Cardiac Imaging
Transesophageal Echocardiogram
Cardiac MRI
Cardiac CT

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Ways to visualize the heart

• Xray
  – Chest film
  – Computed tomography
    • Calcium evaluation
    • Coronary arteriography
  – Angiography/Fluoroscopy

• Ultrasound
  – Transthoracic echocardiogram (TTE)
  – Transesophageal echocardiogram (TEE)
  – Intravascular ultrasound (IVUS)
  – Intracardiac ultrasound (ICE)

• Magnetic Resonance (CMR)
  – Too many types of sequences to list

• Angioscopy
Transesophageal Echo

Internal Medicine Boards perspective

• TEE/Cardioversion for atrial fibrillation
• Endocarditis
• The Stroke evaluation
  – Patent Foramen Ovale
  – Atrial Septal Defect
  – Cardiac source of embolus

• These will also be the situations most commonly faced by primary care physicians
Transesophageal Echo
Procedural description

- NPO overnight
- Oropharynx anesthetized
- Conscious sedation
  - 2mg versed +/- 25mg demerol or 25 mcg fentanyl
- TEE probe advanced gently into the esophagus
- Exam duration typically 10 minutes of probe activity
- Risks include esophageal perforation
  - Especially with zenkers diverticulum, webs, strictures
- Overall low risk of complications
TEE/Cardioversion for atrial fibrillation

• General recommendations for atrial fibrillation with planned cardioversion
  – INR goal 2-3
  – 3 weeks before cardioversion
    • Unless onset of Afib <48 hours before cardioversion
  – 4 weeks after cardioversion

• Patients less tolerant of atrial fibrillation
  – Heparin/LWMH at diagnosis/admission
  – TEE to evaluate for Left Atrial appendage thrombus
  – Safe to cardiovert if no thrombus seen?
TEE/Cardioversion ACUTE trial

- Randomized, prospective
- Patients with atrial fibrillation
- Compared 3 weeks on anticoagulation prior to cardioversion vs TEE guided
- 70 sites, 1222 patients
- 8 weeks followup
- Primary outcome: Embolic events
  - 0.8% TEE, 0.5% conventional (p=0.5)
- Minor and Major bleeding
  - 2.9% TEE, 5.5% conventional (p=0.03)

Endocarditis

• Most often affects left sided valves
  – Ideally suited for TEE
  – Exception is IV drug users
• Typically vegetations occur on low pressure side of valves
• TEE more sensitive than TTE to see
  – Vegetations
  – Regurgitation
  – Leaflet damage/perforation
  – Abscess formation
  – Unstable prosthesis
Feigenbaum, 6th ed
The stroke evaluation
Cardiogenic etiologies of stroke

• Left atrial thrombus
• Left ventricular thrombus
• Patent foramen ovale (PFO) or atrial septal defect (ASD)
  – Allows “paradoxic” embolization
  – Venous thrombus passes through interatrial septum
• Cardiac masses
  – Endocarditis/vegetations
  – Tumors
Feigenbaum, 6th ed
Which TIA/stroke patients need a TEE?

• Which patients need a TTE?
  – Almost everyone

• Who needs a TEE?
  – Patients younger than 45
  – Older patients without identified cause of CVA

• However
  – Controversial whether findings change management
  – Anticoagulation indicated for thrombus
  – Treatment/Surgery indicated for masses/vegetations
  – PFO/ASD
    • Closure may or may not be helpful
    • Anticoagulation usually not indicated for primary/secondary prevention
    • About 10-20% of general population have a PFO!
Other situations where TEE is useful

• When TTE is suboptimal to answer a clinical question
• Prosthetic valve evaluation
• Cardiac masses
• Pulmonary vein stenosis
• Native valve stenosis/regurgitation
• Cardiac Anuerysm, pseudoaneurysm
• Aortic dissection

• Evaluation of ejection fraction alone is challenging with TEE
Feigenbaum, 6th ed
Cardiac MRI
Some modalities

• Coronary arteriography
• Cardiac tissue evaluation
• Cardiac masses
• Cardiac perfusion
• Infarct/viability assessment
• Quantification
  – Valve stenosis/regurgitation
  – Ejection fraction
• Great vessels
• Stress testing/wall motion
How does MRI/CMR work?
A brief overview

• Our body is mostly water
• Water has H+ atoms
• A magnetic field is used to align all H+ atoms
• A radiofrequency pulse hits these atoms and knocks them out of alignment
• As the atoms “relax” back toward alignment, they send out another radiofrequency signal which is detected
CMR procedure

- NPO
- Specifics depend on protocols run
- CMR studies are pre-specified
  - Cannot ‘shotgun’ everything
- Gadolinium used if contrast is indicated
  - Non-nephrotoxic
  - But it is a heavy metal, which limits total amount given
- Duration of scan variable: 15 minutes – 1+ hours
CMR Coronary Arteriography

3 Tesla CMR of coronary arteries

Braunwald 7th ed
CMR tissue evaluation

• Right Ventricular dysplasia
• Infiltrative cardiomyopathies
  – Amyloid
  – Hemochromatosis
  – Sarcoidosis
• Cardiac Masses
  – Malignant/benign
CMR Cardiac Viability and perfusion

- Cardiac perfusion can be visualized by using gadolinium contrast
  - Can quantify perfusion
  - Infarcted segments perfuse slowly or not at all
  - Cardiac Syndrome X patients show slow perfusion

- An area that is infarcted is not viable, and will not benefit from revascularization

- Delayed enhancement
  - Gadolinium contrast injected, then imaging performed 10-15 minutes later
CMR Perfusion

Imaging after Gadolinium injection demonstrates lack of perfusion in the inferoseptal wall. Cath shows RCA and LAD stenoses

Braunwald 7th ed
Subendocardial infarct produced by ligation of a dog coronary artery
Infarcted area appears bright

Braunwald 7th ed
CMR Quantification

• 3D imaging allows volume calculations
• Gold standard?
  – Right and Left ventricular ejection fractions
  – Stenotic valve areas (planimetry)
  – Valvular regurgitation volumes
Great vessel imaging

• High sensitivity for aortic detection
• Often can identify the site of intimal tear

• However
  – Limited monitoring available in MRI scan
  – Patient needs to be hemodynamically stable
  – Contraindicated with ICD, pacemaker
CMR stress testing

• Performed with dobutamine
• Analysis of wall motion
• Very uncommon in routine practice
Cardiac Computed Tomography

- Coronary artery calcium scoring
- Coronary arteriography
  - Atherosclerosis
  - Bypass grafts
  - Anomaly
- Pericardial imaging
  - Constriction/calcification
- Left atrial imaging
  - Appendage thrombus
  - Pulmonary vein anatomy
- Functional imaging
  - Chamber size, volumes, EF
  - Perfusion/Viability?
Cardiac Computed Tomography

• Calcium scoring
  – Non-contrast study
  – Multidetector CT, at least 16 slice
    • Most common, scanner can be used for any other application
  – Electron beam CT (EBCT)
    • Less common, exclusively used for calcium scoring
  – Scan time about 10-15 seconds
• Beam focused by electromagnetic coil
• Very rapid imaging (50-100ms)
CT calcium scoring

Braunwald, 7th ed
Calcium scoring

• Scoring is a combination of manual and automated calcium identification
• Scores generally reported as a number and an age-matched percentile
• Current guidelines use only the absolute number
  – <100 low risk/normal
  – 100-400 low-moderate risk; modify risk factors
  – >400 high risk; consider stress test
## Interpreting Calcium Score asymptomatic patients

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Calcium Score</th>
<th>Annual coronary event rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low risk</td>
<td>0</td>
<td>0.12%</td>
</tr>
<tr>
<td>Mild risk</td>
<td>1-100</td>
<td>0.37%</td>
</tr>
<tr>
<td>Moderate risk</td>
<td>101-299 or 399</td>
<td>0.71%</td>
</tr>
<tr>
<td>High risk</td>
<td>&gt;=300 or 400</td>
<td>1.56%</td>
</tr>
</tbody>
</table>

Cardiac CT coronary angiogram
a brief history

• Is it possible to get a coronary angiogram without the risk of a heart catheterization?
• Initial CT’s had a single detector
• 1999 – 4 slice multidetector CT
  – 1st attempts at CT coronary angiograms
• 2001 – 16 slice multidetector CT
• 2004 – 64 slice MDCT
CT angiogram procedure

- NPO except fluids
- Give beta blockers to control heart rate
  - Target rate <65
  - Slower is better
- Before contrast injection, give SL NTG
  - Dilates coronary vessels for better imaging
  - No viagra, cialis, levitra use!
- Contrast injected
- Breath hold
- Scan time is approximately 15 seconds (64 slice)
Factors involved in coronary imaging

• Heart is a moving object
  – It beats
  – It moves with respiration
  – Temporal resolution and “number of slices”

• Coronary vessels are small
  – Smallest stent is 2.0 mm diameter
  – Spatial resolution
Sequential vs Helical CT scan

Temporal resolution depends on how quickly the scanner can image a “slice;” this correlates with speed of scanner revolution.

Braunwald 7th ed
Inside a 64 slice CT scanner
Effect of Slices
4 Slice
64 Slice
“Fast” temporal resolution
“Medium” temporal resolution
“Slow” Temporal Resolution
## Comparing the technology

<table>
<thead>
<tr>
<th></th>
<th>Coronary Calcium</th>
<th>Coronary Arteriography – 64 slice</th>
<th>Fluoroscopy (Cath)</th>
<th>CMR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiation</strong></td>
<td>1.5 mSV</td>
<td>8-22 mSv (avg 10-12)</td>
<td>3-5 mSv</td>
<td>0</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>1.5mm (0.4mm)</td>
<td>0.6mm</td>
<td>0.2mm</td>
<td></td>
</tr>
<tr>
<td><strong>IV contrast</strong></td>
<td>no</td>
<td>80-120cc</td>
<td>60-120cc</td>
<td>no</td>
</tr>
<tr>
<td><strong>Breath Hold</strong></td>
<td>10s</td>
<td>10s</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td><strong>Temporal Resolution</strong></td>
<td>50-100 ms (83ms)</td>
<td>165ms (Fast (&lt;30ms))</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Limitations of CTA

• Temporal resolution
  – Currently tube rotates at 330ms
    • Only need ½ rotation to obtain imaging, so temporal resolution is around 165ms
  – This is limiting factor for temporal resolution
  – Dual source CT may improve this
  – Why not just rotate the tube faster?
    • Tube components weigh about 2000 pounds
    • At current speeds (180 rpm), about 18 G’s generated
    • To improve rotation speed to 200ms, 75 G’s would be generated
LAD stenosis

CTA of stent
TABLE 2. Diagnostic Performance and Predictive Value of 64-Slice CT Coronary Angiography for the Detection of ≥50% Stenoses on QCA

<table>
<thead>
<tr>
<th>Segment-based analysis</th>
<th>n</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
<th>PPV, %</th>
<th>NPV, %</th>
<th>+ LR</th>
<th>- LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>All segments</td>
<td>725</td>
<td>99 (94–98)</td>
<td>95 (93–95)</td>
<td>76 (67–89)</td>
<td>100 (99–100)</td>
<td>20.81</td>
<td>0.01</td>
</tr>
<tr>
<td>Proximal segments</td>
<td>204</td>
<td>100 (89–100)</td>
<td>97 (93–98)</td>
<td>83 (67–97)</td>
<td>100 (97–100)</td>
<td>29.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mid segments</td>
<td>142</td>
<td>97 (83–99)</td>
<td>94 (83–97)</td>
<td>81 (63–96)</td>
<td>99 (94–99)</td>
<td>15.47</td>
<td>0.04</td>
</tr>
<tr>
<td>Distal segments</td>
<td>121</td>
<td>100 (68–100)</td>
<td>97 (92–99)</td>
<td>73 (39–98)</td>
<td>100 (96–100)</td>
<td>37.67</td>
<td>0.00</td>
</tr>
<tr>
<td>Side branches</td>
<td>258</td>
<td>100 (87–100)</td>
<td>94 (99–95)</td>
<td>65 (48–85)</td>
<td>100 (98–100)</td>
<td>16.57</td>
<td>0.00</td>
</tr>
<tr>
<td>LM</td>
<td>51</td>
<td>100 (21–100)</td>
<td>100 (93–100)</td>
<td>100 (92–100)</td>
<td>100 (2–100)</td>
<td>∞</td>
<td>0.00</td>
</tr>
<tr>
<td>LAD</td>
<td>230</td>
<td>97 (85–100)</td>
<td>92 (88–95)</td>
<td>69 (53–86)</td>
<td>99 (96–99)</td>
<td>12.68</td>
<td>0.03</td>
</tr>
<tr>
<td>LCx</td>
<td>235</td>
<td>100 (88–100)</td>
<td>97 (94–99)</td>
<td>83 (66–97)</td>
<td>100 (98–100)</td>
<td>34.33</td>
<td>0.00</td>
</tr>
<tr>
<td>RCA</td>
<td>209</td>
<td>100 (89–100)</td>
<td>95 (91–97)</td>
<td>77 (60–95)</td>
<td>100 (97–100)</td>
<td>19.89</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient-based analysis</th>
<th>All segments</th>
<th>n</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
<th>PPV, %</th>
<th>NPV, %</th>
<th>+ LR</th>
<th>- LR</th>
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<td>All segments</td>
<td>51</td>
<td>100 (91–100)</td>
<td>92 (67–99)</td>
<td>97 (66–99)</td>
<td>100 (73–100)</td>
<td>13.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

PPV indicates positive predictive value; NPV, negative predictive value; + LR, positive likelihood ratio; − LR, negative likelihood ratio; LM, left main coronary artery; LCx, circumflex coronary artery; and RCA, right coronary artery. For segment-based analysis, analysis of 725 segments visualized on the conventional angiogram and classified according to a 17-segment modified AHA classification was performed. Segments were further classified on the basis of their location within the coronary tree (proximal, mid, or distal segments of the main coronary artery arteries or side branches) and their location within a single vessel (LM, LAD, LCx, or RCA). For patient-based analysis, analysis of 51 patients was performed. Values in parentheses represent 95% CIs.

CT of Pericardium
CT of LV thrombus
CT of LA Myxoma
CT pulmonary veins

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Now for some “real world” cases
Obese patient
Misregistration
patient did not hold breath
How to analyze Cardiac CT
LAD Aneurysm and stenosis
axial cuts
LAD aneurysm MIP
Summary of Technologies

• TEE
  – Atrial fibrillation/cardioversion
  – Endocarditis
  – Aortic dissection
  – ASD/PFO

• CMR
  – Not widely available
  – Wide range of imaging techniques
  – No contrast, no radiation
Summary of Cardiac CT

• Calcium scoring
  – Low radiation, noncontrast
  – Risk stratification (>=400 is high risk)
  – Low/intermediate risk patients?
  – Not very useful over age of 65
Tips for the Boards

• CMR not likely to be on boards
• TEE
  – Atrial fibrillation
    • If pt is hemodynamically unstable, cardiovert without waiting for a TEE
  – Endocarditis
    • Should be 1st test in patients with hx of prosthetic valve or prior endocarditis
    • Use for any patient with hemodynamic or electrical complication of endocarditis
  – CVA
• CT
  – Calcium score >400 is high risk
  – Unlikely that CTA will be on boards
Patient selection for Cardiac CT Angiography

• Coronary arteriography
  – Higher radiation, contrast exposure
• Need slow, regular heart rhythm
• Factors limiting interpretation
  – Calcification (? Calcium score >700 uninterpretable)
  – Stents
  – Inability to hold breath for 10-15s
  – Obesity
  – Grafts can be identified and interpreted, but distal vessel evaluation can be challenging
Who should have CTA?

- No guidelines yet
- In my humble opinion
  - Lower risk patients with atypical/noncardiac chest pain
  - Patients <65 years of age
  - No prior known CAD/stent
  - Cooperative patient
  - Sinus rhythm
Interpreting a CTA

• A negative CTA almost certainly means that the patient does not have any coronary stenosis >50%
  – 99% Negative predictive value on per-segment basis
• A positive CTA has a 75% positive predictive value on a per-segment basis
• Calcium usually does not mean stenosis, but exceptions are possible
As you go into practice…

- Be cautious with CTA
- Do not use CTA when a stress test would be better
- Payers will not pay for tests that do not produce quality results
- We should not convert the current 2 step paradigm (stress test → cath) to a 3 step paradigm (CT → stress test → cath)
- Studies will hopefully guide our practice