Cardiac CT Imaging: The Fundamentals

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• No disclosures
Fundamentals of Cardiac CT

1. Cardiac CT CPT codes
2. Coronary Calcium Scoring
3. Coronary CT Angiography
   1. Applications: ED, angina, bypass grafts, stents, anomalies
   2. CT techniques
   3. Patient selection and optimization
4. Other applications of Cardiac CT
   1. TAVR
   2. Left atrium
5. Radiation dose considerations
6. Conclusions
Cardiac CT CPT Codes

- **75571** — Computed tomography, heart, without contrast material, with quantitative evaluation of **coronary calcium**

- **75572** — Computed tomography, heart, with contrast material, for evaluation of **cardiac structure and morphology** (including 3D image postprocessing, assessment of cardiac function, and evaluation of venous structures, if performed) **(TAVR, LA/pulmonary veins pre-ablation)**

- **75573** — Computed tomography, heart, with contrast material, for evaluation of cardiac structure and morphology in the setting of **congenital heart disease** (including 3D image postprocessing, assessment of LV cardiac function, RV structure and function and evaluation of venous structures, if performed)

- **75574** — Computed tomographic angiography, heart, **coronary arteries and bypass grafts** (when present), with contrast material, including 3D image postprocessing (including evaluation of cardiac structure and morphology, assessment of cardiac function, and evaluation of venous structures, if performed)
Coronary Calcium Score and Cardiovascular Risk

• CAC scoring is a widely available, consistent, and reproducible means of assessing risk for major CV outcomes
• No IV contrast, low radiation dose
  • If CCTA ordered then CAC score will precede CCTA
• Most appropriate for asymptomatic patients with low-intermediate risk of atherosclerotic cardiovascular disease
Coronary Calcium as a Predictor of Coronary Events
6722 subjects followed for 4 years

<table>
<thead>
<tr>
<th>Coronary-Artery Calcium Score</th>
<th>Major Coronary Event(\dagger)</th>
<th>Any Coronary Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No./No. at Risk</td>
<td>Hazard Ratio (95% CI)</td>
</tr>
<tr>
<td>0</td>
<td>8/3409</td>
<td>1.00</td>
</tr>
<tr>
<td>1–100</td>
<td>25/1728</td>
<td>3.89 (1.72–8.79)</td>
</tr>
<tr>
<td>101–300</td>
<td>24/752</td>
<td>7.08 (3.05–16.47)</td>
</tr>
<tr>
<td>&gt;300</td>
<td>32/833</td>
<td>6.84 (2.93–15.99)</td>
</tr>
<tr>
<td>Log(_2)(CAC+1)(\ddagger)</td>
<td>32/833</td>
<td>1.20 (1.12–1.29)</td>
</tr>
</tbody>
</table>

* CAC denotes coronary-artery calcium score, and CI confidence interval.
\(\dagger\) Major coronary events were myocardial infarction and death from coronary heart disease.
\(\ddagger\) Each unit increase in log\(_2\)(CAC+1) represents a doubling of the coronary-artery calcium score.

Coronary Calcium Score and Cardiovascular Management

- Suggested guideline: 10-year ASCVD risk estimate plus CAC scoring
- <5%: statin is not recommended regardless of CACS.
- 5-7.5%: consider statin; CACS = 0 statin not recommended; CACS >1 consider statin.
- >7.5-20%: recommend statin; CACS = 0 statin not recommended; CACS >0 recommend statin.
- >20%: recommend statin regardless of CACS.

Coronary CTA (CCTA)

- Anatomic methods alone not perfect
  - functional significance: research into FFR-CT and CT perfusion
- CCTA able to evaluate ≥ 2mm sized vessels
- In low-intermediate risk patients (≤ 20% risk of CAD event in 10 years)
- CCTA has high Negative Predictive Value 97-99%
- CCTA has moderate Positive Predictive Value 50-85%
- *CCTA as gatekeeper for coronary catheterization*
Clinical Application of CCTA in CAD

1. Detection of CAD in symptomatic patients without known heart disease, either nonacute or acute presentations

2. Detection of CAD in patients with new-onset or newly diagnosed clinical heart failure and no prior CAD

3. Preoperative coronary assessment prior to noncoronary cardiac surgery

4. Patients with prior electrocardiographic exercise testing - Normal test with continued symptoms or intermediate risk Duke treadmill score

5. Patients with prior stress imaging procedures - Discordant electrocardiographic exercise and imaging results or equivocal stress imaging results

Clinical Application of CCTA in CAD

6. Evaluation of new or worsening symptoms in the setting of a past normal stress imaging study

7. Risk assessment post-revascularization - Symptomatic if post-coronary artery bypass grafting or asymptomatic with prior left main coronary stent of 3 mm or greater

8. Evaluation of cardiac structure and function in adult congenital heart disease

9. Evaluation of cardiac structure and function - Ventricular morphology and systolic function

10. Evaluation of cardiac structure and function - Intracardiac and extracardiac structures

Detection of Coronary Artery Disease
Inherent Advantages of Cardiac MDCT

1. Non invasive
2. Simultaneous imaging of coronary vessel lumen and wall
3. Offers stenosis assessment and plaque characterization
CT Data Reconstruction and Interpretation

MPR

Curved MPR

Straightened MPR

Short axis MPR
CT Data Reconstruction and Interpretation

4–chamber view

2–chamber view

Short axis view
CT Data Reconstruction and Interpretation
Challenges in Cardiac CT Imaging

• Heart motion (cardiac & respiratory)
  • Breath-holding for 10 sec
  • Cardiac ECG gating (synchronization)
• Non-symmetric, non-axial geometry
  • High resolution, 3D images
• Tortuous small vessels
  • Contrast administration
  • High resolution
  • Control for motion
Timing is Essential…and HR affects radiation dose

Imaging window

LV Volume

ECG

Mid diastole
Patient Selection
CCTA is generally contraindicated if:

• known history of severe and/or anaphylactic contrast reaction
• inability to cooperate with scan acquisition and/or breath-hold instructions
• Pregnancy
• clinical instability (e.g. acute myocardial infarction, decompensated heart failure, severe hypotension)
• renal impairment precluding iodinated contrast
Patient variables that affect the diagnostic accuracy of CCTA

- heart rate variability and arrhythmia
  - Accurate imaging requires “freezing” coronary artery motion
  - Optimal heart rate ≤ 60
  - Variability (a.fib) worse
  - Standard dose 100mg metoprolol PM before exam, 50mg AM of exam
  - IV doses of metoprolol on CT table

- Contraindication to beta-blockade?
  - Active bronchospastic disease, hypertrophic cardiomyopathy, severe aortic valve stenosis, or other precautions or contraindications to beta-blockers

- Ca++ channel blockers can be used on direction of clinician
Patient variables that affect the diagnostic accuracy of CCTA

• Obesity
• Difficulty following breath-hold commands, maintaining body position, raising one or both arms, or lying supine for scanning
• Contraindication to nitroglycerin
  • CCTA requires coronary artery dilatation for optimal imaging
  • Standard dose 0.8mg sl tab/spray if possible, 0.4mg if not
Pre-test instructions

• Avoid caffeine and smoking 12 hours prior to the procedure
• No food for 3–4 hours prior to exam (may drink water or clear fluids without caffeine)
• Take all regular medications the day of exam, especially blood pressure medicine
  • Patients should not have taken a phosphodiesterase inhibitor for 48 hours before the exam
• Take pre-medications for contrast allergy as prescribed by the ordering physician
• suspend metformin for at least 48 hours after contrast administration

72 year old man with unstable angina
Plaque Characterization

• CCTA can identify patients with higher likelihood for major adverse cardiac events (MACE)
  • Plaque burden
  • Segmental stenosis score

• CCTA can identify plaques that are more likely to cause MACE
  • Lesion length
  • Plaque burden
  • Remodeling index
  • Napkin-ring sign

ROMICAT
Rule Out Myocardial Infarction using Computer Assisted Tomography

- 368 chest pain patients with normal initial troponin and nonischemic electrocardiogram
- 50% had negative CCTA: 100% sensitivity and NPV for ACS
- Plaque on CCTA: specificity of 54% and PPV of 17% for ACS
- Stenosis on CCTA: specificity of 87% and PPV of 35% for ACS

ROMICAT-II

• 1000 patients
• early CCTA vs standard evaluation in the emergency department
• CCTA: mean length of stay in the hospital was reduced by 7.6 hours (P<0.001) and more patients were discharged directly from the emergency department (47% vs. 12%, P<0.001)
• no undetected acute coronary syndromes and no significant differences in major adverse cardiovascular events
• After CCTA, there was more downstream testing and higher radiation exposure
Chest Pain in the ED: Initial Assessment

<table>
<thead>
<tr>
<th>Indication</th>
<th>Echocardiography</th>
<th>CMR</th>
<th>SPECT</th>
<th>CCTA</th>
<th>CCath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive initial diagnosis of NSTEMI/ACS</td>
<td>Rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Initial ECG and/or biomarker analysis unequivocally positive for ischemia</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>A</td>
</tr>
<tr>
<td>Equivocal initial diagnosis of NSTEMI/ACS</td>
<td>M*</td>
<td>M*</td>
<td>A</td>
<td>A</td>
<td>R</td>
</tr>
<tr>
<td>4. Equivocal initial troponin or single troponin elevation without additional evidence of ACS</td>
<td>R</td>
<td>M</td>
<td>M*</td>
<td>A</td>
<td>R</td>
</tr>
<tr>
<td>5. Ischemic symptoms resolved hours before testing</td>
<td>R</td>
<td>M</td>
<td>M*</td>
<td>A</td>
<td>R</td>
</tr>
<tr>
<td>Low/intermediate likelihood initial diagnosis of NSTEMI/ACS</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>A</td>
<td>R</td>
</tr>
<tr>
<td>6. TIMI risk score = 0, early hsTrop negative</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Normal or nonischemic on initial ECG, normal initial troponin</td>
<td>R</td>
<td>R</td>
<td>M*</td>
<td>A</td>
<td>R</td>
</tr>
</tbody>
</table>

Appropriate use key: A = appropriate; M* = may be appropriate as determined by lack of consensus by rating panel; R = rarely appropriate.

Chest Pain in the ED: After troponins

<table>
<thead>
<tr>
<th>Indication</th>
<th>Exercise ECG</th>
<th>Echocardiography</th>
<th>CMR</th>
<th>SPECT/PET</th>
<th>CCTA</th>
<th>CCath</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Diagnosis unequivocally positive for NSTEMI/ACS</td>
<td>M*</td>
<td>M*</td>
<td>M*</td>
<td>M*</td>
<td>M*</td>
<td>A</td>
</tr>
<tr>
<td>Serial troponins or ECG not positive for NSTEMI/ACS</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>9. Serial ECG and troponins negative for NSTEMI/ACS</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>10. Serial ECG or troponins borderline for NSTEMI/ACS</td>
<td>M*</td>
<td>M*</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>M*</td>
</tr>
</tbody>
</table>

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A 66 year old man with suspected coronary artery occlusion one day following diagnostic invasive coronary angiography.
Cardiac MDCT in Acute Chest Pain Syndrome – “Triple Rule Out”

- Significant Left Main Soft Plaque
- Aortic dissection
- Pulmonary Emboli
CCTA vs Standard Care for Non-urgent Chest Pain (PROMISE)

- 10,003 patients
- Randomized to CCTA or functional testing
  - Exercise ECG, Stress echo, or Nuclear stress
- No difference in MACE
- Less likely to have non-obstructive angiography in CCTA group
  - But more CCTA patients went to cath
- Relative equivalence of CCTA and functional tests

## Symptomatic CAD

### Table 1.1. Symptomatic

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.

<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>
<td>R</td>
</tr>
<tr>
<td>2. Low pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>M</td>
<td>R</td>
<td>R</td>
</tr>
<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>
<td>R</td>
</tr>
<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>
</tr>
<tr>
<td>5. High pre-test probability of CAD</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>6. High pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>A</td>
</tr>
</tbody>
</table>

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Sequential testing with abnormal/uncertain prior results

Table 2.0. 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)</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>M</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>24. Abnormal rest ECG findings (potentially ischemic in nature such as LBBB, T-wave inversions)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>25. Abnormal prior exercise ECG test</td>
<td>A</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>M</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>

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Asymptomatic CAD

**Table 1.2. Asymptomatic (Without Symptoms or Ischemic Equivalent)**

<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>7. Low global CHD risk, Regardless of ECG interpretability and ability to exercise</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>8. Intermediate global CHD risk, ECG interpretable and able to exercise</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>M</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>9. Intermediate global CHD risk, ECG uninterpretable OR unable to exercise</td>
<td>M</td>
<td>M</td>
<td>R</td>
<td>M</td>
<td>M</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>10. High global CAD Risk, ECG interpretable and able to exercise</td>
<td>A</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>11. High global CAD Risk, ECG uninterpretable OR unable to exercise</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>R</td>
</tr>
</tbody>
</table>

Refer to pages 17 and 18 for relevant definitions.

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Detection of Coronary Artery Disease: Bypass Grafts Evaluation
Detection of Coronary Artery Disease
Bypass Grafts Evaluation
Detection of Coronary Artery Disease
Coronary Stent Evaluation

53-y-old man 3 days following PTCA of LAD
74-year-old man 2 years following PTCA & stent placement in LAD
Evaluation for Anomalous Coronary Arteries

• found incidentally in 0.3%–1% of healthy individuals
• anomalies may be very difficult to visualize at angiography
• 126 nontraumatic sudden deaths in young adults: 31% CA anomalies
  • Eckart RE et al, Ann Intern Med 2004; 141:829–834

TAVR-Transcatheter Aortic Valve Replacement

- Up to 30% of patients with severe AS not surgical candidates
- Edwards Sapien Valve: balloon expanding
- PARTNER trial
  - TAVR superior to valvuloplasty in nonsurgical patients
  - 699 patients: surgery vs TAVR
  - No difference in death @ 1 year
  - TAVR higher stroke risk @ 30 days
  - TAVR higher risk of major vascular complications
  - Surgery higher risk of bleeding and afib
  - TAVR has better valve function (AS) but more AI
- Corevalve: self expanding
TAVR planning

• CCT for aortic root measurements
• Chest/Abdomen/Pelvis CTA for access vessels
• Patients usually elderly, extensive ASCVD, renal impairment
• 60ml contrast used
• Promote hydration
• No beta blockers or NTG
  • Although arrhythmias/Afib may impact image quality
Measurements
Annular cross-sectional area (CSA)

- Area = 379 mm²
- $D_{csa} = 22.0$ mm
Coronary artery distances
Common iliac measurement

Gregory Pearson MD PhD, Society of Thoracic Radiology 2015
Cardiac CT pre-ablation for Atrial Fibrillation

- Left Atrium/Pulmonary Vein Anatomy
- Left Atrial Thrombus
- Complications of ablation
- CT/MR for electroanatomic map fusion
Radiation Dose of Cardiac Imaging Procedures

• CCTA (476 exams in 12 centers) median effective dose was $9.6 \text{ mSv}$ (IQR = 13.2 mSv)
• single photon emission computed tomography (310 exams in 9 centers) effective dose was $9.3$ (IQR = 2.8)
• positron emission tomography (85 in 3 centers) effective dose $1.8$ (IQR = 1.6)
• invasive coronary angiography (199 in 9 centers) effective dose $7.4$ (IQR = 7.3)

Cardiac CT Dose—Trends and Future Progress

- Spiral CTA
- Adaptive ECG Pulsing
- Step-and-Shoot
- High-pitch dual spiral technique
- Helical SURE Cardio Prospective

Dose (in mSv)
Conclusions

• Cardiac CTA has a proven role in evaluation of coronary artery disease
• Appropriate patient selection and preparation
• Multiple additional applications of cardiac CT
• Radiation doses improving with modern technologies
• If questions, consult your friendly radiology colleagues