The Emerging Role of Cardiac CT in Cardiovascular Imaging

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Conflict Disclosures

I have no significant financial relationship with any companies whose product may be germane to the content of their presentations or who are supporting this program.
Learning Objectives

• Describe the ways that cardiac CT (CCT) can be used to diagnose cardiovascular disease
• Introduce key concepts involved in the acquisition and interpretation of cardiac computed tomography (CCT) images
• Review the literature comparing cardiac CT to conventional coronary angiography including imaging quality and prognosis
• Discuss case vignettes that highlight some of the strengths of CCT
Multimodality Cardiovascular Imaging Center at the White River Junction VAMC

Area of specialty focus in the section of cardiology:

- Echocardiography- including advanced techniques (3D, myocardial strain)
- Nuclear Cardiology
- Cardiac MRI
- Cardiac CT
The Challenge of Imaging the Heart

• The anatomy is complex and variable
  – four chambers, four valves, pericardium, coronary arteries

• The heart is constantly moving
  – systole and diastole
  – respiratory motion

• It’s located deep inside the chest
  – protected by sternum/ribs
  – surrounded by lungs
WHAT DIAGNOSTIC TOOLS DO WE HAVE?

HISTORY AND PHYSICAL

ECG

LAB TESTING

ECHOCARDIOGRAPHY

MYOCARDIAL PERFUSION IMAGING

CARDIAC MRI

CARDIAC CT

Blankstein R, Introduction to Noninvasive Cardiac Imaging. Circulation 2012; 125 e267-e271
Our New Scanner (Install Summer 2016)

320 detector rows
640 slice capability
16 cm coverage/rotation

Image acquisition in 0.35 seconds

0.5 mm x 0.5 mm x 0.5 mm voxel size

Can capture high resolution images of the heart in a single beat

Toshiba Aquilion One, Toshiba
Information that can be Obtained

- Chamber Size
- Anatomy of Great Vessels (Ao, PA)
- Venous Mapping
- Coronary Anatomy, including Hard and Soft Plaque, and soon functional imaging
- Lung Anatomy, including granulomas and tumor
Key Advances in CCT

• **Gating** – images could be timed to the rhythm of the heart, allowing a series of slices to be captured at the same point in time

• **Multidetector Rows** (16 → 64 → 128 → 256/320) – increased thickness of sections captured

• **Reconstruction Software** – improved image quality using increasingly less radiation
How is a Study Performed?

Very similar to PE protocol CT:

1) IV placed for contrast administration
2) Telemetry for gating
3) Heart rate slowed using a beta-blocker, nitroglycerin given to optimize coronary vasodilation
4) Brief breath hold
5) Bolus of contrast (70-80 mL) administered
6) Image collection takes ~0.3 seconds
7) Processing and Interpretation
Technical Limitations

- Breath Hold
- Arrhythmia (AF/PVC/PAC)
- Heart Rate (>65)
- Coronary Artery Calcification/Stents
- Body Habitus
- Patient Cooperation/Claustrophobia
Hear that drumbeat about CT scans and radiation exposure? It's growing louder.

A medical technician prepares a patient for a CT scan at Tokushima University Hospital in Tokushima, Japan. This is simply for "what it looks like" purposes. (Everett Kennedy Brown / EPA)

Hospitals Blame Manufacturers For High Radiation

LOS ANGELES (AP) — Two Southern California hospitals blamed the manufacturer of their CT scanners for radiation overdoses received by 18 patients.

The statements by Bakersfield Memorial Hospital and Los Angeles County-University of Southern California Medical Center came as federal regulators continue to investigate allegations of similar problems nationwide.

The high doses of radiation at the two California hospitals were found in patients who had brain scans conducted with...

Exposure to Low-Dose Ionizing Radiation from Medical Imaging Procedures

## Ionizing Radiation

<table>
<thead>
<tr>
<th>Exam</th>
<th>Representative Dose (mSV)</th>
<th>Time to Receive Equivalent Background Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CXR PA/Lat</td>
<td>0.1</td>
<td>12 days</td>
</tr>
<tr>
<td>Head CT</td>
<td>2</td>
<td>8 months</td>
</tr>
<tr>
<td>Low dose Chest CT</td>
<td>1-3</td>
<td>4-12 months</td>
</tr>
<tr>
<td>PE Protocol Chest CT</td>
<td>10</td>
<td>3 years</td>
</tr>
<tr>
<td>Abd/Pelv CT</td>
<td>10-15</td>
<td>3-5 years</td>
</tr>
<tr>
<td>Nuclear Stress (1 day, Tc99m-sestamibi)</td>
<td>12</td>
<td>4 years</td>
</tr>
<tr>
<td>Nuclear Stress (Thallium)</td>
<td>30</td>
<td>10 years</td>
</tr>
<tr>
<td>Cardiac CTA</td>
<td>1-5</td>
<td>4-20 months</td>
</tr>
<tr>
<td>Coronary Angiography</td>
<td>5-15</td>
<td>2-5 years</td>
</tr>
</tbody>
</table>
What do the Images Look Like?
| Transaxial | Volume Rendering | Curved Multiplanar Reconstruction |
How does CCT Stack up against…

Stress Testing?

Invasive Coronary Angiography?
Stress Testing at WRJ VAMC

- Exercise Treadmill Test
- Exercise Treadmill + Echo (Stress-Echo)
- Bicycle Stress + Echo
- Exercise Treadmill + MPI (Nuclear)
- Vasodilator Stress + MPI
## Accuracy of Stress Testing for Detecting Obstructive CAD

<table>
<thead>
<tr>
<th>Test</th>
<th>Sn (%)</th>
<th>Sp (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETT</td>
<td>68</td>
<td>77</td>
</tr>
<tr>
<td>Ex-MPI</td>
<td>88</td>
<td>70</td>
</tr>
<tr>
<td>Pharm MPI</td>
<td>89</td>
<td>77</td>
</tr>
<tr>
<td>Ex-Echo</td>
<td>85</td>
<td>77</td>
</tr>
</tbody>
</table>

## Annualized Rate of MI/Cardiac Death by Stress Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Median F/u (mo)</th>
<th>Normal</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETT</td>
<td>30</td>
<td>0.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Ex-MPI</td>
<td>20</td>
<td>0.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Pharm-MPI</td>
<td>22</td>
<td>1.8</td>
<td>10.0</td>
</tr>
<tr>
<td>Ex-Echo</td>
<td>36</td>
<td>0.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Arbab-Zadeh A, Heart Int 2012 7(1)
Table 3

Direct comparison of computed tomography angiography vs single-computed-tomography for detecting ≥50% coronary artery stenoses quantitative coronary angiography.

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>CTA sensitivity</th>
<th>CTA specificity</th>
<th>SPECT sensitivity</th>
<th>SPECT specificity</th>
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</thead>
<tbody>
<tr>
<td>Budoff et al.</td>
<td>30</td>
<td>95</td>
<td>89</td>
<td>81</td>
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<td>Schuijf et al.</td>
<td>58</td>
<td>100</td>
<td>81</td>
<td>70</td>
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<td>Gaemperli et al.</td>
<td>78</td>
<td>94</td>
<td>100</td>
<td>53</td>
<td>83</td>
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<tr>
<td>Gallagher et al.</td>
<td>85</td>
<td>86</td>
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<td>71</td>
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<tr>
<td>Budoff et al.</td>
<td>48</td>
<td>92</td>
<td>78</td>
<td>76</td>
<td>57</td>
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<tr>
<td>Arbab-Zadeh et al.</td>
<td>62</td>
<td>95</td>
<td>100</td>
<td>86</td>
<td>45</td>
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<tr>
<td>Hamirani et al.</td>
<td>122</td>
<td>99</td>
<td>74</td>
<td>55</td>
<td>39</td>
</tr>
<tr>
<td>Pooled results</td>
<td>483</td>
<td>96</td>
<td>88</td>
<td>66</td>
<td>69</td>
</tr>
</tbody>
</table>

CTA = computed tomography angiography; SPECT = single-photon emission computed tomography.
Outcomes of Anatomical versus Functional Testing for Coronary Artery Disease (PROMISE)

- 10,003 symptomatic patients randomized to CTA vs. functional stress testing

- Primary outcome: death, MI, unstable angina, major procedural complication

- Pretest likelihood of CAD 53%

- Follow-up 25 months

- Primary Outcome: 3.3% (CTA) vs. 3.0% (functional) p=NS

Douglas P, et al. NEJM 2015; 372(14)
Coronary Angiography

• Current gold standard

• **Strengths**: excellent spatial and temporal resolution, hemodynamics, intervention

• **Weaknesses**: projection imaging, bleeding, mechanical complications, radiation, iodinated contrast (allergy, nephrotoxicity)
Types of Coronary Remodeling

- **R1**
- **E**
- **C**
- **R2**

[Diagram showing different stages of coronary remodeling with labels R1, E, C, R2 and annotations for plaque and lumen.]
Comparison of CT Angiography to Invasive Coronary Angiography (ICA)

- Chao SP, et al. compared 256 row CTA in patients with suspected CAD, compared with diagnostic cath

- 104 pts agreed to undergo CTA prior to undergoing ICA

- Per segment analysis ROC AUC 0.92

- Sn 94%  Sp 95%  PPV 78%  NPV 98.7%

Chao SP, et al. EHJ 2010; 31: 1916-1923
Case Vignette #1

67 year old man with history of hypertension, hyperlipidemia and active tobacco use who presents to the ED complaining of 8 hours of persistent left sided chest discomfort. Initial ECG and cardiac enzymes are unremarkable.

Admit for “rule out”? 
Traditional Clinical Pathway: “The Rule Out”

- Admit to the hospital
- “Rule out” via serial cardiac biomarkers +/- ECG
- Arrange stress test
- Wait for stress test to be performed and interpreted
- Discharge patient, or arrange for further care (diagnostic cath, outpatient follow-up)
CTA Alternative Pathway

- Low-intermediate risk patients
- If first set of cardiac enzymes negative then perform cardiac CTA

- If no coronary disease then discharge home
- If CAD present then admit for additional management
Rule Out Myocardial Infarction by Computer Assisted Tomography (ROMICAT)

- Blinded observational study

- 368 pts. presenting to the ED with acute chest pain, normal initial troponin and non-ischemic ECG
- All pts. received CTA but providers were blinded to the findings

- 8% had ACS
- 50% had no evidence of CAD, of these CTA had 100% Sn and NPV for ACS
- At 2 y. follow-up prognosis was excellent, no major adverse cardiovascular events

Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Triage (CT-STAT)

– 699 pts. With low-intermediate risk presentations for ACS (TIMI ≤4)
– Randomized to CTA (n=361) or rest-stress MPI (n=338).

– Time to diagnosis reduced (2.9 h vs 6.3 h, p<0.001)
– ED costs lowered ($2137 vs. $3458, p<0.001)
– No missed cases of ACS

Coronary CT Angiography vs. Standard Evaluation in Acute Chest Pain (ROMICAT-II)

- 1000 pts. Presenting with CP to the ED randomized to early CTA or Standard of Care (SOC)

- CTA vs. SOC:
  - Reduced median length of stay (8.6 h vs. 26.7 h, p<0.001)
  - Reduced time to diagnosis (5.8 h vs. 21.0 h, p<0.001)
  - Rate of MACE at 30 d. similar (2 vs. 6 events, p=0.18)
  - Cost of care similar (~4k)

CT Angiography for Safe Discharge of Patients with Possible Acute Coronary Syndromes (ACRIN-PA)

- 1370 pt.s randomized with neg. ECG and enzymes, TIMI <2 2:1 to CTA (n=908) vs. Standard of Care (n=462)

- No missed ACS
- Safety: Upper bound of 95% CI for missed ACS was <1%
- Higher rate of direct ED discharges (50% vs. 23%)
- Shorter length of stay (18 vs. 25 h)

Litt H, et al. NEJM 2012
Case Vignette #2

69 year old man with coronary artery disease (prior MI, DES to RCA in 2007), hypertension, tobacco use (active), AAA (s/p EVAR), peripheral vascular disease with claudication.

CT for pulmonary nodules and mediastinal lymph nodes, had CT scan. Possible CT aneurysm with peripheral calcifications measuring ~1.5 cm
- Size, shape and location of the lesion can be better characterized

- Potential for intervention better assessed
Case Vignette #3

43 year old woman who developed multiple episodes of syncope in the setting of GI illness. Brief runs of polymorphic VT spontaneously terminating. Taken to cath lab and found to have anomalous right coronary artery. But what course?
Use of CT for visualization of anomalous coronary anatomy

Roper, et al. JACC 2008
The Future

– Ultra Low Dose CTA
– CCT with CT FFR/CT Perfusion Imaging
– Plaque Characterization
– Characterization of cardiac structures
– CTA for Atrial Thrombus?
Ultra-Low Dose CTA

Stehli, J. et al. studied 36 patients with CCTA using MBIR (model based iterative reconstruction) scheduled to undergo cath.

BMI range 17-39 kg/m²
Radiation Exposure: 0.29 +/- 0.12 mSv (CCTA) vs. 13.7 +/- 9.7 mSv (ICA)

Diagnostic Accuracy (vs. ICA):
Sn 100%  Sp 74%  PPV 77%  NPV 100%
Accuracy: 86%

JACC 2014; 64: 772-80
CT-Fractional Flow Reserve

Evidence of hemodynamic significant of a given coronary lesion

Good correlation with catheter based measurements (FFR) and stress imaging
Plaque Characterization

Specific plaque characteristics predictive of high risk lesions → increased likelihood of developing ACS

Nature Reviews Cardiology 2014 11:390-402
Left Atrial Appendage Morphologies

Di Biase L, et al. JACC 2012; 60(6)
CCT for Left Atrial Thrombus

Meta Analysis of LAA thrombus by CCT in patients with atrial fibrillation

- 19 studies, 2955 patients
- LA thrombus 8.9%
- Sn 96% Sp 92% PPV 41% NPV 99% Accuracy 94%

- Subanalysis using delayed imaging technique,
  Sn 100%, Sp 99% PPV 92% NPV 100% Accuracy 99%

Summary

• CCT provides non-invasive coronary assessment near equivalent to diagnostic coronary angiography

• New techniques and clinical pathways may become available within the next year employing this technology

• Anticipate CCT program will be up and running by Summer-Fall 2016
Thank You