CARDIAC CT AND MRI: STATE OF THE ART

Charles S. White, M.D.
Director, Thoracic Imaging
Diagnostic Radiology
University of Maryland School of Medicine
INTRODUCTION

- Cardiac MRI and CT were first introduced in the 1980’s although cardiac CT only became widely used after 2000.
- They serve as complementary techniques to other cardiac imaging including nuclear imaging and echocardiography.
OBJECTIVES

- CARDIAC CT – THE BASICS
- CARDIAC CT – MAJOR INDICATIONS
- CARDIAC MRI – THE BASICS
- CARDIAC MRI – MAJOR INDICATIONS
# CARDIAC CT ANGIOGRAPHY

## PROS AND CONS

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Wide field-of-view</td>
<td>- Ionizing radiation</td>
</tr>
<tr>
<td>- Superb anatomic detail</td>
<td>- Iodinated contrast</td>
</tr>
<tr>
<td>- Some functional information</td>
<td>- Some functional limitations (cannot directly measure gradients)</td>
</tr>
</tbody>
</table>

CORONARY CTA PROTOCOL

COR CTA

Coronary CTA contrast protocol
- Test injection (IV check)
  - 20 ml (saline) @ 6 cc/sec
- Injection protocol (3 phase)
  - 70 ml (100%) @ 6 cc/sec
  - 30 ml (50/50) @ 5 cc/sec
  - 50 ml (saline) @ 5 cc/sec
- Bolus tracking

Recon cardiac phase(s)
LV WALL MOTION ASSESSMENT

- Tube output (x-ray) ON
- Retrospective ECG Gating
- Spiral Acquisition
- Maximum tube output
- Reduced tube output
- Spiral Acquisition
LV FUNCTIONAL ASSESSMENT

Strong correlation between CT and MRI LV function ($r > 0.95$)
Prospective gating
- Around 80% lower radiation
- No functional analysis
- Not always suitable
  - Certain arrhythmias
  - Higher heart rates >70
  - Large pts
RADIATION SPARING
ITERATIVE RECONSTRUCTION ALGORITHM

- Computationally intense
- Better modeling of geometry
- Two options
  - Save on dose
  - Maximize image quality
# CARDIAC RADIATION DOSES

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background - Yearly</td>
<td>3.6</td>
</tr>
<tr>
<td>Sesta/Thal – rest/stress</td>
<td>1.5-5/6-25</td>
</tr>
<tr>
<td>Cardiac Cath</td>
<td>3-15</td>
</tr>
<tr>
<td>Chest CT (conventional)</td>
<td>5</td>
</tr>
<tr>
<td>Gated Coronary CTA (CCTA)</td>
<td>10-15</td>
</tr>
<tr>
<td>Gated CCTA – dose modulated</td>
<td>6-9</td>
</tr>
<tr>
<td>Gated CCTA - prospective axial</td>
<td>3-4</td>
</tr>
<tr>
<td>Gated CCTA – prospective/IR</td>
<td>2-3</td>
</tr>
<tr>
<td>Gated CCTA- prospective helical/IR/low kVp</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
OBJECTIVES

- CARDIAC CT – THE BASICS
- CARDIAC CT – MAJOR INDICATIONS
- CARDIAC MRI – THE BASICS
- CARDIAC MRI – MAJOR INDICATIONS
#1 OBSTRUCTIVE CORONARY DISEASE

- Best is low-intermediate risk symptomatic pt.
- Stenosis >70% is significant; >50% in L main
- Can assess plaque characteristics
  - Vulnerable plaque
- Supplement with flow dynamics
  - eg, CT fractional flow reserve (FFR)

www.lmp.facmed.utoronto.ca
OBSTRUCTIVE CORONARY DISEASE
OBSTRUCTIVE CORONARY DISEASE
OBSTRUCTIVE CORONARY DISEASE

Myocardial bridge
## Obstructive Coronary Disease Literature (CCTA VS Cath)

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CorE64 JACC 2008</td>
<td>291</td>
<td>85</td>
<td>90</td>
<td>91</td>
<td>83</td>
<td>Stable CP, Prevalence 56%</td>
</tr>
<tr>
<td>ACCURACY JACC 2008</td>
<td>230</td>
<td>94</td>
<td>83</td>
<td>48</td>
<td>99</td>
<td>Stable CP, Prevalence 13%</td>
</tr>
<tr>
<td>Meijboom JACC 2009</td>
<td>360</td>
<td>99</td>
<td>64</td>
<td>85</td>
<td>97</td>
<td>Acute/stable CP, Prevalence 68%</td>
</tr>
</tbody>
</table>
"The CT characteristics of plaques associated with ACS include positive vascular remodeling, low plaque density, and spotty calcification. It is logical to presume that plaques vulnerable to rupture harbor similar characteristics."
Obstructive Coronary Disease

CT Fractional Flow Reserve

One weakness of CT has been difficulty in getting flow information from CT angiography.

Fractional Flow Reserve = pressure difference across coronary stenosis (usually measured during cath)

Courtesy: Heartflow.com
OBSTRUCTIVE CORONARY DISEASE

FRACTIONAL FLOW RESERVE

LAD lesion by CCTA

CCTA image

CT-FLOW model with simulated hyperemia

Courtesy: Heartflow.com
OBSTRUCTIVE CORONARY DISEASE
FRACTIONAL FLOW RESERVE

N=252 DeFACTO study

<table>
<thead>
<tr>
<th></th>
<th>FFR_{CT} ≤0.80</th>
<th>CT ≥50%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>73 (67-78)</td>
<td>64 (58-70)</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>90 (84-95)</td>
<td>84 (77-90)</td>
</tr>
<tr>
<td><strong>Specificity</strong></td>
<td>54 (46-83)</td>
<td>42 (34-51)</td>
</tr>
<tr>
<td><strong>PPV</strong></td>
<td>67 (60-74)</td>
<td>61 (53-67)</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>84 (74-90)</td>
<td>72 (61-81)</td>
</tr>
</tbody>
</table>

No. of Patients in Group: 252

Abbreviations: CT, computed tomographic angiography; FFR_{CT}, fractional flow reserve calculated from CT; NPV, negative predictive value; PPV, positive predictive value.

Min JAMA 2012;308:1237
#2 PRE-PROCEDURE CARDIAC VALVES

- Used prior to transcatheter aortic valve replacement (TAVR)
- Assess size/shape of annulus
- Distance from annulus to coronary orifices
- Also useful for other valves
TAVI REFORMATS
TRANSCATHETER AORTIC VALVE IMPLANTATION (TAVI OR TAVR)
MITRAL VALVE ASSESSMENT

Chen RadioGraphics 2009;29:1393
MITRAL VALVE

MV vegetation
#3 CALCIUM SCORING

Threshold = 130HU  
Agatston score
CALCIUM CT SCORES RISK STRATIFICATION

https://www.mesa-nhlbi.org/Calcium/input.aspx
RELATIVE RISK

Courtesy: J. Rumberger MD
CALCIUM SCORING - INDICATIONS

ACCF/AHA 2010 guideline on coronary calcium

Class IIa

1. Measurement of CAC is reasonable for cardiovascular risk assessment in asymptomatic adults at intermediate risk (10% to 20% 10-year risk).\textsuperscript{52,53} (Level of Evidence: B)

Class IIb

1. Measurement of CAC may be reasonable for cardiovascular risk assessment in persons at low to intermediate risk (6% to 10% 10-year risk).\textsuperscript{53–55} (Level of Evidence: B)

Class III: No Benefit

1. Persons at low risk (<6% 10-year risk) should not undergo CAC measurement for cardiovascular risk assessment.\textsuperscript{52,53,56} (Level of Evidence: B)

Circ 2010;122:2748
#4 LEFT ATRIAL EVALUATION MAPPING FOR RF ABLATION

- Treatment for Atrial Fibrillation
- Usually radiofrequency ablation
- Probing tool destroys abnormal conduction pathways in LA
  - Most near PV ostia
- Risk of post-procedure pulmonary vein stenosis
LEFT ATRIAL EVALUATION
RF ABLATION
LEFT ATRIAL EVALUATION

Left atrial appendage thrombus

Pulmonary vein occlusion
LA RF ABLATION COMPLICATION

Aortoesophageal fistula

Courtesy: S. Aquino MD
Cardiac masses are uncommon – beware of mimics

Thrombi most often seen on imaging

Metastases 40-100X more common than primaries (but not imaged that frequently)

Most common primary benign cardiac tumor is myxoma

Most common primary malignant tumor is angiosarcoma (rare)
CARiddiac Masses
Anatomic Variant

Crista Terminalis
- Smooth muscle ridge from the superior vena cava to the inferior vena cava
- Fusion point between primitive RA and smooth sinus venosus portion of RA
- Occasional mistaken for thrombus on echocardiography
CARDIAC MASS

LV Thrombus
CARDIAC MASS

RV catheter related thrombus
CARDIAC MASS

Lipomatous hypertrophy of atrial septum
CARDIAC MASS

Myxoma
MALIGNANT CARDIAC TUMOR

Angiosarcoma
CARDIAC TUMOR

RV/PA uterine sarcoma mets
OTHER INDICATIONS

- CORONARY ANOMALIES
- BYPASS GRAFT AND STENT ANALYSIS
- PERICARDIAL DISEASE
- AORTIC DISEASE
- CONGENITAL HEART DISEASE (ESP. IN ADULTS)
- ACUTE ED CHEST PAIN
OBJECTIVES

- CARDIAC CT – THE BASICS
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- CARDIAC MRI – THE BASICS
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<tr>
<td>Wide field-of-view</td>
<td>Claustrophobia</td>
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<tr>
<td>Excellent anatomic detail</td>
<td>Gadolinium contrast (NSF reports)</td>
</tr>
<tr>
<td>Excellent functional</td>
<td>Pacers/ICDs</td>
</tr>
<tr>
<td>information</td>
<td></td>
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CARDIAC MRI PREP

- Requires cardiac gating
- A dedicated cardiac coil will permit better image quality with decreased imaging time
- Pacemakers/ICDs may be used with appropriate caution in non-pacemaker dependent patients, particular with MRI conditional devices
MYOCARDIAL ASSESSMENT
MRI PROTOCOL

Bright Blood Cine - SSFP

1st Pass Perfusion with Gadolinium

Viability Imaging

**Selected Cases: Myocardial edema (T2 weighted), dark blood sequences

16-30 phases per cardiac cycle - SSFP

IV 0.2 mmol/kg Gd Fast GRE

Delayed Enhancement LGE

TI-scout - IR pulse with myocardial nulling (10 min) - GRE
BRIGHT BLOOD CINE - SSFP

- Assess wall motion (global and segmental)
- Evaluate wall thickening
- Valvular stenosis and regurgitation
- Calculations
  - Stroke volume (EDV-ESV/EDV)
  - Ejection fraction (EDV-ESV/EDV)
  - Can adjust parameters for BMI
BRIGHT BLOOD CINE - SSFP

Short axis  

4 chamber
CARDIAC MRI – OTHER AXES

3 chamber (LVOT) view

2 chamber view
MYOCARDIAL PERFUSION/VIABILITY

- **Perfusion**
  - First-pass sequence to look for perfusion defects

- **Delayed enhancement (LGE)**
  - Generally 10-15 min after injection of Gd-chelate
  - Myocardium is “nullled” (black) with an inversion pulse
  - Areas of enhancement (high signal) are abnormal (indicates retention of Gd in myocardium in infarction/fibrosis – cause “T1-shortening”)
MYOCARDIAL VIABILITY

Delayed enhancement (LGE)
- Gd-contrast passes into extracellular spaces in myocardium (both normal and disease)
- Infarction or fibrosis/increased extracellular space leads to Gd retention
- Retained Gd shortens T1 relative to wash-out areas leading to enhancement on delayed images
MYOCARDIAL VIABILITY
TI-SCOUT

Retained Gd area

Normal myocardium
MYOCARDIAL PERFUSION/VIABILITY

Delayed Enhancement (LGE) 10 minutes after gado
OBJECTIVES

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- CARDIAC MRI – THE BASICS
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#1 CARDIAC ISCHEMIA/INFARCTION

- Cardiac MRI has a valuable role in evaluation of cardiac ischemia
- Complementary to nuclear imaging
- Can assess function, perfusion, viability
- MRI stress testing
ISCHEMIC INJURY
A SPECTRUM

STUNNED MYOCARDIUM
- Acute occlusion, then reperfusion
  - Spontaneous vs PCT
- Moderate/severe stenosis with exercise
- Causes wall motion abnormality that resolves

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<th>Myocardial Status</th>
<th>Wall motion</th>
<th>Perfusion (LGE)</th>
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<tr>
<td>Stunned</td>
<td>Abnl</td>
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<tr>
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STUNNED MYOCARDIUM

Stunned

Infarcted

Methodist DeBakey CV J 2013:9:163
ISCHEMIC INJURY
A SPECTRUM

HIBERNATING MYOCARDIUM
- Chronic low state leading to reduced contractility
- Myocardial cells “down-regulate”
- Reversible

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HIBERNATION AND MI

function  perfusion  LGE

Hibernating  Infarcted
ISCHEMIC INJURY
A SPECTRUM

- INFARCTED – NON-VIABLE

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Acute MI = segmental and subendocardial or transmural LGE – can lead to dilated “ischemic cardiomyopathy”

DDx = non-ischemic cardiomyopathy, typically non-segmental, non-subendocardial LGE
ACUTE ANTEROLATERAL MI

function  perfusion  LGE
THE 50% RULE
TRANSMURAL INFARCT EXTENT

- The transmural percentage of LGE correlates with the likelihood of successful outcome of CABG or stenting-based revascularization (standard used for viability)
- More than 50% transmural involvement is often used as a threshold for pursuing revascularization
THE 50% RULE
TRANSMLURAL INFARCT EXTENT

Figure 4. Relation between the Transmural Extent of Hyperenhancement before Revascularization and the Likelihood of Increased Contractility after Revascularization.

Data are shown for all 804 dysfunctional segments and separately for the 462 segments with at least severe hypokinesis and the 160 segments with akinesia or dyskinesis before revascularization. For all three analyses, there was an inverse relation between the transmural extent of hyperenhancement and the likelihood of improvement in contractility.

Kim NEJM 2000;343:1445
MRI STRESS TESTING

- Can be performed with:
  - Adenosine, Dobutamine, Regadenoson
  - MRI-compatible treadmill
- Generally Rest-Stress
- Stress perfusion with Gd followed by LGE
MRI STRESS TESTING

Treadmill MRI Stress/SPECT vs CATH

Table 4. Test Characteristics Compared to Angiography (70% Stenosis Cutoff)

<table>
<thead>
<tr>
<th>Test</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
<th>Positive Predictive Value, %</th>
<th>Negative Predictive Value, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise stress CMR</td>
<td>76.6 (48.8–94.3)</td>
<td>98.7 (92.3–99.9)</td>
<td>91.7 (59.7–99.6)</td>
<td>96.3 (88.9–99.0)</td>
</tr>
<tr>
<td>Exercise stress SPECT</td>
<td>50.0 (24.0–76.0)</td>
<td>93.7 (85.4–97.7)</td>
<td>58.3 (28.6–83.5)</td>
<td>91.5 (82.7–96.2)</td>
</tr>
</tbody>
</table>

CMR indicates cardiac magnetic resonance; SPECT, single photon emission computed tomography.
Definition (ESC – 2008)
“A myocardial disorder in which the heart muscle is structurally and functionally abnormal in the absence of coronary artery disease, hypertension, valvular disease and congenital heart disease sufficient to explain the observed myocardial abnormality”

Major categories from an imaging perspective (WHO -1995)
- Dilated (congestive) cardiomyopathy
- Hypertrophic cardiomyopathy (HCM) –obstructive vs nonobstructive
- Restrictive cardiomyopathy - infiltrative
- Arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C)
- Unclassified cardiomyopathy
CARDIOMYOPATHIES

Imaging

- Assess LVEF and wall motion
  - LVEF may be normal, decreased or increased
  - Wall motion abnormalities, if present are typically global
- Delayed enhancement (LGE)
  - Nonsegmental – distinct from ischemia
  - Often midmyocardial, subepicardial or diffuse
DILATED CARDIOMYOPATHY

MRI morphology/function

- Markedly dilated LV and/or RV chamber
- Normal to slightly thinned wall
- Reduced ejection fraction
- May have LGE
DILATED CARDIOMYOPATHY
DELAYED ENHANCEMENT (LGE)
HYPERTROPHIC CARDIOMYOPATHY

Types

- Asymmetric septal (ASH, IHSS) *
- Midventricular *
- Apical
- Concentric

* often obstructive
HYPERTROPHIC CARDIOMYOPATHY
HYPERTROPHIC CARDIOMYOPATHY
LGE
Sarcoidosis

- Cardiac involvement important prognostic factor – sudden death
- Mixed edema/fibrotic changes
- MRI findings:
  - Segmental motion abnormalities
  - T2W edema sequences useful
  - DE – in areas of segmental abnormality
RESTRICTIVE CARDIOMYOPATHY SARCOIDOSIS

T2W edema sequence

LGE
#3 CONGENITAL HEART DISEASE

- Assess simple or complicated congenital heart disease morphologically
- No radiation for children/infants
- Calculate shunts/gradients
- Time-of-flight imaging
- Post-operative complications
CONGENITAL HEART DISEASE
UNREPAIRED

Qp:Qs = 2.9
CONGENITAL HEART DISEASE REPAIRED

TOF with post-repair pulmonary regurgitation
OTHER INDICATIONS

- PERICARDIAL DISEASE – PARTICULARLY CONSTRUCTION
- CARDIAC MASSES
- AORTIC DISEASE
- LEFT ATRIAL EVALUATION PRIOR TO RF ABLATION
CONCLUSION

- Both cardiac CT and MRI have a variety of indications and are complementary to other cardiac imaging techniques
- Cardiac CT provides unsurpassed anatomical detail
- Cardiac MRI provides outstanding functional detail without ionizing radiation