Plaque Erosion: A New in vivo Diagnosis

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Michael & Kathryn Park Endowed Chair in Cardiology
Three most common underlying mechanisms include plaque rupture, plaque erosion, and calcified nodule. Plaque rupture is well characterized. However, in vivo studies on plaque erosion and calcified nodule are limited.

To evaluate the prevalence and morphological characteristics of erosion and calcified nodule by OCT in the patients with ACS.
Histology studies

1. van der Wal et al reported that the prevalence of plaque rupture and erosion was 60% and 40%, respectively.

2. Farb et al studied 50 sudden death cases and found ruptures in 28 (56%) patients and erosions in 22 (44%).

3. Hisaki et al reported 70 (56.4%) plaque ruptures and 54 (43.5%) erosions in 124 lesions.
OCT Plaque Classification

Disrupted Fibrous Cap
- Underlying plaque: Lipid
- Underlying plaque: Calcium
  - Protruding nodular calcium
  - Attached thrombus
  - Superficial calcium
  - Substantive calcium proximal and/or distal to lesion

Plaque Rupture

OCT-Calcified Nodule

Intact Fibrous Cap
- DEFINITE:
  - Thrombus (+)
  - Intact underlying plaque visualized
- PROBABLE:
  - Thrombus (-)
  - Irregular surface
  - Thrombus (+)
  - Underlying plaque not visualized
  - No superficial lipid or calcium proximal or distal to lesion

OCT-Erosion

Others
- Tight stenosis
- Large thrombus
- Dissection
- Hematoma
- Spasm
- Fissure

OCT Plaque Classification
Plaque Rupture

57M, STEMI
Plaque Erosion

31M, STEMI
Calcified Nodule

73M, NSTEACS
Rupture  Erosion  Ca Nodule
Incidence of Rupture, Erosion, and Calcified nodule

- OCT-CN: 10 (9%)
- OCT-Erosion: 39 (38%)
- Definite: 23 (22%)
- Probable: 16 (16%)
- Plaque Rupture: 55 (53%)

n = 104

JACC 2013
Conclusions

(1) OCT is able to define plaque erosion and calcified nodules in addition to rupture *in vivo*;

(2) More than one third of ACS cases caused by erosion;

(3) In erosion, vascular integrity is better preserved with larger lumen and platelet rich thrombus is more frequently observed;
Relationship Between Underlying Plaque Morphologies and Residual Thrombus Pattern in Patients with STEMI after Thrombolytic Therapy: an In Vivo OCT Study

In collaboration with Prof. C. Stefanadis, Greece

JACC 2014

Sining Hu, MD
The role of underlying plaque morphologies in determining the patterns and distribution of coronary thrombus is unknown.

To evaluate the relationship between the underlying plaque morphologies and residual thrombus patterns and distribution in culprit lesions of patients with STEMI by OCT after thrombolytic therapy.
Analysis
Post-lysis Residual Thrombus

Rupture

Erosion
Plaque Rupture, Plaque Erosion and Calcified Nodule in Patients with STEMI: A Combined OCT and IVUS Study

Takumi Higuma, MD, PhD

JACC Interv. 2015
Objects

1. To evaluate the incidence of PR, PE, and CN in STEMI

2. To study the detailed plaque morphology in these 3 groups using OCT and IVUS

3. To evaluate the correlation between acute outcome (TIMI grade, myocardial blush grade, max CK) and plaque morphology
145 STEMI
• From Jan 2013 to Jun 2014
• Within 12 hrs from symptom onset

112 STEMI
• Plaque Rupture: 72 (64.3%)
• Plaque Erosion: 30 (26.8%)
• Calcified Nodule: 9 (8.0%)
• SCAD: 1 (0.9 %)

111 STEMI for detail analysis

Cardiogenic shock: 4
Unsuccessful thrombectomy: 3
Instent thrombosis: 3
Unsuccessful OCT: 5
Unsuccessful IVUS: 8
Poor image: 4
Massive thrombus: 4
Coronary embolism: 2

Others: 1
Underlying Mechanisms of STEMI

- Plaque rupture: 72 (64.3%)
- Plaque erosion: 30 (26.8%)
- Calcified nodule: 9 (8.0%)
- Others: 1 (0.9%)

Total 112 STEMI

Intra-observer’s reliability 0.85
Inter-observer’s reliability 0.87
OCT Findings

A. Lipid plaque

- Plaque rupture: 100%
- Plaque erosion: 43.3%
- Calcified nodule: 55.8%

B. TCFA

- Plaque rupture: 97.0%
- Plaque erosion: 3.7%
- Calcified nodule: 11.1%

C. Macrophage

- Plaque rupture: 97.2%
- Plaque erosion: 51.7%
- Calcified nodule: 66.7%

D. Microchannel

- Plaque rupture: 54.2%
- Plaque erosion: 13.8%
- Calcified nodule: 22.2%

E. Cholesterol crystal

- Plaque rupture: 55.6%
- Plaque erosion: 20.7%
- Calcified nodule: 11.1%

* A P value < 0.017 was considered significant
IVUS Findings

**Eccentric plaque**

- Plaque rupture: 31.9%
- Plaque erosion: 73.3%
- Calcified nodule: 11.1%

*P < 0.001*  
*P = 0.001*

**Constrictive remodeling**

- Plaque rupture: 4.2%
- Plaque erosion: 26.7%
- Calcified nodule: 55.6%

*P < 0.001*  
*P = 0.002*
Acute outcomes after PCI

A. Myocardial brush grade ≤ 1
- Plaque rupture: 30.6%
- Plaque erosion: 6.7%
- Calcified nodule: 22.2%

B. No reflow
- Plaque rupture: 38.9%
- Plaque erosion: 13.3%
- Calcified nodule: 22.2%

C. Peak CK
- Plaque rupture: 3004 IU/L
- Plaque erosion: 2268 IU/L
- Calcified nodule: 1600 IU/L
Summary

1. The incidence of erosion was 26.8% in STEMI.
2. Erosion had lower prevalence of TCFA and other features of plaque vulnerability.
3. Erosion had more eccentric plaques with more constrictive remodeling.
4. Erosion had better outcome after PCI in patients with STEMI.
Morphologic Characteristics of Eroded Coronary Plaques: A Combined Angiographic, OCT, and IVUS Study

Int J Cardiol 2014

Jinwei Tian, MD, PhD
Plaque erosion accounts for 1/4 - 1/3 of STEMI and acute coronary syndrome (ACS).

Systemic milieu such as thrombogenic status and/or endothelial dysfunction may be an essential precondition for the occurrence of plaque erosion.

However, ACS patients frequently have multiple lesions and not all plaques develop erosion resulting in occlusive thrombus formation.
Hypothesis

- Since the systemic milieu is the same, we hypothesized that plaque morphological features would be different between eroded culprit plaques (ECP) and non-eroded, non-culprit plaques (NENCP).
## Angiographic findings

<table>
<thead>
<tr>
<th></th>
<th>ECP (n=26)</th>
<th>NENCP (n=43)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MLD, mm</strong></td>
<td>1.42 ± 0.70</td>
<td>2.23 ± 0.67</td>
</tr>
<tr>
<td><strong>RD, mm</strong></td>
<td>3.32 ± 0.76</td>
<td>3.43 ± 0.64</td>
</tr>
<tr>
<td><strong>DS, %</strong></td>
<td>59.7 ± 12.2</td>
<td>35.6 ± 14.7</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAD</td>
<td>14(54)</td>
<td>10(23)</td>
</tr>
<tr>
<td>RCA</td>
<td>8(31)</td>
<td>22(51)</td>
</tr>
<tr>
<td>LCX</td>
<td>4(15)</td>
<td>11(26)</td>
</tr>
</tbody>
</table>
## OCT findings

<table>
<thead>
<tr>
<th></th>
<th>ECP (n=26)</th>
<th>NENCP (n=43)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fibrous Plaque</strong></td>
<td>9(35)</td>
<td>13(30)</td>
<td>0.689</td>
</tr>
<tr>
<td><strong>Lipid rich plaque</strong></td>
<td>15(58)</td>
<td>23(54)</td>
<td>0.705</td>
</tr>
<tr>
<td><strong>TCFA</strong></td>
<td>2(8)</td>
<td>7(16)</td>
<td>0.065</td>
</tr>
<tr>
<td><strong>FCT, (\mu m)</strong></td>
<td>142 ± 56</td>
<td>125 ± 73</td>
<td>0.281</td>
</tr>
<tr>
<td><strong>Maximum lipid arc, °</strong></td>
<td>227 ± 61</td>
<td>204 ± 71</td>
<td>0.096</td>
</tr>
<tr>
<td><strong>Lipid length, mm</strong></td>
<td>9.4 ± 6.1</td>
<td>9.2 ± 4.7</td>
<td>0.830</td>
</tr>
<tr>
<td><strong>Plaque rupture</strong></td>
<td>0(0)</td>
<td>3(7)</td>
<td>0.285</td>
</tr>
<tr>
<td><strong>Thrombus</strong></td>
<td>22(85)</td>
<td>3(7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Calcification</strong></td>
<td>10(39)</td>
<td>10(23)</td>
<td>0.165</td>
</tr>
<tr>
<td><strong>Cholesterol crystal</strong></td>
<td>10(39)</td>
<td>8(19)</td>
<td>0.045</td>
</tr>
<tr>
<td><strong>Macrophage</strong></td>
<td>18(69)</td>
<td>15(35)</td>
<td>0.009</td>
</tr>
<tr>
<td><strong>Microvessel</strong></td>
<td>17(65)</td>
<td>8(19)</td>
<td>&lt;0.001</td>
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</tbody>
</table>
## IVUS findings

<table>
<thead>
<tr>
<th></th>
<th>ECP (n=26)</th>
<th>NENCP (n=43)</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td><strong>Lesion segment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaque burden</td>
<td>75.5±12.1</td>
<td>61.5±11.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Remodeling index</td>
<td>1.04±0.15</td>
<td>0.99±0.13</td>
<td>0.127</td>
</tr>
<tr>
<td>EEM CSA, mm²</td>
<td>13.0±4.3</td>
<td>13.3±5.4</td>
<td>0.920</td>
</tr>
<tr>
<td>Lumen CSA, mm²</td>
<td>2.9±1.7</td>
<td>5.4±2.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Max intima thickness</td>
<td>1.84±0.59</td>
<td>1.35±0.46</td>
<td>0.002</td>
</tr>
<tr>
<td>Min intima thickness</td>
<td>0.40±0.37</td>
<td>0.28±0.17</td>
<td>0.141</td>
</tr>
<tr>
<td>Plaque eccentricity</td>
<td>0.78±0.21</td>
<td>0.77±0.16</td>
<td>0.949</td>
</tr>
<tr>
<td><strong>Proximal reference segment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEM CSA, mm²</td>
<td>13.6±4.34</td>
<td>14.5±5.49</td>
<td>0.654</td>
</tr>
<tr>
<td>Lumen CSA, mm²</td>
<td>7.03±2.78</td>
<td>8.21±3.76</td>
<td>0.342</td>
</tr>
<tr>
<td><strong>Distal reference segment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEM CSA, mm²</td>
<td>11.3±4.01</td>
<td>13.4±5.29</td>
<td>0.246</td>
</tr>
<tr>
<td>Lumen CSA, mm²</td>
<td>6.35±2.72</td>
<td>7.41±3.26</td>
<td>0.396</td>
</tr>
<tr>
<td></td>
<td>Univariate regression</td>
<td>Multivariable regression</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>OR</td>
<td>95%CI</td>
<td>P</td>
</tr>
<tr>
<td>LAD</td>
<td>3.85</td>
<td>1.35-10.9</td>
<td>0.012</td>
</tr>
<tr>
<td>Plaque burden</td>
<td>7.13</td>
<td>2.39-21.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MaxIT</td>
<td>2.62</td>
<td>0.96-7.20</td>
<td>0.061</td>
</tr>
<tr>
<td>Lumen area</td>
<td>6.22</td>
<td>2.07-18.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Microvessel</td>
<td>8.26</td>
<td>2.71-25.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cholesterol crystal</td>
<td>2.73</td>
<td>0.91-8.23</td>
<td>0.074</td>
</tr>
<tr>
<td>Macrophage</td>
<td>4.20</td>
<td>1.48-11.9</td>
<td>0.007</td>
</tr>
</tbody>
</table>
Unlike rupture, plaque types, fibrous cap thickness, lipid content, and remodeling index did not appear to be important for plaque erosion.

Interestingly, the location of a plaque in the LAD, microvessels, and greater plaque burden were independently related to plaque erosion.

Our findings showed that local morphological characteristics are also important in addition to systemic biomarkers such as myeloperoxidase levels to predict the risk of plaque erosion.
Computer Aided Imaging Analysis Algorithm to Enhance In Vivo Diagnosis of Plaque Erosion

In collaboration with Prof. J. Fujimoto, MIT

Circulation CV Imag 2014

Zhao Wang, PhD
Computer Aided Diagnosis of Plaque Erosion

Likelihood of Plaque Erosion
Erosion: Facts

1. Incidence *in vivo*: 27- 38%
2. Vascular integrity: better preserved
3. Lumen: larger
4. Better response to antithrombotic therapy
5. Less inflammation
6. Eccentric plaque and constrictive remodeling
7. Better outcome after PCI
8. Diagnosis became easier
Implication

1. Incidence: 27-38%

Clinically important
1. Incidence: 27-38%.
2. Vascular integrity: better preserved
3. Lumen: larger
4. Better response to antithrombotic therapy
5. Less inflammation.
6. Eccentric and constrictive remodeling
7. Better outcome after PCI.
8. Detection became easier.

Pharmacologic therapy
Implication

PCI may be treatment of choice.

1. Incidence: 27-38%.
2. Vascular integrity: better preserved.
3. Lumen: larger.
4. Better response to pharmacologic
5. Less inflammation
6. Eccentric and constrictive remodeling
7. Better outcome after PCI
8. Diagnosis became easier
Optimal Treatment

Unknown
Collaborators

Registry
20 sites

MGH
Yoshiyasu Minami, MD, PhD
Takumi Higuma, MD, PhD
Lei Xing, MD, PhD
Erika Yamamoto, MD, PhD
Jiannan Dai, MD
Krysztof Bryniarski, MD
Thomas Zanchin, MD
Paul Lee
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Taishi Yonetsu, MD
Haibo Jia, MD
Sining Hu, MD
Jinwei Tian, MD
Lei Gao, MD
Tsunenati Soeda, MD

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James Fujimoto, PhD
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Peter Stone, MD

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Marc Feldman, MD PhD

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Shanghai Univ. China
Jujie Xiao, MD, PhD

Athens Medical School, Greece
Christofus Stefanadis, MD, PhD

Catholic University, Italy
Filippo Crea, MD
Luigi Biasucci, MD
MGH OCT Registry Sites

- USA: Emory University
- Japan: National Heart Centre Singapore
- Korea: Asian Medical 
  Ajou University Hosp., Yeouido University 
  East-West Asia Inst., Centre 
  Kyunghee University Hosp., 
  National Heart Centre Singapore
- Australia: The Northern Hosp.
  Concord Repatriation Hosp.
  Prince Charles Hosp.
Thank You