CAD: Plaque Characterization and Detection of Coronary Arterial Stenosis

Jim Adams, MD, FACC
Glagov's Model
Three-dimensional reconstruction of the heart and coronary arteries obtained by electron beam tomography (EBT) in 1994

Ref: (3)
• Typical visualization of the coronary arteries by contrast-enhanced computed tomography (coronary CT angiography).

Ref: (3)
• **Curved multiplanar reconstruction.**

Curved multiplanar reformatting view (MPR) reconstructions often have an appearance similar to a traditional angiogram

Ref: (3)
(A) Noncalcified plaque of the proximal right coronary artery with positive remodeling (arrow).

(B) Partly calcified, partly noncalcified plaque that extends from the left main into the proximal left anterior descending coronary artery can be seen (large arrow indicates noncalcified plaque; arrowhead, calcified plaque). In addition, a noncalcified, ulcerated plaque is present just a little further distal in the left anterior descending coronary artery (double arrows).

Ref: (3)
This is the typical appearance of a high-grade stenosis in transaxial images.

Ref: (3)
(B) MIP (5-mm thick) reconstruction  An eccentric lumen reduction of the proximal left circumflex coronary artery is seen (arrow).

(C) To confirm, a multiplanar reconstruction  s rendered in a plane parallel to the course of the proximal left anterior descending coronary artery (see insert). Again, a stenosis is suspected (arrow), but it has to be made certain that this impression is not caused by the surrounding tissue and structures.
(D) MIP (5-mm thickness) in the same plane as panel C.

(E) Curved multiplanar reconstruction of the left anterior descending coronary artery shows the entire proximal and mid segment of the vessel in a single image (arrow indicates stenosis).

Ref: (3)
• (F) Three-dimensional reconstruction (arrow indicates stenosis). Although three-dimensional reconstruction is visually pleasing, it does not add any information to what can be obtained from two-dimensional images.
• (G) Corresponding invasive coronary angiogram. A high-grade stenosis of the left anterior descending coronary artery is confirmed (arrow).

Ref: (3)
Interpretation of coronary computed tomography (CT) angiography can be more difficult than seen in these examples.

(A) Transaxial cross-section (0.75-mm slice thickness) at the level of the proximal left circumflex coronary artery.

A contrast-enhanced lumen cannot clearly be seen, which raises the suspicion of a stenosis (arrow). However, it may be possible that the vessel is outside the image plane.

Therefore, the next step would be to render a maximum intensity projection (MIP).

(B) MIP (5-mm thick) reconstruction in exactly the same level as panel A.

Ref: (3)
(C) multiplanar reconstruction is rendered in a plane parallel to the course of the proximal left anterior descending coronary artery (see insert). Again, a stenosis is suspected (arrow), but it has to be made certain that this impression is not caused by the vessel leaving the image plane.

(D) 5-mm thick MIP reconstruction is rendered in the same plane as the image in panel C. The eccentric, short lumen reduction is appreciable, along with a partly calcified plaque a little more proximal.

Ref: (3)
(E) Corresponding invasive coronary angiogram which also shows a high-grade, eccentric, proximal stenosis of the left circumflex coronary artery (arrow).

Ref: (3)
Which post-processing technique is the most accurate method for measuring stenoses?
What post-processing technique is the most accurate method for measuring stenosis

A. **Free oblique MPR**
B. Transverse MPR
C. Thin MIP
D. 3-D volume rendering
E. Curved MPR
What post-processing technique is the most accurate method for measuring stenosis

A. Free oblique MPR

The thinnest slice pictures available will allow the most detailed analysis of the stenosis. Volume averaging with mip may obscure the stenosis.
What post-processing technique is the most accurate method for measuring stenosis

A. Free oblique MPR

Ferencik Rad. 2007

The evaluation of multidetector CT coronary angiography with interactive image display methods, especially interactive oblique MPRs, permits higher diagnostic accuracy than evaluation of prerendered images (curved MPR, curved MIP, or VRT images).
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* Inevaluable arteries.

Accuracy of Post-Processing Methods for Stenosis Detection
(40 patients, 16 slice CT)

Ferencik et al, Radiology 2007
Which post-processing technique is least accurate for the detection of coronary artery stenoses?
QUESTION
What post-processing technique is the least accurate method for measuring stenosis?

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B. Transverse MPR
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Which post-processing technique is least accurate for the detection of coronary artery stenoses?

Discussion:

• 3-D volume rendering while it can be suggestive of a site of stenosis it is useless in accurately assessing for the severity of stenosis because depending on the gain settings the stenosis can be varied from no stenosis to total occlusion.
Techniques for Static Image Analysis and Display
Techniques for Static Image Analysis and Display

1. Axial slice review - A C S :  Axial, Coronal, Sagittal angles
1. Review of axial slices
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Techniques for Static Image Analysis and Display

2. Maximum Intensity Projection - MIP

Ref: (1)
1. Review of axial slices
2. Maximum Intensity Projection (MIP)

5 mm

Ref: (1)
Techniques for Static Image Analysis and Display

2. Maximum Intensity Projection - Thin MIP

Ref: (1)
2. Maximum Intensity Projection - Thicker MIP
Techniques for Static Image Analysis and Display

3. Multiplanar Reconstruction - MPR

Ref: (1)
Techniques for Static Image Analysis and Display

4. Multiplanar MIP Reconstruction

Ref: (1)
Techniques for Static Image Analysis and Display

5. Curved Multiplanar Reconstruction - CPR

Ref: (1)
Techniques for Static Image Analysis and Display

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Techniques for Static Image Analysis and Display

5. Curved Multiplanar Reconstruction - CPR - C-MPR

MIP image of same patient with angiographic correlation

Ref: (1)
6. 3-D Volume Rendered Technique - VRT
Techniques for Static Image Analysis and Display

6. 3-D Volume Rendered Technique - VRT - VR - 3d-VR
   - Shaded surface display - SSD
Techniques for Static Image Analysis and Display

7. Minimum Intensity Projection - Min-IP

Ref: (1)
Techniques for Static Image Analysis and Display

7. Minimum Intensity Projection - Min-IP
Techniques for Static Image Analysis and Display

8. 4-D Rendering    - Time dimensional

Ref: (1)
Techniques for Static Image Analysis and Display

8. 4-D Rendering
   - Time dimensional
   - Useful in all modes (mpr, mip, vrt)
     - visual interpolation, ala invasive angio.
     - best phase assessment
     - functional and hemodynamic assessment.
Techniques for Static Image Analysis and Display

9. Signal - Noise Ratios - Correctional programs
Techniques for Static Image Analysis and Display

9. Signal - Noise Ratios - Correctional programs
   a. Preprocessing - on the ‘raw’ data
   b. Postprocessing - on the ‘recon’d’ data

Ref: (1)
Summary Points - I

• 2-Dimensional review (thin slice, axial, MPR, MIP) are the most accurate techniques for stenosis detection
• MIP problems: Overlap, calcium
• 3-D Imaging is not accurate for stenosis quantification

Ref: (1)
QUESTION
The greatest limitation of the maximum intensity projection image reconstruction technique is . . . ?

A. The least brightest pixel is projected onto the image.
B. Motion artifacts are increased.
C. Calcified and non-calcified structures may appear to be merged.
D. Brighter pixels can be projected over a vessel’s lumen.
E. All of the above.
The greatest limitation of the maximum intensity projection image reconstruction technique is . . . ?

D. Brighter pixels can be projected over a vessel’s lumen.

This overlapping of the brightest pixels does not allow for accurate assessment of lumen diameter. MPR or very thin MIP projections may limit this problem.
The greatest limitation of the maximum intensity projection image reconstruction technique is . . . ?

D. Brighter pixels can be projected over a vessel’s lumen.

However, mpr projections or very thin mip reconstructions may create the false illusion of stenoses.
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Downside to thicker mip projections

In thin slice mip or in mpr projections luminal diameter is more accurately projected.

Ref: (1)
Downside to thicker mip projections

In thin slice mip or in mpr projections luminal diameter is more accurately projected.
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Axial vs. Multiplanar MIP

Axial MIP
Axial vs. Multiplanar MIP

Multiplanar MIP

Ref: (1)
4. Curved MPR
5. 3-D Reconstruction

"Volume Rendering Technique" (VRT)
3-D Rendering is not accurate!
3-D Rendering is not accurate!
### Accuracy of Post-Processing Methods for Stenosis Detection

(40 patients, 16 slice CT)

**Ferencik et al, Radiology 2007**

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Plaque Severity by CTA - MIP Projections
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Proximal LAD with mild mixed plaque - calcified and non-calcified plaque (soft?)
Proximal LAD with mild mixed plaque - calcified and non-calcified plaque (soft ?)
Mid and distal RCA (dominant) showing multiple areas of focal, nonobstructing calcification (<25% stenosis)
Artifactual proximal posterior descending artery (PDA) stenosis due to ‘out-of-plane’ effect.

Ref: (1)
High grade proximal RCA stenosis with mixed calcified and non-calcified plaque.
Plaque Severity by CTA - MIP Projections

High grade proximal RCA stenosis with mixed calcified and non-calcified plaque.
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**Average sensitivities:**
- Single Source CT: 90 – 92%
- Dual Source CT: 93 – 95%
- Average 5%
## Accuracy of CT for the Detection of CAD

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Ref: (1,8,9,27)
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| *Abdullah et al*     |       |       |      |      |
| 64-slice            | 98%   | 91%   | 97%  | 94%  |

*Eur Heart J 2007*

| *Hamon et al*        |       |       |      |      |
| 4-64 slice          | 96%   | 74%   | 94%  | 83%  |

*JACC 2006*

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### Meta Analyses: Per-Patient

Ref: (1, 8, 9, 27)
Accuracy of CT for the Detection of CAD
Summary of Points to Remember

• Rather high sensitivity
• Somewhat lower specificity
• High negative predictive value
  – In experienced centers
  – In single-center studies
  – That get published (publication bias)
Accuracy of CT for the Detection of CAD

CORE64 Trial

350 patients
Suspected CAD (10% previous PCI)
Mean heart rate 60/min
59 patients excluded for calcium score > 600
97% of all segments evaluable

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</tbody>
</table>

AHA, Nov. 2007
Accuracy of CT for the Detection of CAD
Multi-Center Trial - (not on CT Boards)

CORE64 Trial

350 patients
Suspected CAD (10% previous PCI)
Mean heart rate 60/min
59 patients excluded for calcium score > 600
97% of all segments evaluable

Per-Vessel Sensitivity: 76%
Specificity: 93%
NPV: 89%

AHA, Nov. 2007

Ref: (1,10)
Accuracy of CT for the Detection of CAD

CT Performs Best in Non-High-Risk Patients!
(PPV and NPV depend on the pre-test likelihood)

Meiboom et al., JACC 2007; 50:1469-1475
264 patients with suspected CAD, 64-slice CT and cath

<table>
<thead>
<tr>
<th>Likelihood of CAD</th>
<th>n</th>
<th>Sens</th>
<th>Spec</th>
<th>NPV</th>
<th>if CTA „negative“</th>
</tr>
</thead>
<tbody>
<tr>
<td>High risk</td>
<td>105</td>
<td>98%</td>
<td>74%</td>
<td>83%</td>
<td>17%</td>
</tr>
<tr>
<td>Intermediate risk</td>
<td>83</td>
<td>100%</td>
<td>84%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Low risk</td>
<td>66</td>
<td>100%</td>
<td>93%</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Ref: (1,11)
Accuracy of CT for the Detection of CAD

Lower NPV (83%) meant that 17% of high risk patients were thought to be normal by CTA but really had significant lesions.

<table>
<thead>
<tr>
<th>Likelihood of CAD</th>
<th>n</th>
<th>Sens</th>
<th>Spec</th>
<th>NPV</th>
<th>if CTA „negative“</th>
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</tr>
<tr>
<td>Low risk</td>
<td>66</td>
<td>100%</td>
<td>93%</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Case example of mild LAD stenosis
Case example of mild LAD stenosis by cath
Positive case example of mid LAD stenosis
Positive case example of mid LAD stenosis
Case example of Acute Coronary Syndrome
Note vessel enlargement and surrounding thrombus
Case example of Acute Coronary Syndrome
Note the swelling of the stenotic area of the vessel

Ref: (1)
QUESTION
For the detection of coronary artery stenosis, CT angiography typically has . . . ?

A. Higher specificity than negative predictive value
B. Higher positive predictive value than specificity
C. Lower positive predictive value than negative predictive value
D. Higher sensitivity than negative predictive value
For the detection of coronary artery stenosis, CT angiography typically has . . . ?

A. Higher specificity than negative predictive value
B. Higher positive predictive value than specificity
C. Lower positive predictive value than negative predictive value
D. Higher sensitivity than negative predictive value
For the detection of coronary artery stenosis, CT angiography typically has . . . ?

C. Lower positive predictive value than negative predictive value

Discussion:

CTA tends to over-estimate stenosis, hence, specificity is lower.
CTA is very good at ruling out stenosis
CTA is usually applied in patients who are more likely to be normal - “mass effect” always give higher NPPV
For the detection of coronary artery stenoses, CT angiography typically has . . . ?

C. Lower positive predictive value than negative predictive value

<table>
<thead>
<tr>
<th></th>
<th>Sens.</th>
<th>Spec.</th>
<th>NPV</th>
<th>PPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanhoenacker 4-slice</td>
<td>84%</td>
<td>93%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiology 2007 16-slice</td>
<td>83%</td>
<td>96%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>64-slice</td>
<td>93%</td>
<td>96%</td>
<td></td>
</tr>
<tr>
<td>Abdullah et al 64-slice</td>
<td>86%</td>
<td>96%</td>
<td>97%</td>
<td>83%</td>
</tr>
<tr>
<td>Eur Heart J 2007 4-64 slice</td>
<td>81%</td>
<td>93%</td>
<td>97%</td>
<td>68%</td>
</tr>
</tbody>
</table>

**Meta Analyses: Per-Segment**

Ref: (1,8,9,27)
Can CTA Quantify Stenosis?

Significant correlation, . . . but
Wide limits of agreement.

Ref: (1,12),
Can CTA Quantify Stenosis ?


Significant correlation, . . . but

Wide limits of agreement.

Good correlation but wide limits of agreement
- e.g. CTA est’d 50% lesion - could range bet. 30 – 70% at cath

Ref: (1,12),
Can CTA Quantify Stenosis?

Figure 5. Bland-Altman Analysis of Stenosis Grading Using Multislice Computed Tomography (M5CT) vs. Conventional Invasive Coronary Angiography.

Dashed lines indicate 95% confidence limits; bold line, bias.

Ref: (1,13), Hoffmann et al., JAMA 2005.
Important Summary Points

A. High sensitivity to detect coronary stenoses, with high negative predictive value

B. Positive predictive values typically lower:
   - Overestimates stenosis

C. No accurate grading of stenosis severity

D. CTA performs best in patients whom do not have a very high likelihood of actually having a stenoses
   - Use CTA to rule-out disease
     “I never want to do a normal cath again!”

Ref: (1)
“I never want to do a normal cath again!”

Low risk patients:
Atypical chest pain,
false positive treadmill
“I never want to do a normal cath again!”

LBBB

Ghostine et al, JACC 2006

66 patients with LBBB, 64 slice CT

Per patient: Sensitivity 97%
Specificity 95%
“I never want to do a normal cath again!”

**Heart Failure - New Onset**

---

*Andreini et al, JACC 2006*

61 patients with heart failure of unknown cause, 16 slice CT

<table>
<thead>
<tr>
<th>Per patient</th>
<th>Sensitivity</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specificity</td>
<td>96%</td>
</tr>
<tr>
<td></td>
<td>NPV</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>PPV</td>
<td>81%</td>
</tr>
</tbody>
</table>
"I never want to do a normal cath again!"

**Acute Chest Pain Syndrome**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffmann et al, Circulation 2006</td>
<td>104 pts with acute chest pain (no enzymes, no ECG) 14/14 patients with coronary stenoses detected (sensitivity 100%, specificity 82%)</td>
</tr>
<tr>
<td>Goldstein et al, JACC 2007</td>
<td>297 patients with low risk acute chest pain MDCT: 3.4 hours, $1586 Standard of care: 15 hours, $1872</td>
</tr>
</tbody>
</table>

Ref: (1,17,18)
Scientific Statements About CTA


“Especially in the context of ruling out disease in patients with low to intermediate likelihood of disease, CT coronary angiography may develop into a clinically useful tool. CT coronary angiography is reasonable for the assessment of obstructive disease in symptomatic patients (Class IIa, Level of Evidence B).”

Budoff et al, Circulation 2006;114:1761-1791
“Especially in the context of ruling out disease in patients with low to intermediate likelihood of disease, CT coronary angiography may develop into a clinically useful tool. CT coronary angiography is reasonable for the assessment of obstructive disease in symptomatic patients (Class IIa, Level of Evidence B).”

Budoff et al, Circulation 2006;114:1761-1791
Scientific Statements About CTA
- Appropriateness Criteria, JACC 48(7); 2006

<table>
<thead>
<tr>
<th>INDICATION</th>
<th>SCORE</th>
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<tbody>
<tr>
<td>Detection of CAD With Prior Test Results - Evaluation of Chest Pain Syndrome (CT Angiogram) Uninterpretable or equivocal stress test result (exercise, perfusion, or stress echo)</td>
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</tr>
<tr>
<td>Detection of CAD: Symptomatic - Evaluation of Chest Pain Syndrome (CT Angiogram) Intermediate pre-test probability of CAD, ECG uninterpretable or unable to exercise</td>
<td>7</td>
</tr>
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</tr>
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</tr>
<tr>
<td>Detection of CAD: Symptomatic - Evaluation of Intra-Cardiac Structures (CT Angiogram) Evaluation of suspected coronary anomalies.</td>
<td>9</td>
</tr>
<tr>
<td>Structure and Function - Morphology (Use of CT Angiogram) Assessment of complex congenital heart disease including anomalies of coronary circulation, great vessels, and cardiac chambers and valves</td>
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<tr>
<td>Structure and Function - Evaluation of Intra- and Extra-cardiac Structures (Use of Cardiac CT) Evaluation of cardiac mass (suspected tumor or thrombus), Patients with technically limited images, from echocardiogram, MRI, or TEE</td>
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</tr>
</tbody>
</table>

QUESTION
CTA would not be appropriate in which of the following clinical scenarios?

A. A 65 y.o. woman with chest pain who has an equivocal ST changes on a stress echo study.
B. A 45 y.o. man with atypical chest pain, LBBB, and who is unable to exercise due to an old knee injury.
C. A 54 y.o. woman in the emergency room with atypical chest pain, normal resting EKG and negative cardiac enzymes x one.
D. A 75 y.o. man previously asymptomatic and with new onset congestive heart failure and EKG suggesting an old inferior MI.
E. None of the above
CTA would not be appropriate in which of the following clinical scenarios?

E. None of the above (i.e., appropriate in all)
CTA would not be appropriate in which of the following clinical scenarios?

E. None of the above (i.e., appropriate in all)

Coronary CTA is reliable to rule out coronary artery stenoses in patients with a low to intermediate likelihood of disease.
CTA in LBBB of Uncertain Etiology

Ghostine et al., JACC 2006

66 patients with LBBB, 64 slice CT

Per patient  Sensitivity  97%
Specificity  95%
CTA in Heart Failure of Uncertain Etiology

Andreini et al, JACC 2006

61 patients with heart failure of unknown cause, 16 slice CT

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<tr>
<td></td>
<td>NPV</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>PPV</td>
<td>81%</td>
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</table>
CTA in Preoperative Assessment for Valve Surgery

Meijboom et al, JACC 2006

70 patients prior to aortic valve replacement, 64 slice CT
No atrial fibrillation/renal failure.

<table>
<thead>
<tr>
<th>Per patient</th>
<th>Sensitivity</th>
<th>100%</th>
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<tbody>
<tr>
<td></td>
<td>Specificity</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>NPV</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>PPV</td>
<td>82%</td>
</tr>
</tbody>
</table>

Ref: (1,16)
CTA in Acute Chest Pain

Hoffmann et al, Circulation 2006

104 pts with acute chest pain (no enzymes, no ECG)
14/14 patients with coronary stenoses detected
(sensitivity 100%, specificity 82%)

Goldstein et al, JACC 2007

297 patients with low risk acute chest pain

MDCT: 3.4 hours, $ 1586
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Ref: (1,20)

"Especially in the context of ruling out disease in patients with low to intermediate likelihood of disease, CT coronary angiography may develop into a clinically useful tool. CT coronary angiography is reasonable for the assessment of obstructive disease in symptomatic patients (Class Ila, Level of Evidence B)."

Budoff et al., Circulation 2006, 114:1761-1791
Coronary CTA is reliable to rule out coronary artery stenoses in patients with a low to intermediate likelihood of disease.
Stenosis vs Occlusion?
Can CT tell which is which?
Stenosis vs Occlusion?
Can CT tell which is which? - Not Reliably
Long interruptions of the coronary lumen are more likely to be total occlusions.

Collateral flow / retrograde vs. antegrade filling cannot be determined in CT.
Coronary CTA predictors of CTO recanalization success:

- Lesion length

- Extent of calcification

Mollet et al, Am J Cardiol 2005
Important Summary Points  
- Dr. Achenbach - July 2008

A. Lesions in ACS are often “swollen”, positively remodeled, and/or have a rim of contrast.

B. CTA does not very reliably differentiate between total occlusion and high grade stenosis.

C. Predictors of CTO recanalization success:
   - Lesion length
   - Calcification within the occlusion
Imaging of Non-calcified Plaque

Ref: (1)
Imaging of Non-calcified Plaque

Plaque characterization my CTA is --
Imaging of Non-calcified Plaque

... is difficult!

CT spatial resolution: 
~0.4 mm
Imaging of Non-calcified Plaque

Challenges: NOISE

Ref: (1)
Imaging of Non-calcified Plaque

Challenges: MOTION
Imaging of Non-calcified Plaque

Challenges: MOTION
Imaging of Non-calcified Plaque

Motion free image - mip

Ref: (1)
Imaging of Non-calcified Plaque

<table>
<thead>
<tr>
<th>Study</th>
<th>Patient Count</th>
<th>Plaque Detection Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schoenhagen et al, 2003</td>
<td>14 patients</td>
<td>Accuracy per segment: 87%-90%</td>
</tr>
<tr>
<td>Achenbach et al, 2003</td>
<td>22 patients</td>
<td>Sensitivity per segment: 94% (all)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensitivity per 3 mm segment: 53% (non-calcified)</td>
</tr>
<tr>
<td>Leber et al, 2004</td>
<td>37 patients</td>
<td>Sensitivity per 3 mm segment: 85% (all)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>82% (non-calcified)</td>
</tr>
<tr>
<td>Leber et al, J 2006</td>
<td>19 patients</td>
<td>Sensitivity per 3 mm segment: 83% (all)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95% (calcified)</td>
</tr>
</tbody>
</table>

Ref: (1)
Imaging of Non-calcified Plaque

• Accuracy and Sensitivity of CTA for detecting noncalcified plaque is not well known. Very little data as of yet and only with small numbers of patients.

• To find completely noncalcified plaque the sensitivity is probably going to be in the range of 50 to 80%.

• However, the sensitivities will be much higher when studies also include calcified plaque.
Imaging of Non-calcified Plaque

Plaque Quantification

• Can we accurately quantify the amount of plaque in the coronary arteries?
  • Not reliably
  • Good correlations in a few studies
  • Lots of scatter
Can we accurately quantify the amount of plaque in the coronary arteries?
- Not reliably
- Good correlations in a few studies
- Lots of scatter

Plaque Quantification

Plaque area, $r = 0.55$
Moselewski et al., AJC 2004

Plaque volume, $r = 0.83$
Leber et al., JACC 2006

Plaque volume, $r = 0.74$
Bruinig et al., Cath Card Int 2007
Imaging of Non-calcified Plaque

Plaque Characterization by CT?

Histological Markers

- Thin fibrous cap (< 65 μm)
- Necrotic core
- Macrophage infiltration

CT Markers

Ref: (1)
Plaque Characterization by CT
Remodeling Index

Achenbach et al, JACC 2006
Plaque Characterization by CT
Remodeling Index

Remodeling Index: 1.5

Hoffmann et al, JACC 2006
### Plaque Characterization by CT

<table>
<thead>
<tr>
<th></th>
<th>Lipid Rich</th>
<th>Fibrous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schroeder JACC 2001</td>
<td>14 HU</td>
<td>91 HU</td>
</tr>
<tr>
<td>Becker Eur Radiol 2006</td>
<td>47 HU</td>
<td>104 HU</td>
</tr>
<tr>
<td>Leber JACC 2004</td>
<td>49 HU</td>
<td>91 HU</td>
</tr>
<tr>
<td>Carrascosa AJC 2006</td>
<td>71 HU</td>
<td>116 HU</td>
</tr>
<tr>
<td>Pohle Atheroscler 2007</td>
<td>58 HU</td>
<td>121 HU</td>
</tr>
<tr>
<td>Motoyama Circ J 2007</td>
<td>11 HU</td>
<td>78 HU</td>
</tr>
</tbody>
</table>

Mean density: 46 HU
Plaque Characterization by CT

<table>
<thead>
<tr>
<th></th>
<th>Saline</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumen</td>
<td>66</td>
<td>120</td>
<td>270</td>
<td>502</td>
</tr>
<tr>
<td>Plaque</td>
<td>20</td>
<td>44</td>
<td>94</td>
<td>136</td>
</tr>
<tr>
<td>Calcium</td>
<td>210</td>
<td>232</td>
<td>239</td>
<td>247</td>
</tr>
<tr>
<td>Surrounding</td>
<td>-112</td>
<td>-132</td>
<td>-130</td>
<td>-139</td>
</tr>
</tbody>
</table>

Attenuation in plaque is influenced by luminal contrast

Cademartiri et al, Eur Radiol 2005
Which Plaques will Cause ACS?

4 small studies compared ACS lesions to "stable" lesions:

- ACS lesions: more positive remodeling
- ACS lesions: less frequently calcified/ spotty calcification
- Non-calcified ACS lesions: Lower CT attenuation

Leber AJC 2003; Hoffmann JACC 2006; Schuif Acad Radiol 2007; Motoyama JACC 2007
Why the excitement about detecting/characterizing non-stenotic plaque?

=> Potential use for risk stratification in asymptomatic individuals.

BUT: No clinical data

High radiation exposure

Coronary calcium is already pretty good!
Imaging of Non-calcified Plaque

Plaque Characterization by CT?

• Can we accurately characterize the atherosclerotic plaque in the coronary arteries?
  • NOT YET

The goal is to:

• Tell which is dangerous or likely to rupture
• Tell which is likely to cause future problems
• Tell which are metabolically active
• Tell which are healing and/or less dangerous
Table 2. Detection of CAD: Asymptomatic (Without Chest Pain Syndrome)

<table>
<thead>
<tr>
<th>Indication</th>
<th>Appropriateness Criteria (Median Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asymptomatic (Use of CT Angiogram)</td>
</tr>
<tr>
<td>10. Low CHD risk (Framingham risk criteria)</td>
<td>I (1)</td>
</tr>
<tr>
<td>11. Moderate CHD risk (Framingham)</td>
<td>I (2)</td>
</tr>
<tr>
<td>12. High CHD risk (Framingham)</td>
<td>U (4)</td>
</tr>
</tbody>
</table>

Per consensus 2006:

Use of CT angiography in asymptomatic individuals is NOT appropriate!
SUMMARY V

1. Imaging non-stenotic plaques by CTA is possible, but difficult.

2. Quantification and characterization is not reliable.

3. In plaques associated with ACS: trend towards lower CT density, less calcium, more positive remodeling.

4. CTA for risk stratification in asymptomatic individuals is NOT appropriate!
Question: The most pertinent finding in this image is . . . ?

A. LAD occlusion
B. Ostial RCA occlusion
C. Circumflex branch occlusion
D. Diagonal branch occlusion
E. None of the above

Ref: (1)
The most pertinent finding in this image is . . . ?

D. Diagonal branch occlusion
The most pertinent finding in this image is . . . ?

D. Diagonal branch occlusion
QUESTION  Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

A. More stenotic by CTA.
B. Less stenotic by CTA.
C. Equally stenotic by CTA
D. Highly variable.
E. None of the above.
Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

A. More stenotic by CTA.

On average CTA tends to overcall stenoses.
Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

A. More stenotic by CTA.

On average CTA tends to overcall stenoses.

Ref: (1)
Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

A. More stenotic by CTA.

On average CTA tends to overcall stenoses. (Same patient)
Oblique MIP image suggests high grade mid LCX stenosis at take off of the obtuse marginal branch.

Ref: (1)
QUESTION   Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

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Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

A. More stenotic by CTA.

On average CTA tends to overcall stenoses. (Same patient)
QUESTION:
Which lesion is more likely to have a high grade stenosis?

A. 1 - (LAD Diagonal Br.)
B. 2 - (Mid LCX-LOM)
C. 2 - (LAD Diagonal Br.)
D. 1 - (Mid LCX-LOM)
E. Cannot judge from this image alone.

Ref: (1)
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The lesion in the mid LCX appears to severe, while the take off of the diagonal branch cannot be assessed accurately due to the thickness of the MIP.
Oblique MIP image suggests high grade mid LCX stenosis at take off of the obtuse marginal branch.
QUESTION
Which of the following statements in not true as regards the accuracy of cardiac CTA for assessing severity of CAD?

A. The high negative predictive value (NPV) of cardiac CTA is partly due to the low prevalence of disease in scanned populations.
B. Most segments are normal, so even if a few stenosed segments are missed the NPV stays high.
C. The sensitivity for detecting CAD by CTA is higher than the NPV.
D. The specificity for detecting CAD by CTA is higher than the positive predictive value.
E. All are true statement.
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The high negative predictive value is partly due to the low prevalence of disease.

Most segments are normal – even if a few stenosed segments are missed, the NPV stays high.
Why NPV is always high in low risk population

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The high negative predictive value is partly due to the low prevalence of disease.

Most segments are normal – even if a few stenosed segments are missed, the NPV stays high.

1000 segments – 20 have a stenosis
Only 10 stenoses found.
Of 990 „negative“ CT findings, 980 were correct: 98.9% NPV
QUESTION
CTA is a relatively poor predictor of total occlusion of a coronary artery vs. a high grade, subtotal occlusion primarily because of . . . ?

A. Decreased temporal resolution.
B. Increased signal to noise ratios.
C. Inadequate spatial resolution.
D. All of the above.
E. None of the above.
CTA is a relatively poor predictor of total occlusion of a coronary artery vs. a high grade, subtotal occlusion primarily because of . . . ?

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Occlusion vs. Stenosis?

C. Inadequate spatial resolution.
QUESTION
Which of the following is not true about CTA imaging of chronic total occlusions of the coronary arteries?

A. Long interruptions of the coronary lumen are more likely to be total occlusions.

B. Collateral or retrograde flow versus antegrade filling can sometimes be determined by CTA.

C. Diminished spatial resolution limits differentiation of chronic total occlusions from high grade lesions.

D. Thrombus can be reliably differentiated from noncalcified plaque.

E. All of the above are true.
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Occlusion vs. Stenosis?

CTA does not reliably predict total occlusion vs. high grade stenosis.

Long interruptions of the coronary lumen are more likely to be total obstructions.

Collateral flow / retrograde vs. antegrade filling cannot be determined in CT.

Ref: (1)
The CTA greatest predictor of success for recanalization of a chronic total occlusion of a coronary artery include...

A. Extent of calcification in the entire vessel.
B. Extent of calcification in the proximal segment.
C. The distance of the occlusion from the orifice.
D. Duration of occlusion of the vessel.
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CT Predictors of PCI Success with CTO

Lesion length and Extent of calcification

Coronary CTA predictors of CTO recanalization success:
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Mollet et al, Am J Cardiol 2005

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Mollet et al., Am J Cardiol 2005
CAD Lecture
12 questions
QUESTION
What post-processing technique is the most accurate method for measuring stenosis?

A. Free oblique MPR
B. Transverse MPR
C. Thin MIP
D. 3-D volume rendering
E. Curved MPR
QUESTION
What post-processing technique is the least accurate method for measuring stenosis?

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QUESTION
The greatest limitation of the maximum intensity projection image reconstruction technique is . . . ?

A. The least brightest pixel is projected onto the image.
B. Motion artifacts are increased.
C. Calcified and non-calcified structures may appear to be merged.
D. Brighter pixels can be projected over a vessel’s lumen.
E. All of the above.
QUESTION
For the detection of coronary artery stenosis, CT angiography typically has . . . ?

A. Higher specificity than negative predictive value
B. Higher positive predictive value than specificity
C. Lower positive predictive value than negative predictive value
D. Higher sensitivity than negative predictive value
QUESTION
CTA would not be appropriate in which of the following clinical scenarios?

A. A 65 y.o. woman with chest pain who has an equivocal ST changes on a stress echo study.
B. A 45 y.o. man with atypical chest pain, LBBB, and who is unable to exercise due to an old knee injury.
C. A 54 y.o. woman in the emergency room with atypical chest pain, normal resting EKG and negative cardiac enzymes x one.
D. A 75 y.o. man previously asymptomatic and with new onset congestive heart failure and EKG suggesting an old inferior MI.
E. None of the above
The most pertinent finding in this image is . . . ?

A. LAD occlusion
B. Ostial RCA occlusion
C. Circumflex branch occlusion
D. Diagonal branch occlusion
E. None of the above

Ref: (1)
QUESTION    Most frequently the estimated severity of stenosis of coronary lesions (see arrow) as judged by CTA as compared with invasive angiography is more likely to be graded as . . . ?

A. More stenotic by CTA.
B. Less stenotic by CTA.
C. Equally stenotic by CTA
D. Highly variable.
E. None of the above.
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Thick MIP image

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