96</td>
</tr>
<tr>
<td>Lipid (n=41)</td>
<td>Sensitivity 85* Specificity 94</td>
<td>Sensitivity 59 Specificity 97</td>
</tr>
</tbody>
</table>

Data are demonstrated as percentages. *p<0.05 vs IVUS
Comparison between IVUS and OCT

**Scan area**
- **IVUS**: 10 - 15 mm
- **OCT**: 7.0 mm

**Max. penetration depth**
- **IVUS**: 4 - 8 mm
- **OCT**: 1 – 1.5 mm

**Blood clearing**
- **IVUS**: Not required
- **OCT**: Required

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Inferior AMI (71y.o. Male)
Inferior-AMI (71y.o., M)  Plaque Rupture

Ruptured Fibrous Cap

Fibrous Cap Thickness
= 40μm

TL : True Lumen
UL : Ulceration

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Ruptured Fibrous Caps
Anteroseptal AMI (80y.o., M)

Fibrous cap thickness = 60 μm
Thickness of fibrous caps
Histology vs OCT


\[ y = 0.98x - 16.52 \]
\[ r = 0.92, \ p < 0.001 \]
Anteroseptal AMI  (80 y.o. Male)
Anteroseptal AMI (80y.o., M)

↑ Erosion (Ulceration)
↑ Thrombus
Inf-AMI  (71y.o., M)  Thrombus

Red Thrombus

Intensity Half Distance = 135 μm

Thrombectomy
Thrombus

OCT  |  CAS  |  IVUS

WT  |  RT  |  WT

1mm  |  1mm  |
Differentiation between red and white thrombus

Differentiation between red and white thrombus

<table>
<thead>
<tr>
<th>Attenuation coefficient (mm$^{-1}$)</th>
<th>Final concentration of erythrocytes relative to the original blood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10-2</td>
</tr>
<tr>
<td>8</td>
<td>10-1</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>101</td>
</tr>
<tr>
<td>2</td>
<td>102</td>
</tr>
</tbody>
</table>
**Comparison of plaque Images in AMI**

**(OCT vs. CAS vs. IVUS) n=30**


<table>
<thead>
<tr>
<th></th>
<th>OCT</th>
<th>*CAS</th>
<th>**IVUS</th>
<th>*p</th>
<th>**p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaque Rupture (%)</td>
<td>73</td>
<td>47</td>
<td>40</td>
<td>0.035</td>
<td>0.009</td>
</tr>
<tr>
<td>Ulceration (erosion) (%)</td>
<td>23</td>
<td>3</td>
<td>0</td>
<td>0.022</td>
<td>0.005</td>
</tr>
<tr>
<td>Thrombus (%)</td>
<td>100</td>
<td>100</td>
<td>33</td>
<td>1.000</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Red thrombus (%)</td>
<td>100</td>
<td>90</td>
<td>-</td>
<td>0.076</td>
<td>-</td>
</tr>
<tr>
<td>White thrombus (%)</td>
<td>100</td>
<td>93</td>
<td>-</td>
<td>0.150</td>
<td>-</td>
</tr>
<tr>
<td><strong>TCFA (≤65 μm) (%)</strong></td>
<td>83</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fibrous cap thickness (μm)</td>
<td>49 ± 21</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>LRP (Lipid Arch &gt;180°) (%)</strong></td>
<td>83</td>
<td>-</td>
<td>67</td>
<td>-</td>
<td>NS</td>
</tr>
</tbody>
</table>

TCFA; Thin Cap Fibro-Atheroma, LRP; Lipid Rich Plaque
Pathohistological characteristics of vulnerable plaque

Assessment by OCT

- Positive remodeling
- Eccentric plaques
- Lipid-rich plaques (necrotic core)
- Thin fibrous cap
- Rupture or ulceration of fibrous caps
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- Macrophage accumulation
OCT findings

Low Mφ

High Mφ

250 µm

CD68 (macrophage)
Macrophages
Macrophages
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Summary
Assessment of vulnerable plaque by OCT
Comparison with pathohistology

- Positive remodeling
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Comparison with pathohistology:

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Corresponding Images of OCT and Angioscopy

Angioscopy vs OCT

Plaque color vs lipid size

Plaque color vs fibrous cap thickness

IVUS-derived TCFA


- Percent atheroma volume = \( \frac{(EEM \text{ area} - \text{Lumen area})}{EEM \text{ area}} \times 100 \geq 40\% \)
- Nectrotic core \( \geq 10\% \)
- Without evident overlying fibrous tissue
Figure 2

VH-IVUS vs OCT

Without evident overlying fibrous tissue

With evident overlying fibrous tissue

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Distribution of fibrous cap thickness in cases with VH-TCFA

Frequency (number)

Thickness of fibrous cap (μm)

TCFA
Not TCFA

40 60 80 100 120 140 160 180 200 220

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Concordance & discordance between VH-IVUS and OCT in the assessment of TCFA

<table>
<thead>
<tr>
<th>IVUS-VH Diagnosis</th>
<th>OCT Diagnosis</th>
<th>TCFA (n=11)</th>
<th>Not TCFA (n=36)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH-TCFA (n=31)</td>
<td></td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td>Not VH-TCFA (n=16)</td>
<td></td>
<td>2</td>
<td>14</td>
</tr>
</tbody>
</table>
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Summary

- OCT can identify lipid-rich plaques more sensitively compared with IVUS.
- OCT can demonstrate rupture or ulceration of fibrous cap with higher detection rate than that of IVUS or CAS.
- OCT could detect intracoronary thrombus almost exclusively which was confirmed by CAS.
- OCT may estimate macrophage accumulation within fibrous caps.
Frequency domain OCT (M4)
Conclusion

OCT should be the most ideal tool in the assessment of vulnerable plaques among various intravascular imaging modalities.
Unstable AP
The culprit lesion was LCX (#11), and TCFA (①), plaque rupture (②,③) and intracoronary thrombus (②, ③, ④) were observed by OCT. Although the plaques in LAD (⑦, ⑧) were not observed, plaque rupture (⑤, ⑥) were detected by OCT in the non-culprit lesions of LCX (#13).
Also OCT revealed TCFA (9-13) and plaque rupture (11, 12, 13) in the non-culprit lesions of RCA.
# OCT analysis of the non-culprit plaques

<table>
<thead>
<tr>
<th></th>
<th>Non-culprit plaque</th>
<th></th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMI (n=43)</td>
<td>SAP (n=25)</td>
<td></td>
</tr>
<tr>
<td>Plaque rupture (n, %)</td>
<td>10 (24)</td>
<td>1 (4)</td>
<td>0.035</td>
</tr>
<tr>
<td>Plaque ulceration (n, %)</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>0.632</td>
</tr>
<tr>
<td>Intracoronary thrombus (n, %)</td>
<td>11(26)</td>
<td>0 (0)</td>
<td>0.006</td>
</tr>
<tr>
<td>Fibrous cap thickness (μm)</td>
<td>109±55.5</td>
<td>194±81.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lipid arc &gt; 90° (n, %)</td>
<td>18 (42)</td>
<td>12 (48)</td>
<td>0.623</td>
</tr>
<tr>
<td>TCFA (n, %)</td>
<td>15(35)</td>
<td>2 (8)</td>
<td>0.012</td>
</tr>
</tbody>
</table>
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Thrombus

OCT

CAS

IVUS
Optical Coherence Tomography (OCT)

- Size of imaging core (0.4 mm)
- Microscopic resolution (10-20 μm)
- Real time Imaging (15 frames/s)
Fibrous plaque
Fibrocalcific plaque

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Fibro-lipidic plaque
## Comparison between IVUS and OCT

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<thead>
<tr>
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<th>OCT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dynamic range</strong></td>
<td>40 - 60 dB</td>
<td>90 - 110 dB</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>(axial) 100 - 150 µm</td>
<td>15 - 20 µm</td>
</tr>
<tr>
<td></td>
<td>(lateral) 150 - 300 µm</td>
<td>25 - 40 µm</td>
</tr>
<tr>
<td><strong>Size of imaging core</strong></td>
<td>0.8 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td><strong>Frame rate</strong></td>
<td>30 frames/s</td>
<td>15 frames/s</td>
</tr>
</tbody>
</table>