Plaque Characterization:
Non-Calcified, Calcified, Partially Calcified
Is that all CT can do?
Cardiac Function and Perfusion

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- Member, Board of Directors (unpaid)
  - Certification Board of Cardiovascular CT (CBCCT)
  - Society of Cardiovascular Computed Tomography (SCCT)

Iodinated Contrast not FDA approved for cardiac CT

Life History of Atheromas

“Vulnerable Plaque”

Characteristics of Vulnerable Plaques
- Plaque area
- Necrotic Core
- Inflammation
- Spotty Calcification
- Positive Remodelling
- Vasa Vasorum
- Hemorrhage
- Ulceration / Intraplaque Dye Penetration

Plaque Detection
& Area / Volume Quantification
Coronary Plaque Detection: CT vs. IVUS

- 83 segments in 22 patients
- Sensitivity plaque per segment: 94% (all)
- 16-slice CT
- Achenbach et al., Circulation 2003

- 58 vessels in 37 patients
- Sensitivity plaque detection: 85% (all)
- 16-slice CT
- Leber et al., JACC 2004

- 36 vessels in 19 patients
- Sensitivity plaque detection: 90% (all)
- 64-slice CT
- Leber et al., JACC 2006

- 685 segments in 45 patients
- Interobserver agreement: 93% (κ = 0.85)
- 16-slice CT (375 ms rotation)
- Ferencik et al., JACC 2006

Sensitivity plaque per segment: 94% (all)
Sensitivity plaque detection: 85% (all)
Sensitivity plaque detection: 90% (all)
Interobserver agreement: 93% (κ = 0.85)

Plaque Calcification Types

- Partially Calcified
  - Non-calcified plaque
  - Spotty calcification
  - Calcified plaque
  - Coarse calcification

Measurements of Plaque Size

- Ex vivo: Coronary Arteries
  - 16 slice CT
  - Wall area

- In vivo: Plaque area CT vs. IVUS
  - 2D

- In vivo: Plaque volume CT vs. IVUS

Plaque volume

- 24 ± 35 mm³ vs. 43 ± 60 mm³
- 89 ± 66 mm³ vs. 90 ± 73 mm³

Remodeling Index
Coronary plaque characteristics in ACS and stable AP patients (n = 27)

<table>
<thead>
<tr>
<th></th>
<th>Culprit Lesions in ACS (n=14)</th>
<th>Lesions in SAP (n=13)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer vessel area at stenosis (mm²)</td>
<td>21.2±7.0</td>
<td>15.6±10.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Luminal area at stenosis (mm²)</td>
<td>3.7±1.6</td>
<td>2.1±1.4</td>
<td>0.18*</td>
</tr>
<tr>
<td>Plaque area (mm²)</td>
<td>17.5±5.9</td>
<td>13.5±10.7</td>
<td>0.02*</td>
</tr>
<tr>
<td>Degree of stenosis (%)</td>
<td>79.8±7.2</td>
<td>82.7±8.7</td>
<td>0.79*</td>
</tr>
<tr>
<td>RI</td>
<td>1.4±0.3</td>
<td>1.2±0.3</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Semi-quantitative Plaque Burden - Prognosis

0-5 vs. >5 of segments with plaque present

Low Attenuation Plaque
Napkin Ring Sign
Napkin-ring Sign: CT signature of high-risk coronary plaques?

Cross Sections of a Coronary Plaque (Late Fibroatheroma)
Non-calcified plaque with a napkin-ring sign:
Low CT attenuation core (22.0 to 31.0 HU) &
Outer rim of high CT attenuation (35.0 to 76.0 HU).

Low Attenuation Plaque (LAP) Metrics
Prognostic Value?

<table>
<thead>
<tr>
<th>LAP volume (mm³)</th>
<th>ACS within 12 months</th>
<th>No ACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SE</td>
<td>30.5 ± 4.1</td>
<td>1.2 ± 1.3</td>
</tr>
<tr>
<td>95% confidence interval</td>
<td>(22.3 to 38.8)</td>
<td>(-1.3 to 3.8)</td>
</tr>
</tbody>
</table>

Maximum LAP area (mm²)

| Mean ± SE         | 4.7 ± 0.5          | 0.6 ± 0.2 |
| 95% confidence interval | (3.6 to 5.7)     | (0.2 to 0.9) |

Maximum LAP area/plaque area (%)

| Mean ± SE         | 32.5 ± 4.5         | 7.8 ± 1.4 |
| 95% confidence interval | (22.5 to 40.4)  | (3.0 to 10.5) |

Plaque Disruption

Diagnostic Performance of CTA Features of Plaque Disruption

<table>
<thead>
<tr>
<th>Feature</th>
<th>Sensitivity, % (95% CI)</th>
<th>Specificity, % (95% CI)</th>
<th>PPV, % (95% CI)</th>
<th>NPV, % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulceration or IDP, n=109</td>
<td>52.6 (40.0–64.0)</td>
<td>81.9 (76.2–86.8)</td>
<td>51.3 (39.8–62.6)</td>
<td>82.7 (77.0–87.5)</td>
</tr>
<tr>
<td>Ulceration, n=53</td>
<td>53.8 (42.2–65.2)</td>
<td>94.9 (91.1–97.4)</td>
<td>73.2 (65.0–80.2)</td>
<td>95.1 (93.9–96.1)</td>
</tr>
<tr>
<td>IDP, n=80</td>
<td>52.6 (40.0–64.0)</td>
<td>81.9 (76.2–86.8)</td>
<td>51.3 (39.8–62.6)</td>
<td>82.7 (77.0–87.5)</td>
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Plaque Inflammation
**Indirect Plaque Inflammation Marker**

Soluble CD163 (Monocyte/Macrophage Activation Marker) is associated with Noncalcified Coronary Plaque in HIV Patients

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
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<tbody>
<tr>
<td>sCD163 low</td>
<td>sCD163 high</td>
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<tr>
<td>sCD163 low</td>
<td>sCD163 high</td>
</tr>
</tbody>
</table>

sCD163 levels correlated with # coronary segments with noncalcified plaque \((r=0.23, p=0.02)\), but not with # segments with calcified plaque nor Agatston calcium score.


**Molecular Imaging of Plaque Inflammation**

18F-FDG uptake indicates high cellular metabolic activity → plaque inflammation


**Potential Targets for Plaque Imaging**

- **Indirect Plaque Inflammation Marker**
- **Molecular Imaging of Plaque Inflammation**
- **Unidentified**

**Immunohistochemistry**

Axial slice corresponding to low enhancement at N1177 CT

Axial slice corresponding to intense enhancement at N1177 CT

Weak macrophage infiltration

Strong macrophage infiltration


**Non-Calcified, Calcified, Partially Calcified**

Is That All CT Can Do?

- No CT can do much more:
  - Positive Remodeling
  - Area and Volume
  - Low Attenuation
  - Napkin Ring Sign
  - Spotty calcification
  - Ulceration and Intraluminal Dye Penetration
  - Inflammation
Non-Calcified, Calcified, Partially Calcified

Is That All CT Can Do?

But there are a few things CT cannot do:

- Identify “Thin Cap” in TCFA
- Intraplaque hemorrhage
- Vasa Vasorum
- Plaque Erosion
- Predict MACE vs. Asymptomatic Ruptures

Cardiac Function

Background

- Every retrospectively gated Coronary MDCT raw dataset contains information about ventricular & valvular function and myocardial perfusion
- Functional analysis requires additional reconstruction of multiphasic datasets
- Perfusion analysis may be performed via post-processing of the coronary CTA dataset (average weighted 5-10mm MPR)

Ventricular Function

Multiple cardiac phases in one spatial location → cine images

Volumetric Ejection Fraction Calculation

- 4D workstation
- Threshold volumetric lumen detection
- Manual reference of mitral valve plane
EF by 64-slice MDCT vs. SPECT

Bland-Altman Plot

R = 0.90

4D CT Ventriculogram

Dyskinesia in LAD Territory → acute MI

Akinesia in RCA Territory - acute MI

Regional Wall Motion Assessment
Regional Wall Motion Assessment

Navigating 4D Datasets

17 segment AHA classification

1. Anterior
2. Anterior septal
3. Anterior lateral
4. Lateral inferior
5. Lateral anterior
6. Lateral posterior
7. Posterior superior
8. Posterior inferior
9. Inferior anterior
10. Inferior lateral
11. Inferior
12. Diaphragmatic
13. Right anteroseptal
14. Right inferoseptal
15. Right lateral
16. Right posterolateral
17. Right inferior

Comprehensive cCT analysis for ACS

- 102 patients, 34 AMI
- Analyzed for myocardial perfusion defect (vs. SPECT & biomarkers), regional wall motion defects (vs. TTE), and global LV function (vs. TTE)


Regional Wall Motion (RWM) - MDCT vs. TTE

Agreement between RWM by MDCT and:

- Clinical assessment of AMI territory \( K = 0.82 \)
- TTE (4-point scale, 17 myocardial segments) \( K = 0.79 \)

Perfect agreement in 96% of segments (1664 out of 1734)


54 \( \hat{\sigma} \) 3 h substernal pain, pain relief after nitro negative 1st Troponin / CK-MB - non-diagnostic EKG
54-year-old male, 3 h substernal pain, pain relief after nitroglycerin.
Negative 1st Troponin / CK-MB - non-diagnostic EKG.

Functional Information from Cardiac CT:
- LAD Occlusion
- Myocardial Akinesis ± LV thrombus
- Perfusion Defect
- Culprit Lesion in LAD
- Perfusion
Porcine Infarct Model
LAD surgically ligated → non reperfusion infarct

Attenuation in infarcted area significantly lower than in normally perfused myocardium, p<0.01

Perfusion Imaging
MRI vs. MDCT vs. Pathology

Single Perfusion Phase May Suffice

Acute MI

Infarct size $r = 0.73$

Nieman, Abbara, Cury et al, AHA 2005
Acute LAD Infarct

Acute LCX Infarct

Delayed Enhancement

MRI - DE
CT - DE
CT perfusion

Microvascular Obstruction

CT
MRI

FIRST PASS
DELAYED ENHANCEMENT

FP Perfusion Defect Size

DE Microvascular Obstruction Size

Nieman et al.
N=21, 18 male, 60 +/- 13 years
STEMI within 5 days
MRI / barb2 right FP, DE and CT / barb2 right FP, DE
FP Perfusion Defect Size
DE Microvascular Obstruction Size
Dual-energy CT
Iodine maps

80kV  140kV

Dual Energy


Acute vs. chronic MI

Chronic MI

Chronic Infarct with Aneurysm

CT MRI

Contrast bolus 60-80 cc @ 4 cc/sec

Adenosine Perfusion CT Scan

Resting CTA

Delayed CT

~5 minute Recovery period

~10 minute Delay

Stress/Rest Perfusion CT
Scan protocol, order, gating variations

Coregistered short-axis image sets

Stress Agent
Contrast
CT Protocol
Image Analysis

Stress
Rest
Delayed

Courtesy Brian Ghoshharjha, MGH

Courtesy Brian Ghoshharjha, MGH
MGH Stress Perfusion CT Experience

N=34; BMI 30.4+/-5
Stress perfusion CT, radionuclide imaging (MPI), conventional angiography

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12.7mSv average dose (stress, rest, AND delayed enhancement)

Blankstein et al. JACC, September 2009 15;54(12):1072-84

Thank you!

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