Multimodality Imaging and Heart Disease

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Disclosures: None

Objectives
• Introduction
• Different imaging modalities and their strengths/weaknesses
• Incorporation of multi-modality imaging in different clinical indications
• Appropriateness criteria
• Conclusions

Introduction
• CVD: biggest source of morbidity and mortality
• Many new imaging technologies
• Advances in imaging outpacing our ability to digest the changes
• Cost, risks, what to do with the information?
  – In 2009, CCF did more than 61000 echoes, 7500 CTs and 2500 CMR’s

Imaging and Real Data: A Major Disconnect
• ACC/AHA guidelines:
  – 750 recommendations related to cardiac imaging

Level A
Level B
Level C
Some sobering information !!!!!!!

Recent data shows that only 38% coronary angiographies were clinically indicated.

Different Noninvasive imaging modalities

- Echocardiography
  - Mainstay of noninvasive CV diagnosis
- Myocardial perfusion scintigraphy
  - SPECT, PET
- Cardiac magnetic resonance
- Cardiac computed tomography

Utility and Limitations

<table>
<thead>
<tr>
<th>Imaging technique</th>
<th>Potential diagnostic utility</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo</td>
<td>* LV thickness * valves and hemodynamics * global and regional LV function * ischemia * viability</td>
<td>* Limited acoustic windows * inaccurate wall thickness measurements * suboptimal assessment of subvalvarular apparatus</td>
</tr>
<tr>
<td>MPI</td>
<td>* Ischemia * viability * coronary flow reserve (PET)</td>
<td>* Limited availability (PET) * expensive (PET) * high radiation exposure</td>
</tr>
<tr>
<td>CMR</td>
<td>* LV dimensions * cardiac morphology * tissue characterization * regional myocardial mechanics * aortic pathology</td>
<td>* Limited availability * multiple device-related contraindications</td>
</tr>
<tr>
<td>MDCT</td>
<td>* CAD * LV function and morphology * emerging role in viability * aortic pathology</td>
<td>* Radiation exposure * nephrotoxicity * emerging data</td>
</tr>
</tbody>
</table>

Radiation Doses for Medical Procedures

<table>
<thead>
<tr>
<th>Diagnostic procedure</th>
<th>Typical effective dose (mSv)</th>
<th>Equivalent period of natural background radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural background radiation</td>
<td>3-4 (range 1.5-7.5)</td>
<td>1 year</td>
</tr>
<tr>
<td>Chest X-ray (PA and lateral)</td>
<td>0.04</td>
<td>6 days</td>
</tr>
<tr>
<td>Transatlantic flight</td>
<td>0.03</td>
<td>3 days</td>
</tr>
<tr>
<td>Lung perfusion study (99m Tc)</td>
<td>1</td>
<td>4-6 months</td>
</tr>
<tr>
<td>Calcium scoring</td>
<td>0.8-2</td>
<td>3-6 months</td>
</tr>
<tr>
<td>CT head</td>
<td>2</td>
<td>3 months</td>
</tr>
<tr>
<td>Cardiac catheterization (diagnostic)</td>
<td>3-4</td>
<td>1 year</td>
</tr>
<tr>
<td>64-slice MDCT (with dose modulation)</td>
<td>Male: 4.8-10 Female: 5.8-14</td>
<td>2-3 years</td>
</tr>
<tr>
<td>CT angiographic prospective</td>
<td>2.4</td>
<td>1 year</td>
</tr>
<tr>
<td>68-PET myocardial perfusion</td>
<td>1.5</td>
<td>4-5 years</td>
</tr>
<tr>
<td>99m Tc stress and reinjection</td>
<td>25.1</td>
<td>6-8 years</td>
</tr>
<tr>
<td>Dual isotope (Tc-99m)</td>
<td>22.3</td>
<td>5-6 years</td>
</tr>
</tbody>
</table>

Equivalent period of natural background radiation

Typical effective dose (mSv)

Diagnostic procedure

- Radiation exposure
- Nephrotoxicity
- Emerging data

Further information: Radiation Doses for Medical Procedures (2010).
Noninvasive Diagnostic Testing in Ischemic Heart Disease

Anybody wonder why CAD is such an epidemic?

Different Stress Testing Modalities

- Exercise
  - Treadmill (either with echo or nuclear)
  - Sitting bicycle
  - Supine bicycle
- Pharmacological
  - Dobutamine-- Contractility and HR increase (either with echo, nuclear or CMR)
  - Dipyridamole – vasodilating (mostly nuclear)
  - Adenosine – vasodilating (mostly nuclear, CMR, ?? CT is emerging)
Exercise echocardiography

Sensitivity Comparison of Different Testing Modalities

Specificity of Different Stress Testing Modalities

NUCLEAR TECHNIQUES MORE SENSITIVE BUT LEAST SPECIFIC
Comparison between SPECT (201Tl and 99mTc) and PET-82Rb

<table>
<thead>
<tr>
<th></th>
<th>SPECT</th>
<th>PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>« excellent » images</td>
<td>62%</td>
<td>78%</td>
</tr>
<tr>
<td>Interpretation certainty (normal, abnormal)</td>
<td>81%</td>
<td>96%</td>
</tr>
<tr>
<td>Diagnostic accuracy</td>
<td>71%</td>
<td>87%</td>
</tr>
</tbody>
</table>


Adenosine MRI

Adenosine stress MRI: Sensitivity 100%
Specificity 93%

Adenosine MRI

Dobutamine Echo vs. CMR

208 consecutive cardiac cathes

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo</td>
<td>80%</td>
<td>60%</td>
<td>60%</td>
<td>80%</td>
<td>70%</td>
</tr>
<tr>
<td>CMR</td>
<td>90%</td>
<td>70%</td>
<td>70%</td>
<td>90%</td>
<td>80%</td>
</tr>
</tbody>
</table>

208 consecutive cardiac cathes

Nagel et al. Circ 1999;99:763-70

Stress Echo and Prognosis

Event-free survival (%)

P<0.001

Females, exWMSI<1.25
Males, exWMSI<1.25
Females, exWMSI ≥1.25
Males, exWMSI ≥1.25

Nagel et al. Circ 1999;99:763-70

Stress Echo and Prognosis

Arruda-Olsen et al. JACC 2002

Stress Echo and Prognosis

Arruda-Olsen et al. JACC 2002
Prognostic Value of SPECT Patients with Normal ECG

But life is not that simple

Quest to search for the "predisposed" patient

MI and Severity of Stenosis

MI or SCD as Initial Presentation of CHD

Coronary Calcium Scoring
Possibly indicated in asymptomatic individuals with intermediate Framingham risk score

Prospective study
N=1461
Mean f/u 7.0 years
84 pts AMI or CHD death


MDCT Coronary Angiography
• Diagnostic utility in patients with intermediate likelihood of CAD
• High number of unnecessary invasive procedures†:
  – 40% of women
  – 20-25% of men
  – ? potential in patients to exclude CAD

Meta-Analysis of MDCT for Coronary Artery Stenosis ≥ 16 Slice
• 27 studies with ≥ 16 slice CT between 2002-2006

<table>
<thead>
<tr>
<th>Analysis</th>
<th>N</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>LR + (95% CI)</th>
<th>LR - (95% CI)</th>
<th>DOR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per segment</td>
<td>2279</td>
<td>0.81 (0.72-0.89)</td>
<td>0.93 (0.90-0.97)</td>
<td>21.54 (13.07-35.46)</td>
<td>0.11 (0.06-0.21)</td>
<td>159.32 (93.47-283.43)</td>
</tr>
<tr>
<td>Per vessel</td>
<td>2726</td>
<td>0.82 (0.69-0.86)</td>
<td>0.91 (0.86-0.96)</td>
<td>11.80 (7.57-20.64)</td>
<td>0.08 (0.02-0.21)</td>
<td>146.45 (31.95-574.45)</td>
</tr>
<tr>
<td>Per patient</td>
<td>1370</td>
<td>0.96 (0.94-0.98)</td>
<td>0.74 (0.65-0.84)</td>
<td>5.36 (3.45-8.33)</td>
<td>0.05 (0.03-0.09)</td>
<td>133.05 (57.29-335.34)</td>
</tr>
</tbody>
</table>

STRENGTH IS HIGH SENSITIVITY AND NEGATIVE PREDICTIVE VALUE

†Kugelmas AD, J Am Coll Cardiol 2001;37:497A
Hamon M. J Am Coll Cardiol 2006; 48:1896-1910
Case: 48-year old female presenting to ER with recurrent chest pain. EKG and enzymes negative. Smoker, hypertensive. Underwent 256-slice coronary CT angiography.

HR: 72 BPM
Dose: 3.8 mSEV

Advanced CAD

Heavily calcified 3-vessel CAD
Noncalcified plaque in proximal LAD

Correlation of Coronary CT and Perfusion

MSCT obstructive
N=33

MPI normal
N=14

Angio obstructive
N=33

Angio non-obstructive
N=11

Stenoses in CT not closely correlated to an abnormal MPI

Schuijf et al, JACC 2006

Outcomes after MDCT

>50% stenosis

<table>
<thead>
<tr>
<th>CCTA Result</th>
<th>HR (95% CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.00</td>
<td>0.95</td>
</tr>
<tr>
<td>Any severe</td>
<td>2.65 (1.37-5.12)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Any left main</td>
<td>1.61 (1.05-2.48)</td>
<td>0.04</td>
</tr>
<tr>
<td>Three vessel</td>
<td>2.04 (0.99-4.20)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

N = 1127 patients with symptoms
- 70% with intermediate or high pretest probability
• Endpoint: Death – by Social Security Death Index

Min et al. J Am Coll Cardiol 2007;50:1161-70

Cumulative Survival in Patients with Moderate (>50%) Plaque by CCTA

Time to Follow-up (Years)

Cumulative Survival

None or Mild (<50% Plaque) (n=490)

1Vessel Disease (n=186) p=0.68

2Vessel Disease (n=145) p=0.20

3Vessel Disease (n=200) p=0.045

Left main Plaque (n=106) p<0.0001

X2=34 P<0.0001
Prognostic Utility of MDCTA

227 patients with no documented CAD had 64-MDCTA with 2.5 years fu.

Number of patients at risk of events:

- Group 1: 170
- Group 2: 19
- Group 3: 9
- Group 4: 13

Log-rank statistic: p-value < 0.0001

Coronary Anomalies

Bypass Grafts

MSCT for Coronary Stent Assessment: A Meta-analysis

Sensitivity Specificity Positive Predictive Value Negative Predictive Value

MSCT not good for stents < 2.5 mm in size

Desai MY. European Heart Journal Jan 2009

Desai MY. AJC 2009

Desai MY. American Heart Journal Jan 2009

Desai MY. AJC 2009

Desai MY. AJC 2009
### Diagnostic Accuracy of CT for CABG

**Evaluation: A meta-analysis**

<table>
<thead>
<tr>
<th>Analysis Type and No. of Studies</th>
<th>No. of Grafts</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graft obstruction, 15</td>
<td>3023</td>
<td>97.6</td>
<td>96.7</td>
<td>92.7</td>
<td>86.9</td>
</tr>
<tr>
<td>6-section, 8</td>
<td>1547</td>
<td>99.9</td>
<td>96.4</td>
<td>91.2</td>
<td>96.8</td>
</tr>
<tr>
<td>64-section, 6</td>
<td>975</td>
<td>99.1</td>
<td>96.8</td>
<td>94.1</td>
<td>95.1</td>
</tr>
<tr>
<td>Occlusion, 10</td>
<td>1358</td>
<td>99.3</td>
<td>98.7</td>
<td>95.6</td>
<td>98.8</td>
</tr>
<tr>
<td>Remnants, 6</td>
<td>871</td>
<td>94.4</td>
<td>96.0</td>
<td>84.2</td>
<td>99.4</td>
</tr>
</tbody>
</table>

**Analysis Type**: Analysis Type

**Detection of CAD**: Symptomatic - Evaluation of Chest Pain Syndrome (use of CT angiogram)

**Risk Assessment**: General Population - Asymptomatic (Calcium scoring)

**Detection of CAD with Prior Test Results**: Evaluation of Chest Pain Syndrome (use of CT angiogram)

**Role in Pre-op Planning before Redo OHS**

- In patients undergoing redo OHS CT helps to assess
  - Location of prior grafts
  - Distance of grafts from sternum
  - Proximity of right sided cardiac structures
  - Proximity of aorta
  - Degree of ascending aortic calcification

- Necessary to adopt preventive surgical strategies

**Inappropriate Indications for CT**

<table>
<thead>
<tr>
<th>Indication</th>
<th>Appropriateness Criteria (Median Score)</th>
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<tr>
<td>Detection of CAD: Symptomatic - Evaluation of Chest Pain Syndrome (use of CT angiogram)</td>
<td>(1)</td>
</tr>
<tr>
<td>Detection of CAD: Symptomatic - Acute Chest Pain (use of CT angiogram)</td>
<td>(1)</td>
</tr>
<tr>
<td>Detection of CAD: Asymptomatic - Evaluation of Chest Pain Syndrome (use of CT angiogram)</td>
<td>(1)</td>
</tr>
<tr>
<td>Risk Assessment: General Population - Asymptomatic (Calcium scoring)</td>
<td>(1)</td>
</tr>
<tr>
<td>Detection of CAD with Prior Test Results - Evaluation of Chest Pain Syndrome (use of CT angiogram)</td>
<td>(2)</td>
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</tbody>
</table>

**Appropriate Indications for CT**

<table>
<thead>
<tr>
<th>Indication</th>
<th>Appropriateness Criteria (Median Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of CAD: Symptomatic - Evaluation of Chest Pain Syndrome (use of CT angiogram)</td>
<td>A (7)</td>
</tr>
<tr>
<td>Detection of CAD: Symptomatic - Acute Chest Pain (use of CT angiogram)</td>
<td>A (7)</td>
</tr>
<tr>
<td>Detection of CAD: Asymptomatic - Evaluation of Chest Pain Syndrome (use of CT angiogram)</td>
<td>A (7)</td>
</tr>
<tr>
<td>Risk Assessment: General Population - Asymptomatic (Calcium scoring)</td>
<td>A (7)</td>
</tr>
<tr>
<td>Detection of CAD with Prior Test Results - Evaluation of Chest Pain Syndrome (use of CT angiogram)</td>
<td>A (7)</td>
</tr>
</tbody>
</table>

**Hendel RC et al. JACC September 2006**

Hamon M. Radiology 2008; 247(3): 679-86
Imaging Assessment of Myocardial Viability

Definitions

• Stunned Myocardium
  - Acute MI
  - Decreased function
  - Normal blood flow
  - Has the potential to recover function

• Hibernating Myocardium
  - Reduced contraction at rest
  - Chronically reduced blood flow
  - Function can improve after revascularization

• Nonviable Myocardium
  - Cell death of myocytes and replacement of myocytes by fibrosis or scar tissue
  - Lack of recovery of normal function after revascularization

Viability Imaging and Functional Improvement

Methods for Assessing Viable Myocardium

• Assessment of myocardial metabolism/Cell integrity/perfusion: nuclear techniques

• Assessment of extent of necrosis: MRI

• Contractile reserve: dobutamine echo
Late Survival with Revascularization Versus Medical Therapy for Patients with CAD and LV Dysfunction

- Meta-analysis
- 24 studies (n=3088)
- Revascularization vs. med Rx associated with a reduction in mortality in patients with viability
- No advantage in patients without myocardial viability

CMR assessment of viability: combination of function, stress and scar assessment
- Scar appears bright against a backdrop of dark normal myocardium on special sequences

CMR and viability

DHE-MRI vs. SPECT

DHE-MRI has ~ 10 fold greater spatial resolution than SPECT

MRI versus PET

• Good agreement between DHE-MRI and PET for detecting viability
• However, 11% segments deemed viable by PET showed a scar by MRI

Mean scar %: 1st quartile
Mean scar %: 2nd quartile
Mean scar %: 3rd quartile
Mean scar %: 4th quartile

Log-rank statistic p-value = 0.03

Extent of Scar on MRI and Prognosis
Guidelines for Stress and Viability Testing

- **Class I**
  - Diagnosis of myocardial ischemia in symptomatic patients.
  - Hibernating myocardium
  - For targeted intervention
  - Assessment for restenosis after revascularization in patients
  - With atypical recurrent symptoms.
- **Class IIA**
  - After revascularization in patients with typical recurrent symptoms.
  - In patients unable to exercise or in whom ECG is less reliable
  - After cardiac transplantation.
  - In women with intermediate pretest likelihood of CAD
- **Class III**
  - Asymptomatic persons with low likelihood of CAD
  - Routine periodic reassessment of stable patients for whom no change in therapy is contemplated
  - Routine reassessment of asymptomatic patients after revascularization

Valvular heart disease

- Echo remains the primary diagnostic modality for valvular heart disease
- CMR for accurate LV volumetric assessment
- Emerging role of MDCT in planning prior to percutaneous valve procedures

Different Etiologies of MR

- Mitral valve prolapse
- Papillary muscle rupture

3D echo

- Normal mitral valve from LA
- Mitral valve with P2 flail from LA
CT and CMR and mitral valve morphology

Aortic valve disease

Aortic valve

SBE and ring abscess:
AI with poor leaflet coaptation

Poor leaflet coaptation

Vegetation

No significant coronary artery disease therefore coronary arteriography deferred
Prosthetic Valves

Role of Imaging in Electrophysiology

CRT Applications
A Fib applications

Echo techniques and CRT
- Septal to Posterior Wall Mechanical Delay (SPWMD)
  - M-mode
- Tissue Doppler Imaging (TDI)
  - PW TDI
    Time to onset or peak systolic myocardial velocities
  - Color TDI
    Time to peak systolic myocardial velocities

CT and Cardiac Veins
14 patients had a transmural scar in the posterolateral region and 26 did not. 81% in the no scar group vs. 14% in the scar responded to CRT (p < 0.01).

Kim Y and Desai MY et al. AHJ 2007

MDCT Sensitivity, specificity and NPV 92, 91 and 98%

- Echo is first line modality
- CMR is widely gaining prominence
  - Tissue characterization is key
- Emerging role of MDCT
Hypertrophic CMP: Echocardiography

Cardiac Magnetic Resonance

In 6% patients, CMR accurately diagnosed HCM missed on echocardiography

Abnormal Papillary Muscles and Dynamic LVOT Obstruction

CMR, Fibrosis and HCM: No specific pattern

Typical RV insertion site scar

No scar
**Amyloidosis**

![Images of amyloidosis](Image1)

**Myocarditis**

![Images of myocarditis](Image2)

**ARVD**

![Images of ARVD](Image3)

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### Cox Proportional Hazard Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\chi^2$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHE-CMR Positive</td>
<td>4.91</td>
<td>0.03</td>
</tr>
<tr>
<td>Age</td>
<td>3.8</td>
<td>0.05</td>
</tr>
<tr>
<td>NYHA Class</td>
<td>3.3</td>
<td>0.07</td>
</tr>
<tr>
<td>Low voltage on ECG</td>
<td>0.67</td>
<td>0.41</td>
</tr>
<tr>
<td>Interventricular septal thickness</td>
<td>1.7</td>
<td>0.19</td>
</tr>
<tr>
<td>E/E' $&gt; 15$ on Doppler Deceleration time on</td>
<td>1.12</td>
<td>0.29</td>
</tr>
<tr>
<td>Doppler echocardiography $\leq 150$</td>
<td>1.41</td>
<td>0.23</td>
</tr>
<tr>
<td>Myocardial performance index</td>
<td>2.10</td>
<td>0.15</td>
</tr>
<tr>
<td>Diastology grade</td>
<td>0.35</td>
<td>0.55</td>
</tr>
</tbody>
</table>


*Blauerske et al. Cardiology 2003. 99;103-42*

*Austin B, Desai MY: JACC 2009*
**Sarcoidosis**

- Normal or impaired LVEF
- Edema around granulomas
- Patchy DHE
  - Usually basal-mid anteroseptal and basal lateral segments
- Sens 100%, spec 78% in 58 patients


**Assessment of the Pericardium**

**Echocardiography remains the initial modality of choice**

**Constrictive pericarditis**

Associated with pericardial thickening, calcification, tethering, diastolic septal bounce, conical deformity of the ventricles

**Congenital Heart Disease**

Echo is a first start, but tomographic imaging is vital
Cardiac masses

- Echo is mainstay of initial diagnosis
  - In classic benign lesions, might not need anything else (eg. myxoma, papillary fibroelastomas etc)

- However, multimodality imaging (CMR +/- CT) generally very useful
  - Evaluate for satellite lesions
  - Tissue characterization
  - Extracardiac involvement

Tissue characterization by CMR

- **T1-weighted TSE**
- **Fat sat TSE**
- **T2-weighted TSE**
- **Delayed hyper-enhancement**
MSCT in Cardiac Masses

Intramascular Lipoma
Spindle cell carcinoma

Appropriate Indications for CT and CMR in Structural heart disease

Structure and Function - Evaluation of intra- and extra-cardiac structures

- Evaluation of cardiac mass (suspected tumor or thrombus) A (8)
- Patients with technically limited images from Echo or TEE A (8)
- Evaluation of pericardial conditions (pericardial mass, constrictive pericarditis, or complications of cardiac surgery) A (8)
- Evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation for atrial fibrillation A (8)
- Noninvasive coronary vein mapping prior to placement of biventricular pacemaker A (8)
- Noninvasive coronary arterial mapping, including internal mammary artery prior to repeat cardiac surgical revascularization A (8)

Structure and Function - Evaluation of Aortic and Pulmonary Disease

- Evaluation of suspected aortic dissection or thoracic aortic aneurysm A (9)
- Evaluation of suspected pulmonary embolism A (9)

How Does all This Work Politically??

Manhattan Project
Conclusions

• Multi-modality cardiac imaging has a potential diagnostic role in every facet of cardiovascular medicine
  – Extremely vital in ischemic heart disease; reduce number of invasive procedures
  – Emerging important role in EPS
  – Non-coronary cardiovascular evaluation

• JUST HAVE TO KNOW WHEN TO USE, HOW TO USE AND MORE IMPORTANTLY WHEN NOT TO USE

• Collaboration between cardiology and radiology is key