Imaging the Coronary Arteries
Our Patient, Mr. G.

- 68 year-old male
- 1 year of chest pain with exertion
- Pain resolves with 1 nitroglycerin tablet
- Denies symptoms of heart failure
- Father had MI in 50’s
  - Suspect stable angina
Coronary Artery Imaging Modalities

- Plane film
- Stress EKG
- Stress Echocardiogram
- Nuclear imaging
- Angiography
- EBCT (Electron beam CT)
- IVUS (Intravascular Ultrasound)
- MRA
Cardiac Imaging Modalities

- Plane film
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First Imaging Modality: Nuclear Imaging
Principles of Nuclear Imaging

- Areas of the heart with severe stenosis are always maximally vasodilated in order to increase perfusion
- Areas without stenosis are not vasodilated at rest
- When stimulated, normal vessels vasodilate, stealing blood away from tissue with stenotic vessels
- Therefore, stenotic areas appear black on perfusion studies after stress or vasodilation
Principles of Nuclear Imaging, Continued

• Since stress causes vasodilation, vasodilation is often used as a proxy for stress during nuclear imaging studies
Choosing a Nuclear Imaging Study

- Exercise or pharmacologic stressor?
- Thallium or Sesta-MIBI?
Choosing a “Stressor”

- 3 “pharmacologic stressors:” adenosine, dipyridimole, dobutamine
- Beware: adenosine causes bronchospasm; avoid in COPD or asthma

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Dobutamine</th>
<th>Dipyridamole</th>
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<tbody>
<tr>
<td></td>
<td>Inotropy</td>
<td><strong>inhibits breakdown</strong></td>
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<tr>
<td></td>
<td></td>
<td>Adenosine *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vasodilation</td>
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The “Best” Stress

**Exercise Stress**
- Best approximate of the patient’s expected realistic physical stress.
- Higher specificity for clinically significant CAD.
- More than just a physiologic marker.

**Pharmacologic Stress**
- Best for patients who cannot exercise (arthritis, CVA, amputation, pulm dz, deconditioning).
- Higher sensitivity for anatomic CAD in those unlikely to perform maximally on exercise stress.
Thallium vs. MIBI

Thallium-201
- Potassium analog
- Half-life: 74 hours
- Whole body radiation dose: 0.20 rads/mCi

Technetium-99m SestaMIBI
- Hydrophilic cation
- Half-life: 6 hours
- Whole body radiation dose: 0.02 rads/mCi
<table>
<thead>
<tr>
<th>Thallium-201</th>
<th>Technetium-99m SestaMIBI</th>
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<tr>
<td>• Uptake depends on ATPase → best measure of cell viability</td>
<td>• Uptake depends on cell membranes with intact electrochemical gradient → only fair measure of viability</td>
</tr>
<tr>
<td>• Redistributes over 2-12 hours into all viable cells</td>
<td>• Does not redistribute</td>
</tr>
<tr>
<td>• Measures perfusion and viability independently</td>
<td>• Measures viability only insofar as cells are perfused</td>
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Limitations of Nuclear Imaging

- 10-25% of non-reversible defects found to be viable upon reperfusion
- Artifact often due to hibernating myocardium (viable but chronically hypoperfused tissue)
- Hibernating myocardium may be revealed by thallium reinjection under non-stress conditions
- PET scan best reveals hibernating myocardium: high glucose uptake relative to perfusion
Reading Defects on Nuclear Imaging Studies

• Reversible defect: Ischemia
• Non-reversible defect: Infarct or hibernating myocardium
Mr. G’s Stress Test

• Since Mr. G. was able to exercise, he decided to have an exercise stress test using a Modified Bruce Protocol
What are the Bruce Protocols?

- Treadmill programs where the METS (determined by grade and mph) change every 3 minutes

<table>
<thead>
<tr>
<th>Stage</th>
<th>METS</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified 1</td>
<td>3</td>
<td>Cooking</td>
</tr>
<tr>
<td>Modified 2</td>
<td>4</td>
<td>Light gardening</td>
</tr>
<tr>
<td>Modified 3 = Regular 1</td>
<td>5</td>
<td>Washing clothes, sex</td>
</tr>
<tr>
<td>Regular 2</td>
<td>7</td>
<td>Carrying suitcase</td>
</tr>
<tr>
<td>Regular 3</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Regular 4</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Regular 5</td>
<td>16</td>
<td>Running</td>
</tr>
</tbody>
</table>
Mr. G’s Stress Test at the BIDMC

Thallium injection → Imaging → Exercise/stress Stress EKG → MIBI injection at point of maximal HR → Imaging

From: www.greaterthings.com/Books/ClintonAIDS/
From: www.dis-tenet.com/Procedures/nuclear-cardiology.htm
From: www.perduecreative.com/ fun.html
Mr. G’s Stress Test

- Exercised 6.5 minutes on a modified Bruce protocol
- Stress EKG showed 1-2mm EKG changes inferolaterally
- Had 9/10 chest pain during exercise
So How Did Mr. G. Do?

- 6.5 min on modified Bruce – washing clothes
- Achieved only 74% of maximal heart rate
- Should achieve 80-85% maximal heart rate for a good stress test
Reading Nuclear Imaging Scans

From http://brighamrad.harvard.edu/education/online/Cardiac/anatomic-orient.html

From Braunwald: Heart Disease: Cardiovascular Medicine, 6th ed., 2001, Fig. 9-6
Coronary Artery Territories on Nuclear Imaging

From http://brighamrad.harvard.edu/education/online/Cardiac/coronary-artery-territory.html
Mr. G’s MIBI

Moderate reversible anterior defect

Severe reversible apical defect

From http://brighamrad.harvard.edu/education/online/Cardiac/anatomic-orient.html

From BIDMC PACS
Another example: Patient II

Severe reversible defect in **inferior** region

From http://brighamrad.harvard.edu/education/online/Cardiac/coronary-artery-territory.html

From BIDMC PACS
Last example: Patient III

Severe reversible defect in lateral region

From BIDMC PACS

From http://brighamrad.harvard.edu/education/online/Cardiac/coronary-artery-territory.html
And patient III after CABG…

Lateral defect has partially resolved!

From BIDMC PACS
Back to Mr. G…

- Anterior and apical defects: LAD region stenoses
- Reversibility suggests ischemia
- These regions are still viable and might benefit from cardiac catheterization

Mr. G. goes to cardiac catheterization!
Second Imaging Modality: Cardiac Catheterization
Indications for Cardiac Catheterization

- Gold standard for identification of CAD when noninvasive imaging modalities are equivocal
- Assessment of disease extent for interventional therapy (angioplasty or surgery)
Risks for Coronary Catheterization

- Rare (<0.1%) risk of MI, CVA or death
- Risk increased if: emergency, acute MI, unstable
- Allergic reactions (0.37%)
- Arrhythmia (0.38%)
- Vascular occlusion (0.43%)
- Contrast medium-induced renal failure (3-7%)
Mr. G’s Coronary Catheterization

• Fasting
• Conscious sedation
• 5000U IV Heparin
• Percutaneous catheter into R femoral artery, advanced under fluoroscopy
• Iodine-containing radio-opaque dye injected into coronary arteries
• Digital acquisition of x-ray images
Mr. G.’s Catheterization Results

- 99% stenosis of proximal LAD and first diagonal branch
- 80% stenosis of RCA
Mr. G’s catheterization: Left main artery disease

Defects

Catheter → LAD

Left main ↓ Circumflex Diagonal

From BIDMC Coronary Catheterization Lab
Mr. G’s catheterization: Intermediate step in repair

LAD has been stented, but diagonal has been completely occluded in the process

From BIDMC Coronary Catheterization Lab
Mr. G’s catheterization:
Left main repair completed

Stent has been placed in diagonal

From BIDMC Coronary Catheterization Lab
Mr. G’s catheterization:
Right coronary artery repair

RCA defect ...here corrected with stent
Coronary Angiography vs. IVUS:
Angiographic underestimation of disease

Adapted from Nissen SE, Yock P. *Circulation*. 2001; 103:604-616
Courtesy of Dr. Clouse, BIDMC
Third Imaging Modality: EBCT (Electron-Beam CT)
What Is EBCT?

- Also known as Ultrafast CT (UFCT)
- Electron stream is aimed onto tungsten rings which focus the electrons to generate x-rays
- Moving x-ray tube is eliminated
- Entire heart imaged in one breathhold → eliminates blurring
How Can EBCT Image the Coronary Arteries?

- Noninvasive coronary angiography
- Assessment of myocardial perfusion
- Calcium deposit detection
EBCT Coronary Angiography

- Uses intravenous contrast
- Sensitivity of 77-82% and specificity of 92% for detecting luminal stenoses of >50%
- Limitations: - inadequate image quality
  - requires breathold
  - requires contrast
- Still undergoing refinement
EBCT Coronary Angiography
Patient IV

LAD Imaging

Soft plaque within LAD

3D reconstruction

Pulm. trunk

Obtuse Marginal 1

Aorta

LA

LV

LAD

Courtesy of Dr. Clouse, BIDMC
EBCT Calcium Detection

• Highly controversial means of visualizing calcium within the coronary arteries
• Non-contrast CT
• Not covered by insurance
• $400.00 at BIDMC
• Patients are given a calcium score: estimate of total artery calcification by volume and by arterial location (age/sex –related)
Coronary Artery Calcification
Patient V

From BIDMC PACS
Examples of Coronary Artery Scans

Patient VI
No calcification

Patient VII
Moderate calcification

Patient VIII
Significant calcification

Images courtesy of HeartScan San Francisco
Courtesy of Dr. Clouse, BIDMC
Coronary Calcification Detection

**Advantages**
- 150,000 Americans/yr die from first MI
- All other tests designed to detect disease when patient is symptomatic (70-90% lumenal stenosis)
- EBCT detects calcification with 20% lumenal stenosis
- Coronary Ca\(^{++}\) more Se and Sp than cholesterol for CAD death prediction

**Questions**
- Yes, 90% of plaques contain Ca\(^{++}\), BUT does calcification predict clinically significant plaques?
- Yes, EBCT detects plaques that do not impede flow, BUT do these plaques provide significant risk?
- Does “plaque burden” add to Framingham risk score (CAD prediction)?
Current recommendations for EBCT

- Negative EBCT: Good predictor for clean coronaries
- Positive EBCT:
  - 85% Se and 49% Sp for diagnosis of angiographic CAD (vs. 85% and 91% for MIBI)
  - Greater Ca^{++} = greater likelihood of occlusive CAD
  - BUT no 1:1 relationship
  - AND findings may not be site specific
  - Total calcium underestimates total plaque burden
  - High Ca^{++} score may mean high MI risk in 2-5yrs
References

Acknowledgements

Dan Saurborn, MD
Melvin Clouse, MD
Kevin Donohoe, MD
Thomas Tu, MD
Sven Paulin, MD
Bertrand d’Othee, MD
Eric Niendorf, MD

Gillian Lieberman, MD
Pamela Lepkowski
Larry Barbaras and Cara Lyn D’amour