Cardiac CT for the diagnosis of CAD

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OUTLINE:

1. What is Cardiac CTA?
   - Techniques
   - Patient preparation

2. Where does CT fit in?
   - When can or should it be used?
Cardiac CT:

- Enhanced arterial phase CT images through the thorax optimized for assessment of the coronary arteries.

(Anomalous RCA from left sinus-malignant course)
Components of Exam:

- CORONARY ARTERIES:
  - Calcium Score:
    - Non enhanced images
    - Calcified plaque
  - Coronary CT Angiogram:
    - Arterial phase enhanced images
    - Non-calcified plaque
Cardiac CT:

- Freezes cardiac motion to allow visualization of coronary arteries.
- Non-invasive assessment with resolution close to coronary cath.
- Very dependent on technologies that are rapidly changing and improving.

(Vein graft to PDA)
Cardiac imager must be involved at each step
  - Protocolling - appropriateness criteria
  - Patient prep
  - Image acquisition
  - Image analysis
*Goal:
  - Attempt to freeze cardiac motion
  - Acquire images over multiple heart beats, preferably when the heart is most still
  - Follow ECG in order to establish timing of systole and diastole
CT Parameters: ECG-gating
Retrospective vs. Prospective

Figure 1:
Model shows retrospective ECG gating versus prospective ECG gating. With retrospective gating, the intensity-modulated x-ray beam is on for the entirety of the R-R intervals during imaging. With prospective gating, the x-ray beam is on for about 26% of every other R-R interval.
Prospective ECG Gating

- **Advantages**
  - Low radiation

- **Disadvantages**
  - Susceptible to HR irregularities
Retrospective ECG Gating

- 1. Select images with least motion
- 2. Function
- 3. Increased radiation
Heart Rate:
- Target HR: 55-60
  - Slower heart rate → longer time in diastole
  - Often anxious on table and with flush of contrast
  - Oral B-Blocker (metoprolol or bisoprolol)
  - IV B-Blockers useful for small reductions in HR
- ECG: Arrhythmia, heart block, and atrial fibrillation

(Artefact in RCA from high HR)
Patient Preparation:

Breath-hold: (64 MDCT scanner)

- Retrospective:
  - 6-12 sec; 6-8 heart beats

- Prospective:
  - 8-12 sec; 8-14 heartbeats

(320-MDCT- 1-2 sec)
Patient Preparation:

- Nitroglycerin spray
  - Dilates coronary arteries
  - Contraindications:
    - Viagra
    - Glaucoma
    - Severe aortic stenosis

- IV contrast
  - 60-80 cc
Limitations:

- Calcified atherosclerotic plaque
  - Blooming artefact: over-estimation of stenosis
  - may not be best test for elderly and diabetics

- Body habitus
  - BMI >40
Technological Advances:

- Improvements in technology have led to improved image quality:
  - Multidetector CT:
    - $1 \rightarrow 4 \rightarrow 16 \rightarrow 64$ detectors... 320
      - Better Spatial resolution
      - Better Temporal resolution
      - Decreased Radiation Dose
Image Quality:

- Spatial resolution:
  - 16 MDCT: 0.8 - 1 mm
  - 64 MDCT: 0.5 mm
  - Cardiac cath: 0.2 mm
Temporal Resolution:

- Important because we are imaging a moving object!
  - Can scan a higher heart rates
  - Shorter scan time
    - Lower radiation dose

- Relates to:
  - \( \frac{1}{2} \) of gantry rotation time (180 degrees of rotation)
Cardiac CT previously reported: 6-25 mSv

- at FMC: 1.5-9 mSv
- More complex patients being assessed with retrospective scanning or entire thorax
- Background exposure of living in Calgary: 3 mSv/year

<table>
<thead>
<tr>
<th>Imaging Procedures</th>
<th>Modality</th>
<th>Effective Dose (mSv)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac procedures</td>
<td></td>
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<tr>
<td>Calcium scoring</td>
<td>Electron beam CT</td>
<td>1.0–1.3</td>
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<td></td>
<td>Multiple-row detector CT</td>
<td>1.5–6.2†</td>
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<tr>
<td>Cardiac CT angiography</td>
<td>Electron beam CT</td>
<td>1.5–2.0</td>
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<tr>
<td></td>
<td>Multiple-row detector CT</td>
<td>6†–25</td>
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<tr>
<td>Cardiac SPECT with $^{99m}$Tc or $^{201}$Tl‡</td>
<td>Nuclear medicine</td>
<td>6.0–15.0</td>
</tr>
<tr>
<td>Coronary angiography (diagnostic)</td>
<td>Fluoroscopy</td>
<td>2.1†–6.0</td>
</tr>
<tr>
<td>Chest radiography</td>
<td>Radiography</td>
<td>0.1–0.2</td>
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<tr>
<td>Routine CT procedures</td>
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<tr>
<td>Head CT</td>
<td>Multiple-row detector CT</td>
<td>1–2</td>
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<tr>
<td>Chest CT</td>
<td>Multiple-row detector CT</td>
<td>5–7</td>
</tr>
<tr>
<td>Abdominal and pelvic CT</td>
<td>Multiple-row detector CT</td>
<td>8–11</td>
</tr>
</tbody>
</table>

*Effective dose values are approximate and may vary based on specific imaging parameters and patient characteristics.
Image analysis:

- 3D reconstruction
Extracoronary Findings

- Cardiac chambers / Pericardium
- Aorta & Pulmonary vessels
- Lung parenchyma
- Esophagus
- Upper abdomen
- Bones
Coronary CTA:

- Another cardiac diagnostic imaging exam...
  - Not the definitive test
  - But is an appropriate test in certain settings

- Anatomic vs physiologic information
  - Nuclear
  - Stress echo
  - Stress MRI

- Non-invasive but also non-therapeutic
  - Catheter angiography
Coronary CTA:

- Evolution of a diagnostic test...
  - Initial excitement, high profile ➔
  - Disappointment, challenges and limitations ➔
  - Validation studies ➔
  - Prognostic studies ➔
  - Plateau
## Diagnostic Performance of CCTA: Four (4) Prospective Multicenter Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACCURACY</strong></td>
<td>95</td>
<td>83</td>
<td>64</td>
<td>99</td>
</tr>
<tr>
<td>N=230, Stable Chest Pain; No known CAD; No exclusion criteria; CAD prevalence 13%</td>
<td></td>
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<tr>
<td><strong>Europe</strong></td>
<td>99</td>
<td>64</td>
<td>85</td>
<td>97</td>
</tr>
<tr>
<td>N=360, Acute and Stable Chest Pain; No known CAD; CAD prevalence 68%</td>
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<tr>
<td><strong>MEDIC</strong></td>
<td>95</td>
<td>91</td>
<td>71</td>
<td>99</td>
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<tr>
<td>N=415 (83), No known CAD; 20-80% pretest LK of CAD</td>
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<tr>
<td><strong>CorE64</strong></td>
<td>85</td>
<td>90</td>
<td>91</td>
<td>83</td>
</tr>
<tr>
<td>N=291, Stable Chest Pain; Known / No Known CAD; Exclude CACS &gt;600; CAD prevalence 56%</td>
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</table>

## Diagnosis of Obstructive CAD

<table>
<thead>
<tr>
<th>Test</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise ECG treadmill(^1)</td>
<td>68%</td>
<td>77%</td>
</tr>
<tr>
<td>Exercise Echo treadmill(^2)</td>
<td>86%</td>
<td>81%</td>
</tr>
<tr>
<td>Dobutamine Echo(^2)</td>
<td>~85%</td>
<td>~85%</td>
</tr>
<tr>
<td>Exercise nuclear treadmill(^3)</td>
<td>87%</td>
<td>73%</td>
</tr>
<tr>
<td>Pharmacologic nuclear(^3)</td>
<td>89%</td>
<td>75%</td>
</tr>
<tr>
<td>Coronary CTA(^4)</td>
<td>94%</td>
<td>83%</td>
</tr>
</tbody>
</table>

1. ACC/AHA 2002 Guideline Update for Exercise Testing
2. ACC/AHA/ASE 2003 Guideline Update for the Application of Echocardiography
3. ACC/AHA/ASNC Guidelines for the Clinical Use of Cardiac Radionuclide Imaging
4. ACCURACY study
Prognostic studies of Coronary CTA

- Shift from studies of identifying the prognostic role of CCTA

- Outcomes measured by:
  - major adverse cardiovascular events (MACE):
    - Death (all cause mortality)
    - MI
    - Readmission for unstable angina
    - coronary revascularization.

Hulten et al. JACC 2011
Study Characteristics:

- 18 studies
- Symptomatic patients - suspected to be attributable to CAD
- 9,592 patients
  - 6,035 positive CCTA findings
  - 3,557 normal CCTA findings
- Median follow-up: 20 months
- Mean age: 59
Definitions:

- Normal (or negative) CCTA study:
  - no, minimal

- Nonobstructive CAD:
  - < 50% stenosis of any coronary artery

- Obstructive CAD:
  - > 50% stenosis of any coronary artery.
Figure 2: Annual Event Rates Stratified by Cardiac Computed Tomography Angiography Result
For “NO or Minimal CAD” patients:

- Low event rate of 0.17%
  - No definite CAD-specific
    - all 23 events were all-cause mortality

- excellent prognosis
- less than the background event rate among healthy low-risk individuals (1%).
High-grade stenosis posterolateral branch (PLB), Right dominant system.
Randomized controlled multi-centered clinical trial of Coronary CTA in ED
987 patients (low-risk presentation)
Primary endpoints:
- Length of stay in hospital:
  - Reduced time to discharge by 7.6h
  - Greater number of patients discharged directly from the ED (47% vs 12%)
  - Improved clinical decision making
- No difference in major adverse cardiovascular events at 28 days.

Secondary endpoints:
- Number of diagnostic investigations were increased in CT arm
- Costs were unchanged in CT arm
- Radiation dose was slightly higher in CT arm
CT in ER ROMICAT II sub-study

2y follow-up:

- No / minimal CAD (183 patients):
  - No MACE

- Non-obstructive (<50% stenosis) (117 patients):
  - 30 days: 4 (1.3)
  - 1 year: 4 (1.3)
  - 2 year: 5 (1.8)
Guidelines:

ACCF/SCCT/ACR/AHA/ASE/ASNC/SCAI/SCMR
2010 Appropriate Use Criteria for Cardiac Computed Tomography
Stable ischemic heart disease

- Symptomatic patients Without Known Heart Disease
ACCF/AHA/ASE/ASNC/HFSA/HRS/SCAI/SCCT/SCMR/STS 2013
Multimodality Appropriate Use Criteria for the Detection and Risk Assessment of Stable Ischemic Heart Disease
Stable symptomatic Patients:

- trend toward functional imaging over CCTA as a primary test

<table>
<thead>
<tr>
<th>Indication Text</th>
<th>Exercise ECG</th>
<th>Stress RNI</th>
<th>Stress Echo</th>
<th>Stress CMR</th>
<th>Calcium Scoring</th>
<th>CCTA</th>
<th>Invasive Coronary Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Low pre-test probability of CAD</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>R</td>
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<tr>
<td>ECG interpretable AND able to exercise</td>
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<td>2. Low pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
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<tr>
<td>ECG uninterpretable OR unable to exercise</td>
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<tr>
<td>3. Intermediate pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>M</td>
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<td>ECG interpretable AND able to exercise</td>
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<tr>
<td>4. Intermediate pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>M</td>
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<td>5. High pre-test probability of CAD</td>
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<td>A</td>
<td>A</td>
<td>A</td>
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<td>6. High pre-test probability of CAD</td>
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<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
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<td>A</td>
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<tr>
<td>ECG uninterpretable OR unable to exercise</td>
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Refer to pages 16 and 17 for relevant definitions, in particular Table A and text for age, sex, symptom presentation, and risk factors relevant to each pre-test probability category.
### Sequential Testing (≤90 Days): Uncertain Prior Results

- Appropriate if uncertain or abnormal functional test such as exercise ECG or stress imaging study.

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<th>CCTA</th>
<th>Invasive Coronary Angiography</th>
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<tbody>
<tr>
<td><strong>Equivocal, Borderline, or Discordant Prior Noninvasive Evaluation</strong></td>
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<tr>
<td>Where Obstructive CAD Remains a Concern</td>
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<tr>
<td>30. Prior exercise ECG test</td>
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<td></td>
<td>A</td>
<td>R</td>
<td>A</td>
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<tr>
<td>31. Prior stress imaging study (assumes not repeat of same type of stress imaging)</td>
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<tr>
<td>32. Prior CCTA</td>
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<td></td>
<td></td>
<td></td>
<td>R</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>Prior Coronary Angiography (Invasive or Noninvasive)</strong></td>
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<tr>
<td>33. Coronary stenosis or anatomic abnormality of unclear significance found on cardiac CCTA</td>
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<tr>
<td>34. Coronary stenosis or anatomic abnormality of unclear significance on previous coronary angiography</td>
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</table>
Detection of CAD/Risk Assessment: Asymptomatic individuals

- Without Known Heart Disease
- Calcium Scoring
Calcium Score:
**ACCF/SCCT/ACR/AHA/ASE/ASNC/SCAI/SCMR**  
*2010 Appropriate Use Criteria for Cardiac Computed Tomography*

<table>
<thead>
<tr>
<th>Indication</th>
<th>Appropriate Use Score (1-9)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk Assessment Postrevascularization (PCI or CABG)—Asymptomatic—Prior Coronary Stenting</strong></td>
<td></td>
</tr>
<tr>
<td>43. Prior left main coronary stent with stent diameter ≥3 mm</td>
<td>A (7)</td>
</tr>
<tr>
<td><strong>Evaluation of Cardiac Structure and Function—Adult Congenital Heart Disease</strong></td>
<td></td>
</tr>
<tr>
<td>46. Assessment of anomalies of coronary arterial and other thoracic arteriovenous vessels</td>
<td>A (9)</td>
</tr>
<tr>
<td>47. Assessment of complex adult congenital heart disease</td>
<td>A (8)</td>
</tr>
<tr>
<td><strong>Evaluation of Cardiac Structure and Function—Evaluation of Ventricular Morphology and Systolic Function</strong></td>
<td></td>
</tr>
<tr>
<td>49. Evaluation of left ventricular function</td>
<td>A (7)</td>
</tr>
<tr>
<td>Following acute MI or in HF patients</td>
<td></td>
</tr>
<tr>
<td>Inadequate images from other noninvasive methods</td>
<td></td>
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<tr>
<td>50. Quantitative evaluation of right ventricular function</td>
<td>A (7)</td>
</tr>
<tr>
<td>51. Assessment of right ventricular morphology</td>
<td>A (7)</td>
</tr>
<tr>
<td>Suspected arrhythmogenic right ventricular dysplasia</td>
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<tr>
<td><strong>Evaluation of Cardiac Structure and Function—Evaluation of Intra- and Extracardiac Structures</strong></td>
<td></td>
</tr>
<tr>
<td>53. Characterization of native cardiac valves</td>
<td>A (8)</td>
</tr>
<tr>
<td>Suspected clinically significant valvular dysfunction</td>
<td></td>
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<tr>
<td>Inadequate images from other noninvasive methods</td>
<td></td>
</tr>
<tr>
<td>54. Characterization of prosthetic cardiac valves</td>
<td>A (8)</td>
</tr>
<tr>
<td>Suspected clinically significant valvular dysfunction</td>
<td></td>
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<tr>
<td>Inadequate images from other noninvasive methods</td>
<td></td>
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<tr>
<td>56. Evaluation of cardiac mass (suspected tumor or thrombus)</td>
<td>A (8)</td>
</tr>
<tr>
<td>Inadequate images from other noninvasive methods</td>
<td></td>
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<tr>
<td>57. Evaluation of pericardial anatomy</td>
<td>A (8)</td>
</tr>
<tr>
<td>58. Evaluation of pulmonary vein anatomy</td>
<td>A (8)</td>
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<tr>
<td>Prior to radiofrequency ablation for atrial fibrillation</td>
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<tr>
<td>59. Noninvasive coronary vein mapping</td>
<td>A (8)</td>
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<tr>
<td>Prior to placement of biventricular pacemaker</td>
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<tr>
<td>60. Localization of coronary bypass grafts and other retrosternal anatomy</td>
<td>A (8)</td>
</tr>
<tr>
<td>Prior to reoperative chest or cardiac surgery</td>
<td></td>
</tr>
</tbody>
</table>
Different Uses:

- Bypass grafts
Different Uses:

- Bypass grafts
- Stents (>3mm)
Different Uses:

- Bypass grafts
- Stents
- Coronary anomalies
Different Uses:

- Bypass grafts
- Stents
- Coronary anomalies
- Cardiac Masses / Pericardium

(Left atrial myxoma)

(LV thrombus)
Different Uses:

- Bypass grafts
- Stents
- Coronary anomalies
- Cardiac Masses / Pericardium
- Adult congenital heart disease

(Left atrial myxoma)

(LV thrombus)
Out-patient volumes:

- 2012-13: 889
- 2013-14 (to Dec): 930
Role of coronary CTA is still evolving
- Acute chest pain
- Stable chest pain

Very good at ruling out coronary disease
- If positive, another test may be required.
- Useful when another functional exam is abnormal or equivocal.
Future Directions:

- Coronary CT FFR
- CT perfusion
Diagnostic performance of non-invasive fractional flow reserve derived from coronary CT angiography in suspected coronary artery disease:
The NXT trial


For the NXT Investigators
Case Example

LAD stenosis 70-90%

FFR 0.94

FFR_{CT} 0.93

FFR_{CT} Model
CORE 320

CTA 50% Stenosis + CTP Perfusion Defect VS QCA 50% Stenosis + SPECT Perfusion Defect

CTA 50% Stenosis + CTP Perfusion Defect VS QCA 50% Stenosis

Source: Rochitte et al. Nov 2013
CORE320 Complete Dataset
Scenario 2:

- For Asymptomatic patients risk factor assessment using calcium scoring is appropriate in:
  - Intermediate risk patients
  - Low risk patients with family history
Detection of CAD in Symptomatic Patients: Acute Presentation

- Without Known Heart Disease
ACCF/SCCT/ACR/AHA/ASE/ASNC/SCAI/SCMR
2010 Appropriate Use Criteria
for Cardiac Computed Tomography
Summary:

“In general, use of CCT angiography for diagnosis and risk assessment in patients with low or intermediate risk or pretest probability for coronary artery disease (CAD) was viewed favorably.”

“Testing in high-risk patients, routine repeat testing, and general screening in certain clinical scenarios were viewed less favorably.”
Use of noncontrast computed tomography (CT) for calcium scoring was rated as appropriate within intermediate- and selected low-risk patients.

Appropriate applications of CCT are also within the category of cardiac structural and functional evaluation.
Coronary anomalies are reported in 0.3-1.3% of population.

Most are not felt to be hemodynamically significant.

Malignant Course:
- Carry risk of sudden death; artery impinged upon RVOT during exercise
  - Interarterial Course: Right> Left
Extracoronary Findings:
History - 49 y woman with dyspnea on exertion
Meta-Analysis and Systematic Review of the Long-Term Predictive Value of Assessment of Coronary Atherosclerosis by Contrast-Enhanced Coronary Computed Tomography Angiography

Fabian Bamberg, MD, MPH,*† Wieland H. Sommer, MD,† Verena Hoffmann, PhD,‡ Stephan Achenbach, MD,§ Konstantin Nikolaou, MD,† David Cohen, MD, MPH,¶ Maximilian F. Reiser, MD,† Udo Hoffmann, MD, MPH,* Christoph R. Becker, MD†
Effective Dose (mSv)

- Effective Dose = DLP \times CT (chest) conversion coefficient (0.017)
  - DLP for entire scan
    - (scout, timed-dose, aortic root localization run)
    - DLP = CTDI \times Z-axis scan length
Evaluation of bypass grafts

- Why it is easier
  - Larger size of vessels
  - Less cardiac motion
  - Less calcification in grafts

- Why it is harder
  - Clip artifact
  - Native coronaries heavily calcified
Grafts

Venous

Arterial
Venous grafts
Arterial graft
Stent patency:
Coronary anomalies
Coronary anomalies

Shi. Eur Radiol. 2004; 14: 2172

- 6.6% incidence (suspected CAD)
- 56% malignant course
- 100% diagnosis with MDCT
- 53% diagnosis with angiography
- Limitations of angio
  - Two dimensional modality
  - Selective canalization required
Diagnosis of Ischemia-Causing Coronary Stenoses by Noninvasive Fractional Flow Reserve Computed From Coronary Computed Tomographic Angiograms

Results From the Prospective Multicenter DISCOVER-FLOW (Diagnosis of Ischemia-Causing Stenoses Obtained Via Noninvasive Fractional Flow Reserve) Study

Bon-Kwon Koo, MD, PhD,* Andrejs Erglis, MD, PhD,† Joon-Hyung Doh, MD, PhD,‡ David V. Daniels, MD,§ Sanda Jegere, MD,∥ Hyo-Soo Kim, MD, PhD,* Allison Dunning, MD,¶ Tony DeFrances, MD,# Alexandra Lansky, MD,*‡ Jonathan Leipsic, BSc, MD,∥‡ James K. Min, MD‡

Seoul and Goyang, South Korea; Riga, Latvia; Palo Alto, San Francisco, and Los Angeles, California; New York, New York; New Haven, Connecticut; and Vancouver, British Columbia, Canada

<table>
<thead>
<tr>
<th></th>
<th>FFRCT ≤0.80</th>
<th>CCTA ≥50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>88</td>
<td>91</td>
</tr>
<tr>
<td>Specificity</td>
<td>82</td>
<td>40</td>
</tr>
<tr>
<td>PPV</td>
<td>47</td>
<td>74</td>
</tr>
<tr>
<td>NPV</td>
<td>89</td>
<td>92</td>
</tr>
<tr>
<td>Accuracy</td>
<td>59</td>
<td>84</td>
</tr>
</tbody>
</table>
What about intermediate stenoses?

Source: Tonino PA et al. J Am Coll Cardiol
## Angiographic Versus Functional Severity of Coronary Artery Stenoses in the FAME Study

Fractional Flow Reserve Versus Angiography in Multivessel Evaluation

### % Stenosis by Angiography*

<table>
<thead>
<tr>
<th>% Stenosis by Angiography*</th>
<th>50% to 70% (n = 620, 47%)</th>
<th>71% to 90% (n = 513, 39%)</th>
<th>91% to 99% (n = 96, 15%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR &gt; 0.80</td>
<td>402 (65)</td>
<td>104 (20)</td>
<td>7 (4)</td>
</tr>
<tr>
<td>FFR ≤ 0.80</td>
<td>218 (35)</td>
<td>409 (80)</td>
<td>189 (96)</td>
</tr>
<tr>
<td>Mean FFR for all lesions</td>
<td>0.81 ± 0.12</td>
<td>0.67 ± 0.15</td>
<td>0.52 ± 0.15</td>
</tr>
<tr>
<td>Mean FFR &gt; 0.80</td>
<td>0.89 ± 0.05</td>
<td>0.87 ± 0.05</td>
<td>0.87 ± 0.04</td>
</tr>
<tr>
<td>Mean FFR ≤ 0.80</td>
<td>0.68 ± 0.10</td>
<td>0.62 ± 0.13</td>
<td>0.51 ± 0.13</td>
</tr>
</tbody>
</table>

Source: Tonino et al JACC 2010
## Diagnostic Performance of FFRCT for 30-69% Stenoses by CCTA

<table>
<thead>
<tr>
<th>FFR&lt;sub&gt;CT&lt;/sub&gt;</th>
<th>Accuracy</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR&lt;sub&gt;CT&lt;/sub&gt; ≤ 0.80</td>
<td>83.8</td>
<td>64.9</td>
<td>88.5</td>
<td>60.5</td>
<td>90.0</td>
</tr>
<tr>
<td>CCTA</td>
<td>43.1</td>
<td>85.2</td>
<td>31.2</td>
<td>25.2</td>
<td>88.9</td>
</tr>
</tbody>
</table>

Source: Leipsic et al RSNA 2011
The DeFACTO Study
(Determination of FFR by Anatomic CT Angiography)

• 17-center international study of 252 patients undergoing CCTA and invasive FFR to evaluate the diagnostic performance of \( FFR_{CT} \) compared to coronary CT alone using invasively measured FFR as the reference standard

Source: Min, Leipsic, Berman et al. JAMA 2012: 308 (12): 1237-1245
Discrimination (total patient population, n=252)

- Greater discriminatory power for $\text{FFR}_{\text{CT}}$ versus CT stenosis
  - Per-patient ($\Delta 0.13$, $p<0.001$)
  - Per-vessel ($\Delta 0.06$, $p<0.001$)

*AUC = Area under the receiver operating characteristics curve*
Intermediate stenosis: Discrimination

**Per-Patient**

<table>
<thead>
<tr>
<th></th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR&lt;sub&gt;CT&lt;/sub&gt;</td>
<td>0.80 (95% CI 0.70, 0.89)</td>
</tr>
<tr>
<td>CT</td>
<td>0.52 (95% CI 0.50, 0.64)</td>
</tr>
</tbody>
</table>

**Per-Vessel**

<table>
<thead>
<tr>
<th></th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR&lt;sub&gt;CT&lt;/sub&gt;</td>
<td>0.80 (95% CI 0.71, 0.87)</td>
</tr>
<tr>
<td>CT</td>
<td>0.53 (95% CI 0.50, 0.62)</td>
</tr>
</tbody>
</table>

- Greater discriminatory power for FFR<sub>CT</sub> versus CT stenosis
  - Per-patient (Δ 0.29, p<0.0001)
  - Per-vessel (Δ 0.26, p<0.0001)

* Nakazato et al. Circ Imaging 2013
Discrimination of Ischemia*

Per-Vessel (n=478)

\[
\text{Sensitivity: } 1 - \text{Specificity}
\]

- \( \text{FFR}_{\text{CT}} \): 0.93
- \( \text{CT} \): 0.79

Per-Patient (n=251)

\[
\text{Sensitivity: } 1 - \text{Specificity}
\]

- \( \text{FFR}_{\text{CT}} \): 0.82
- \( \text{CT} \): 0.63

Greater discriminatory power for \( \text{FFR}_{\text{CT}} \) versus CT stenosis

Vessel (\( \Delta 0.14, p<0.001 \))

Patient (\( \Delta 0.19, p<0.001 \))

*Area under the receiver operating characteristics curve
Diagnostic performance of non-invasive fractional flow reserve derived from coronary CT angiography in suspected coronary artery disease: The NXT trial


For the NXT Investigators
Case Example

LAD stenosis 70-90%

FFR 0.94

FFR\textsubscript{CT} 0.93

FFR\textsubscript{CT} Model
CORE 320

Source: Rochitte et al. Nov 2013
Improved Accuracy Beyond CCTA across all Vascular Territories

Source: Rochitte et al EHJ 2013
CORE320 Complete Dataset
Figure Legend:
Symptomatic
## Table 12  Characteristics of tests commonly used to diagnose the presence of coronary artery disease

<table>
<thead>
<tr>
<th>Test</th>
<th>Diagnosis of CAD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensitivity (%)</td>
</tr>
<tr>
<td>Exercise ECG</td>
<td>45–50</td>
</tr>
<tr>
<td>Exercise stress echocardiography⁹⁶</td>
<td>80–85</td>
</tr>
<tr>
<td>Exercise stress SPECT⁹⁶/⁹⁹</td>
<td>73–92</td>
</tr>
<tr>
<td>Dobutamine stress echocardiography⁹⁶</td>
<td>79–83</td>
</tr>
<tr>
<td>Dobutamine stress MRI⁹³/¹⁰⁰</td>
<td>79–88</td>
</tr>
<tr>
<td>Vasodilator stress echocardiography⁹⁶</td>
<td>72–79</td>
</tr>
<tr>
<td>Vasodilator stress SPECT⁹⁶,⁹⁹</td>
<td>90–91</td>
</tr>
<tr>
<td>Vasodilator stress MRI⁹,⁹⁸,¹⁰⁰/¹⁰²</td>
<td>67–94</td>
</tr>
<tr>
<td>Coronary CTA⁹,¹⁰³–¹⁰⁵</td>
<td>95–99</td>
</tr>
<tr>
<td>Vasodilator stress PET⁹⁷,⁹³,¹⁰⁶</td>
<td>81–97</td>
</tr>
</tbody>
</table>

CAD = coronary artery disease; CTA = computed tomography angiography; ECG = electrocardiogram; MRI = magnetic resonance imaging; PET = positron emission tomography; SPECT = single photon emission computed tomography.

⁹ Results without/with minimal referral bias.
⁹³ Results obtained in populations with medium-to-high prevalence of disease without compensation for referral bias.
¹⁰⁵ Results obtained in populations with low-to-medium prevalence of disease.
Coronary CTA:

- Where are we now?

- Strengths:
  - Sensitivity
  - Ruling out CAD
  - Accessibility → ED

- Weaknesses:
  - Ionizing radiation
  - Patient preparation
Detection of CAD in Symptomatic Patients: Acute Presentation

- Without Known Heart Disease

![Flowchart](chart.png)

- Normal ECG and cardiac biomarkers OR ECG uninterpretable OR nondiagnostic ECG OR equivocal biomarkers
  - Low pretest probability of CAD: Appropriate (6, 7, 8)
  - Intermediate pretest probability of CAD: Appropriate (6, 7, 8)
  - High pretest probability of CAD: Appropriate (6, 7, 8)

- Persistent ECG ST segment elevation following exclusion of MI OR "triple rule out"?
  - Uncertain (4, 5)
  - Inappropriate (3)

Definite MI?
Cardiac CT previously reported: 6-25 mSv

- at FMC: 1.5-9 mSv
- More complex patients being assessed with retrospective scanning or entire thorax
- Background exposure of living in Calgary: 3 mSv/year

<table>
<thead>
<tr>
<th>Imaging Procedures</th>
<th>Modality</th>
<th>Effective Dose (mSv)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium scoring</td>
<td>Electron beam CT</td>
<td>1.0–1.3</td>
</tr>
<tr>
<td></td>
<td>Multiple-row detector CT</td>
<td>1.5–6.2†</td>
</tr>
<tr>
<td>Cardiac CT angiography</td>
<td>Electron beam CT</td>
<td>1.5–2.0</td>
</tr>
<tr>
<td></td>
<td>Multiple-row detector CT</td>
<td>6†–25</td>
</tr>
<tr>
<td>Cardiac SPECT with $^{99}$Tc or $^{201}$Tl‡</td>
<td>Nuclear medicine</td>
<td>6.0–15.0</td>
</tr>
<tr>
<td>Coronary angiography (diagnostic)</td>
<td>Fluoroscopy</td>
<td>2.1†–6.0</td>
</tr>
<tr>
<td>Chest radiography</td>
<td>Radiography</td>
<td>0.1–0.2</td>
</tr>
<tr>
<td>Routine CT procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head CT</td>
<td>Multiple-row detector CT</td>
<td>1–2</td>
</tr>
<tr>
<td>Chest CT</td>
<td>Multiple-row detector CT</td>
<td>5–7</td>
</tr>
<tr>
<td>Abdominal and pelvic CT</td>
<td>Multiple-row detector CT</td>
<td>8–11</td>
</tr>
</tbody>
</table>
Coronary CTA is a highly sensitive exam for detection of coronary artery disease.

When used in appropriate population has an excellent negative predictive value.
For Abnormal CCTA findings:

- MACE rate for positive versus negative CCTA findings was 8.8% vs 0.17% per year (p < 0.05)
  - predominantly revascularization

- For death or MI, average annualized event rate was 3.2% versus 0.15% (p < 0.05) for positive versus negative scans.

- After stratifying by nonobstructive CAD and obstructive CAD, incrementally increasing cardiovascular events (MI and revascularization) and all-cause mortality rates occurred with increasing severity of CAD.
## Sequential Testing (≤90 Days): Abnormal Prior Test/Study

<table>
<thead>
<tr>
<th>Indication Text</th>
<th>Exercise ECG</th>
<th>Stress RNI</th>
<th>Stress Echo</th>
<th>Stress CMR</th>
<th>Calcium Scoring</th>
<th>CCTA</th>
<th>Invasive Coronary Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>23. Abnormal rest ECG findings (potentially ischemic in nature such as LBBB, T-wave inversions) Low global CAD risk</td>
<td></td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>24. Abnormal rest ECG findings (potentially ischemic in nature such as LBBB, T-wave inversions) Intermediate to high global CAD risk</td>
<td></td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>25. Abnormal prior exercise ECG test</td>
<td></td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>26. Abnormal prior stress imaging study (assumes not repeat of same type of stress imaging)</td>
<td>R</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>R</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>27. Obstructive CAD on prior CCTA study</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>28. Obstructive CAD on prior invasive coronary angiography</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>29. Abnormal prior CCT calcium (Agatston Score &gt;100)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td></td>
<td>M</td>
<td>R</td>
</tr>
</tbody>
</table>
MACE-Free Survival Based upon the Presence of Non-Obstructive, and Obstructive 1-, 2- and 3-vessel CAD for Individuals Without Modifiable CAD Risk Factors

Source: Leipsic et al. AHA 2012, Radiology June 2013