Detection of vulnerable plaque by OCT

Takashi Akasaka, M.D.
Department of Cardiovascular Medicine
Wakayama Medical University
Wakayama, Japan
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
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 (-)
    - Event (+)
      - UAP
      - AMI
      - 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 $\geq 0.1$ 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.)

ImageWire®

PIU

Wakayama Medical University
OCT vs histology

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

Yabushita et al. Circulation, 2002
Wakayama Medical University
# 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</td>
<td>Sensitivity 88</td>
</tr>
<tr>
<td></td>
<td>Specificity 99</td>
<td>Specificity 86</td>
</tr>
<tr>
<td>Fibrocalcific (n=82)</td>
<td>Sensitivity 96</td>
<td>Sensitivity 98</td>
</tr>
<tr>
<td></td>
<td>Specificity 88</td>
<td>Specificity 97</td>
</tr>
<tr>
<td>Lipid (n=41)</td>
<td>Sensitivity 85*</td>
<td>Sensitivity 59</td>
</tr>
<tr>
<td></td>
<td>Specificity 94</td>
<td>Specificity 97</td>
</tr>
</tbody>
</table>

Data are demonstrated as percentages. *p<0.05 vs IVUS

Wakayama Medical University
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
- Thrombus formation
- Macrophage accumulation
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
- Thrombus formation
- Macrophage accumulation
Inferior-AMI (71 y.o., M) Plaque Rupture

Ruptured Fibrous Cap

Fibrous Cap Thickness = 40 μm

TL: True Lumen
UL: Ulceration

Wakayama Medical University
Anteroseptal AMI (80 y.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 (80y.o., M)

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

Red Thrombus

Intensity Half Distance = 135 μm

Thrombectomy

Wakayama Medical University
Differentiation between red and white thrombus

<table>
<thead>
<tr>
<th></th>
<th>Peak intensity</th>
<th>Intensity half distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red thrombus</td>
<td>130±18</td>
<td>183±42</td>
</tr>
<tr>
<td>White thrombus</td>
<td>145±34</td>
<td>324±50 *</td>
</tr>
</tbody>
</table>

*p = 0.0001

Differentiation between red and white thrombus

White thrombus

Red thrombus

<table>
<thead>
<tr>
<th>Final concentration of erythrocytes relative to the original blood (%)</th>
<th>Attenuation coefficient (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-2}</td>
<td>0</td>
</tr>
<tr>
<td>10^{-1}</td>
<td>2</td>
</tr>
<tr>
<td>10^0</td>
<td>4</td>
</tr>
<tr>
<td>10^1</td>
<td>6</td>
</tr>
<tr>
<td>10^2</td>
<td>8</td>
</tr>
</tbody>
</table>

Wakayama Medical University
## 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>TCFA (≤65 μm) (%)</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>LRP (Lipid Arch&gt;180°) (%)</td>
<td>83</td>
<td>-</td>
<td>67</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

TCFA; Thin Cap Fibro-Atheroma, LRP; Lipid Rich Plaque

Wakayama Medical University
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
- Thrombus formation
- Macrophage accumulation
OCT findings

Low Mφ

High Mφ

OCT

250 µm

CD68 (macrophage)
Macrophages
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 ○
- Thrombus formation ○
- Macrophage accumulation △
Summary
Assessment of vulnerable plaque by OCT
Comparison with pathohistology

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

△ = Better assessed by OCT
○ = Similar assessed by OCT
Unstable AP
Three vessel OCT examinations in a patient with posterior AMI

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).
Three vessel OCT examinations in a patient with posterior AMI

Also OCT revealed TCFA (9-13) and plaque rupture (11, 12, 13) in the non-culprit lesions of RCA.

Wakayama Medical University
**OCT analysis of the non-culprit plaques**

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

- 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.
Conclusion

OCT should be the most ideal tool in the assessment of vulnerable plaques among various intravascular imaging modalities.
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 = \( \frac{\text{EEM area} - \text{Lumen area}}{\text{EEM area}} \times 100 \geq 40\% \)
- 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

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

Table 4

<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>
Pathohistological characteristics of vulnerable plaque

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

OCT

CAS

IVUS

Wakayama Medical University
Optical Coherence Tomography (OCT)

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

1mm

Wakayama Medical University
Fibrocalcific plaque
Fibro-lipidic plaque
# Comparison between IVUS and OCT

<table>
<thead>
<tr>
<th></th>
<th>IVUS</th>
<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>Frame rate</strong></td>
<td>30 frames/s</td>
<td>15 frames/s</td>
</tr>
<tr>
<td><strong>Size of imaging core</strong></td>
<td>0.8 mm</td>
<td>0.4 mm</td>
</tr>
</tbody>
</table>

*Wakayama Medical University*
Optical Coherence Tomography (OCT)
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

To obtain images