Fundamentals of Cardiac CT

Mark C. Hyun, CNMT, NCT, RS, RT(R,N,CT), FASNC
Course Objectives

To understand

- How cardiac CT is integrated with Nuclear Cardiology
- How to prepare for cardiac CT exams
- Technical aspects of cardiac CT
Course Outlines

- Cardiac CT vs Nuclear Cardiology

- Types of Cardiac CT exams
  - CTAC (CT Attenuation Correction)
  - CAC (Coronary Artery Calcium Scan)
  - CCTA (Coronary CT Angiography)
  - Non-Coronary Cardiac CT (Aneurysms, Valve, etc)

- Basic CT physics and scan settings
Coronary Disease Progression

- Calcified Plaque Detected by CT

- Normal
- Early
- Lipid rich
- Internal rupture
- Calcified shell
- Calcified plaque
- Vulnerable
- Rupture
- Thrombus
- Myocardial infarction
- Stable

Inflammation and calcification
Scar development with calcification

?? Role for CTA

>60% stenosis (+) stress/imaging
Cardiac CT vs Nuclear Cardiology

Pre-test likelihood of CAD

- Low
  - Low- to High-Intermediate (15-85%)
  - Intermediate to High (50-100%)

- CAC
- CTA
- Stress SPECT/PET

- Asymptomatic → Prevention
- Symptomatic → Diagnosis
- Known disease → Intervention
Cardiac CT

**Strengths:**
- Non-invasive, rapid, easily performed
- 3D high spatial resolution
- Non-contrast: proven role of CAC for prevention
- Contrast: CCTA
  - Highest sensitivity & specificity for CAD
  - Potential for comprehensive cardiac assessment
  - Function, perfusion, infarct, plaque
  - Strong prognostic value

**Weaknesses:**
- Densely calcified plaques: non-diagnostic
- Dependence on how HR and regular rhythm
- Iodinated contrast
Cardiac CT

**Coronary Anatomy**
- RCA
- LAD
- LCX

**Perfusion**
- Stress
- Rest

**Function**

**Flow**
Myocardial Perfusion SPECT/PET

**Strengths:**
- High technical success rate
- Objective measurements of perfusion & function
- Documented for risk-stratification/management
- Validated for myocardial viability
- Promising new PET tracer

**Weaknesses:**
- No detection of early atherosclerosis
- Frequently underestimates extent of ischemia/CAD
Myocardial Perfusion SPECT/PET

Perfusion

Function

Quantification

Flow
Epicardial vs Microvascular Disease
Course Outlines

- Cardiac CT vs Nuclear Cardiology

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- Basic CT physics and scan settings
Attenuation Correction

Jul 2013

Tx AC

Aug 2016

CTAC
CTAC

1. Topogram

2. CTAC

3. Image Reformat

4. Image Fusion

5. Image Registration
Attenuation Correction

Stress NAC

Rest NAC

Stress AC

Rest AC
Course Outlines

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- Basic CT physics and scan settings
Coronary Artery Calcification (CAC)

If we can see it

We can measure it...
Agatston and Janowitz... AJ score

Originally published: 2003
## CAC Score Scale

<table>
<thead>
<tr>
<th>Score</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None/Normal</td>
</tr>
<tr>
<td>1 – 10</td>
<td>Minimal</td>
</tr>
<tr>
<td>11 – 100</td>
<td>Mild</td>
</tr>
<tr>
<td>101 – 400</td>
<td>Moderate</td>
</tr>
<tr>
<td>401 – 1000</td>
<td>Extensive/Severe</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>Very Extensive/Severe</td>
</tr>
</tbody>
</table>

Coronary artery calcium score directly correlates with risk of events and likelihood of obstructive CAD.
5 USES OF CAC Scan (CCS)

1. Identify patients who do not need further cardiac evaluation (scores of zero)
2. Use a calcium score to screen patients with moderate (intermediate) risk
   - Positive CAC scans indicate incremental risk
   - Alters therapeutic goal (LDL, BP, etc.)
3. Consider serial imaging as ongoing management tool (progression)
4. Improve compliance
5. Adjunct to Non-invasive Angiography/SPECT or PET MPI
FO 60 M ATA, HF, no walk adeno, normal ST response
RJ 75 F ATA, DM, no walk adeno/ normal ST response

CAC 1463 (97th %)
BB 62 M AS, HLD, 13.5 min EX, 95% MPHR, ST dep

CAC 682 (89th %)
CONFIRM Patients with no prior CAD
Prevalence of Obstructive CAD with any CP symptom N=8,660

<table>
<thead>
<tr>
<th>CAC</th>
<th>0-49%</th>
<th>50-69%</th>
<th>≥70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥1000</td>
<td>29</td>
<td>19</td>
<td>53</td>
</tr>
<tr>
<td>400-999</td>
<td>44</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>100-399</td>
<td>63</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>1-99</td>
<td>85</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>0</td>
<td>97</td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

CONFIRM, unpublished, 2016
Coronary Calcium Scan (CCS)

**Acquisition**
- Prospective ECG-triggered axial scanning
- Slice thickness: 2.5 mm
- Standard tube voltage: 120 kVp
- Tube current: 120 – 150 mAs
- Radiation dose: 1 – 2 mSv

**CT CAC Quantification**
- Density of calcification: >130 HU
- Measurement of area: >1 mm³
Calcium Scoring Software

ScImage

Vitrea

QPET
ASSESSMENT OF CORONARY CALCIUM SCORE USING INTEGRATED PET MYOCARDIAL PERFUSION QUANTITATIVE SOFTWARE METHOD: COMPARISON WITH THE STANDARD STAND-ALONE SOFTWARE SYSTEMS


Cedars-Sinai Medical Center, Los Angeles, CA 90048, USA

BACKGROUND

- Assessment of coronary artery from ECG-gated non-contrast performed in conjunction with and has been shown to have prognostic value and to interpretation of the MPI scans.
- However, CAC scoring is performed on a separate workstation or package from that used for MPI availability.
- We sought to compare CAC developed software (Q) which qualitative analyst and quantitatively CAC with two clinically software systems (S and V).

RESULTS

![Graphs showing comparison of CAC scores between software Q, S, and V.](image)

METHODS

- We studied 94 consecutive patients undergoing CAC scanning (age of 67.9 ± 11.2 years) with a 64-slice cardiac PET/CT system. Of the 128 slice CT scanner were analyzed using all three software systems.
- Regression analyses were used to determine the strength of the correlation between the CAC scores from each software.
- The distribution of the CAC score in the standard CAC categories was: none; 1-9, minimal; 10-99, mild; >100, moderate; >400, severe. (Figure 1)

![Figure 1: Graph showing distribution of CAC scores.](image)
Course Outlines

- Cardiac CT vs Nuclear Cardiology

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  - Non-Coronary Cardiac CT (Aneurysms, Valve, etc)

- Basic CT physics and scan settings
Coronary CT Angiography

- Sensitivity & Specificity: $\sim 95\% / 90\%$
- Higher than all other modalities
- Very unlikely to miss high risk disease
Coronary CT Angiography

Level of Risk

- **Very Low**: Assure
- **Low**: Prevent
- **Borderline**: + Stress
- **Can’t tell**: + Stress or cath
- **Medium**: + Cath
- **High**
Indications:

- Evaluation of chest pain
- Suspicion of coronary artery anomalies
- Evaluation of pericardial dz and cardiac masses
- Evaluation of aortic dz (aneurysm, dissection, valve dz)
- Assessment of anatomy in complex congenital heart dz
- Pre- or post-OP evaluation of CABG
- Pulmonary vein evaluation
- Evaluation of suspected PE
Coronary CT Angiography

*Contraindications:*

- **Absolute**
  - Renal insufficiency (i.e., Cr > 1.6 mg/dL)
  - Known h/o anaphylactic contrast reactions
  - Pregnancy
  - Clinical instability
Contraindications:

- Relative
  - Contrast (iodine) allergy
  - Recent IV iodinated contrast administration
  - Hyperthyroidism
  - A-Fib or any irregular heart rhythms
  - Inability to breath hold for at least 10 seconds
  - Morbidly obese
  - Severe coronary calcium
Coronary CT Angiography

Premedication of At Risk Patients

**Oral Protocol:**

<table>
<thead>
<tr>
<th></th>
<th>Medicine</th>
<th>Dosage</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Prednisone</td>
<td>50 mg. PO</td>
<td>13 hours prior to exam</td>
</tr>
<tr>
<td>B</td>
<td>Prednisone</td>
<td>50 mg. PO</td>
<td>7 hours prior to exam</td>
</tr>
<tr>
<td>C</td>
<td>Prednisone</td>
<td>50 mg. PO</td>
<td>1 hour prior to exam</td>
</tr>
<tr>
<td>D</td>
<td>Diphenhydramine</td>
<td>50 mg. PO</td>
<td>in Imaging, approximately 30 minutes prior to exam</td>
</tr>
</tbody>
</table>

**IV Protocol:**

<table>
<thead>
<tr>
<th></th>
<th>Medicine</th>
<th>Dosage</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hydrocortisone</td>
<td>200 mg. IV</td>
<td>13 hours prior to exam</td>
</tr>
<tr>
<td>B</td>
<td>Hydrocortisone</td>
<td>200 mg. IV</td>
<td>7 hours prior to exam</td>
</tr>
<tr>
<td>C</td>
<td>Hydrocortisone</td>
<td>200 mg. IV</td>
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<td>D</td>
<td>Diphenhydramine</td>
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</tbody>
</table>
Coronary CT Angiography

**Safety**

- **Radiation exposure**

  Radiation doses of cardiac CT scans vary greatly depending on the scan setting, scan range, gender, and patient body habitus

  - Chest X-ray: **0.04 – 0.10 mSv**
  - Average annual background radiation: **3 – 5 mSv**
  - Invasive diagnostic coronary angiography: **2.1 – 4 mSv**
  - Coronary CT angiography: **4 – 11 mSv**
  - SPECT MPI: Stress only: **2- 4 mSv**, R/S: **8 – 12 mSv**

- **Contrast Induced nephropathy (CIN)**
Contrast Media–Induced Nephropathy

- Intravascular CM affect kidney function
  - In most cases the effects are confined to a short period of kidney dysfunction that does not produce symptoms and generally goes undetected
  - In some cases CM can result in significant nephrotoxic effects, particularly in patients considered at high risk for nephropathy

- **CIN Risk Factors**
  - Creatinine clearance (eGFR) < 25 mL/min
  - History of diabetes mellitus
  - History of recent administration of iodinated contrast agent
  - Anticipated large volume of CM
  - History of congestive heart failure
Coronary CT Angiography

Patient Assessment & Preparation

- Clinical History
- Scheduling & Screening
- Education & Consent
- Monitoring of Vital Signs (HR & BP)
- Management of Medical Devices
- Lab Values (Renal Function)
- Medication & Dosage
5 Steps to Optimal CCTA

1. Patient Preparation
2. Beta-Blockers and NTG
3. CT Setup and Contrast
4. Scan Protocol
5. Reconstructions
Patient Preparation

- No caffeine x 12 hrs prior to CCTA
- NPO x 4 hrs prior to CCTA
- No cardiovascular activity prior to CCTA
- Patient education to minimize anxiety
  - Holding breath & motion
  - Contrast effects
  - Beta-blockers & NTG

- ECG placement
- IV access
  - Antecubital vein, 18g IV angiocath
  - Injection rate of ≥5 cc/sec
Breathing

- Adequate breath-hold is critical to prevent artifact
- Hyperventilation
- Explain and practice with patient
- Monitor HR during breath-hold

Misaligned breathing artifacts
5 Steps to Optimal CCTA

1. Patient Preparation
2. Beta-Blockers and NTG
3. CT Setup and Contrast
4. Scan Protocol
5. Reconstructions
Heart Rate & Coronary Motion
Cardiac CT – ECG phases

- Optimal phase for reconstruction for CTA
- Diastole @ ~ 70%

Optimal reconstruction phase

Eg. 30  60  70  80
Oral Beta-Blocker Protocol

Metoprolol Administration

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
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<tbody>
<tr>
<td><img src="true" alt="Iodinated Contrast Contraindications" /></td>
<td><img src="true" alt="Prevalent hypersensitivities to beta blocker" /></td>
</tr>
<tr>
<td><img src="true" alt="Asthma / Uses Inhaler" /></td>
<td><img src="false" alt="If yes: How often?" /></td>
</tr>
<tr>
<td><img src="true" alt="Takes Diltiazem" /></td>
<td><img src="false" alt="If yes: Last time taken and dosage?" /></td>
</tr>
<tr>
<td><img src="true" alt="Takes Beta Blocker" /></td>
<td><img src="false" alt="If yes: Last time taken and dosage?" /></td>
</tr>
<tr>
<td><img src="true" alt="Abnormal ECG (e.g. 2nd or 3rd degree heart block)" /></td>
<td><img src="false" alt="Aortic Stenosis" /></td>
</tr>
<tr>
<td><img src="true" alt="Congestive Heart Failure" /></td>
<td><img src="true" alt="HR &lt; 60 bpm" /></td>
</tr>
<tr>
<td><img src="true" alt="SBP &lt; 100 mm Hg" /></td>
<td></td>
</tr>
</tbody>
</table>

*If ALL questions have been answered NO: RN / NP may administer Metoprolol PO with 16 oz water as follows:*

- If HR > 65 bpm, give Metoprolol 100 mg PO
- If HR 60 - 64 bpm, give Metoprolol 50 mg PO

*If ANY question(s) above have been answered YES, consult MD for Metoprolol order*

- See Physician Order sheet for Metoprolol order
IV Beta-Blocker Protocol

<table>
<thead>
<tr>
<th>Step</th>
<th>Dose</th>
<th>HR</th>
<th>BP</th>
<th>Step</th>
<th>Dose</th>
<th>HR</th>
<th>BP</th>
<th>Step</th>
<th>Dose</th>
<th>HR</th>
<th>BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>7</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>2</td>
<td>5 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>8</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>3</td>
<td>5 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>9</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>4</td>
<td>5 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>10</td>
<td>5 mg</td>
<td></td>
<td></td>
<td>5</td>
<td>5 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5 mg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>5 mg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Administer 5 mg Metoprolol IV over 1 minute, record HR and BP every 1 minute (max 50 mg)

Total Amount IV Metoprolol given _____ mg  Time: _____

Administered by: ________________________ MD / NP
Use of Beta Blockers in CCTA

Not used: HR 84

Used: HR 56
Use of Nitroglycerin in CCTA

42 patients randomized to NTG or no NTG
Nitroglycerin Protocol

<table>
<thead>
<tr>
<th>Nitroglycerin Administration</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic cardiomyopathy</td>
<td>☑</td>
<td></td>
</tr>
<tr>
<td>Severe aortic stenosis</td>
<td>☑</td>
<td></td>
</tr>
<tr>
<td>Takes erectile dysfunction meds.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If yes: name of med, dosage, last time taken? ________________________________</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP &lt; 100 mmHg</td>
<td>☑</td>
<td></td>
</tr>
<tr>
<td>Patient experiencing dizziness, syncope, nausea or vomiting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pre Nitro BP ________________ Post Nitro BP ________________

If ALL questions have been answered NO: RN / NP may administer 1 metered spray of Nitroglycerin sublingually.

Administered by: ________________________________ Time: ________________
5 Steps to Optimal CCTA

1. Patient Preparation
2. Beta-Blockers and NTG
3. CT Setup and Contrast
4. Scan Protocol
5. Reconstructions
**Scan Field of View (FOV)**
- Consider minimizing to the heart
- Small reduction in radiation dose

**Scan Range (Z-Axis)**
- 1 cm below carina to just below the inferior margin of the heart
- Significant reduction in radiation dose
**Contrast Protocols**

- Injection rate is important
- Dual- or triple-phase protocols generally preferable (less contrast volume, less artifact)
Contrast Protocols

Single-Phase Contrast Protocol

Multi-Phase Contrast Protocol
Bolus Tracking

- Bolus tracking initiates the breathing instructions and scan, once a threshold attenuation is reached in the aortic root (typically ≥100 HU).
Timing Bolus

- 10-20 cc of contrast to determine the delay for peak opacification of the aortic root
- This delay should be added to a specific time that varies by manufacturer
- A timing bolus may highlight potential problems (kinked elbow, poor IV flow, cardiomyopathy)
Contrast Opacification

Poor Contrast

Good Contrast
5 Steps to Optimal CCTA

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2. Beta-Blockers and NTG
3. CT Setup and Contrast
4. Scan Protocol
5. Reconstructions
# Scan Mode Comparison

<table>
<thead>
<tr>
<th>Scan mode</th>
<th>Helical</th>
<th>Axial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synonyms</td>
<td>Spiral, retrospectively-gated</td>
<td>Step-&amp;-shoot, prospectively-triggered,</td>
</tr>
<tr>
<td>Basic principle</td>
<td>X-ray tube continuously “on” with patient moved through the beam</td>
<td>X-ray tube on &amp; off triggered by the ECG with no scanning between steps as the patient is moved through the scan range</td>
</tr>
<tr>
<td>CT data acquired</td>
<td>Systole and diastole</td>
<td>Set phase (diastole or systole) with some phase tolerance (temporal padding)</td>
</tr>
<tr>
<td>Advantages</td>
<td>Enables flexible reconstruction in the event of arrhythmias or artifacts; evaluation of cine images for systolic &amp; diastolic frames (EF)</td>
<td>Low radiation dose, no loss in image quality for purpose of coronary or structural diagnosis</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Higher radiation dose</td>
<td>Loss of ventricular function evaluation</td>
</tr>
</tbody>
</table>
Gating: General Principles

**Retrospective ECG gating best for:**
- Higher heart rate
- Irregular rhythm
- Known CAD or higher probability of CAD

**Prospective ECG gating best for:**
- Well-controlled heart rate (generally <60-65 bpm)
- Regular rhythm
- Low-probability of CAD
Retrospective ECG Gating

Table Moves

Retrospective Gating

Retrospective Gating with Dose Modulation

-25%
Benefit of Additional Phases

Having multiple phases may reduce the number of non-interpretable studies!!
Prospective ECG Gating
Benefit of Prospective ECG Gating

59 yo female with chest pain
Prospective ECG gating with no padding (0.64 mSv)
Gating Methods in CCTA

Retrospective Gating

Retrospective Gating with Dose Modulation

Prospective Gating

Prospective Gating with Reduced Padding

LaBounty, AJC 2010, AJR 2010
Tube Current and Voltage
Electrons accelerated at tungsten target; when they hit the target, x-ray photons are produced.
Higher current = more photons = less noise
Larger patient = need more photons
Photon attenuation by a given material is affected by the potential energy (voltage) of the photons.
Higher voltage = higher photon energy = less noise (but lower signal and contrast)

Both patients below are 50 year-old males with a BMI of 22-24 kg/m². Other settings and heart rate are the same. Which scan has a lower radiation dose?

Lower kVp
0.76 mSv

Higher kVp
1.55 mSv
Standardized Protocols

To balance image quality and radiation dose, consider protocols that:

1. Adjust tube current and voltage based on body size
2. Assign gating methods based on HR, HRV, and clinical question

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Standardized coronary computed tomographic angiographic protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMI (m/kg²)</strong></td>
<td><strong>Tube Voltage (kV)</strong></td>
</tr>
<tr>
<td>&lt;25</td>
<td>100</td>
</tr>
<tr>
<td>25–29.9</td>
<td>100</td>
</tr>
<tr>
<td>30–33.9</td>
<td>120</td>
</tr>
<tr>
<td>≥34</td>
<td>120</td>
</tr>
</tbody>
</table>

Prospective ECG gating was assigned to all patients with regular heart rates <65 beats/min unless the ordering physician specifically requested retrospective gating. Scan length was minimized in all patients.
5 Steps to Optimal CCTA

1. Patient Preparation
2. Beta-Blockers and NTG
3. CT Setup and Contrast
4. Scan Protocol
5. Reconstructions
Reconstructions

- Filtered Back Projection
- Reconstruction kernel
- Iterative Reconstruction (e.g., MBIR)

Iterative Noise Reduction Methods (e.g., ASIR, SAFIRE)

Acquisition → Projection Data → Projection-space Filters

Image Reconstruction → CT image → Filtered CT image

Image-space Noise Reduction (e.g., SharpView)
Iterative reconstruction lowers image noise:

1. May permit reduced radiation dose by permitting the use of lower current
2. May improve image quality of noisy studies
Motion Correction Algorithms

Multi-Phase Reconstruction

Advanced Processing

Motion Characterization

Motion Compensation

Courtesy of Dr. Jonathon Leipsic
Coronary CT Flow (FFR_{CT})
5 Steps to Optimal CCTA

1. Patient Preparation
2. Beta-Blockers and NTG
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OVERALL GOAL:
Best Image Quality with Highest Patient Safety
Non-Coronary Cardiac CT

- Pericardial disease (effusion, mass)
- Congenital heart disease
- Aortic disease (aneurysm, dissection)
- TAVR (Transcatheter Aortic Valve Replacement)
- LAPV (Left Atrium Pulmonary Vein)
- PE (Pulmonary Embolism)
Pericardial Disease

LV mass with central necrosis

RV

Pericardial effusion
Congenital Heart Disease

Atrial Septal Defects (ASD)  Sinus Venous/Coronary Sinus Defects
Aortic Disease

Aortic Aneurysm

Aortic Dissections
CT Assessment of Annular Sizing
Pre-TAVR

Aortic Valve

- **Aortic Annulus**
  - Perimeter: _______
  - Perimeter Derived Ø: _______
  - Area: _______
  - Area Derived Ø: _______

- **LVOT Ø:** _______

- **RCA Height:** 17.1 mm

- **Sinus Of Valsalva Diameters:**
  - Left: _______
  - Right: _______
  - Non: _______

- **Asc. Aorta Ø:** _______
- **STJ Ø:** _______
- **LCA Height:** 18.3 mm
- **Aortic Valve Calcification:** -
CT Assessment of Annular Sizing
Pre-TAVR
LAPV

ATRIAL FIBRILLATION
Impulses have chaotic, random pathways in atria

Baseline irregular, ventricular response irregular
Pulmonary Arteries

PE

Pulm HTN

RV Strain
New Technologies in Cardiac CT

**Temporal resolution**
- Dual-source/Flash CT
  - Faster gantry rotation
  - 83 ms resolution
  - Reduced need for beta blockers

**Volume coverage**
- 320-slice MDCT
  - Increased z-axis coverage/gantry rotation
  - Whole heart acquisition in 1 beat
  - Perfusion?

**Spatial resolution**
- High Definition CT
  - Improved spatial resolution
  - Improved reconstruction (SNR)
  - Reduced radiation
  - Enhanced Ca2+ and stent imaging, stenosis severity
MPI vs Cardiac CT Volume

**MPI**
- **Total**: 
  - 2010: 4500
  - 2011: 4300
  - 2012: 4100
  - 2013: 3900
  - 2014: 3700
  - 2015: 3500
  - 2016: 3300
  - Decrease: 2%

- **SPECT**: 
  - 2010: 3200
  - 2011: 3000
  - 2012: 2800
  - 2013: 2600
  - 2014: 2400
  - 2015: 2200
  - 2016: 2000
  - Decrease: 5%

- **PET**: 
  - 2010: 1000
  - 2011: 1200
  - 2012: 1400
  - 2013: 1600
  - 2014: 1800
  - 2015: 2000
  - 2016: 2200
  - Increase: 8%

**Cardiac CT**
- **CCT**: 
  - 2010: 1000
  - 2011: 1200
  - 2012: 1400
  - 2013: 1600
  - 2014: 1800
  - 2015: 2000
  - 2016: 2200
  - Increase: 25%

- **CCTA**: 
  - 2010: 900
  - 2011: 1000
  - 2012: 1100
  - 2013: 1200
  - 2014: 1300
  - 2015: 1400
  - 2016: 1500
  - Increase: 26%

- **OP**: 
  - 2010: 800
  - 2011: 900
  - 2012: 1000
  - 2013: 1100
  - 2014: 1200
  - 2015: 1300
  - 2016: 1400
  - Increase: 19%

- **IP**: 
  - 2010: 700
  - 2011: 800
  - 2012: 900
  - 2013: 1000
  - 2014: 1100
  - 2015: 1200
  - 2016: 1300
  - Increase: 16%

- **ED**: 
  - 2010: 500
  - 2011: 600
  - 2012: 700
  - 2013: 800
  - 2014: 900
  - 2015: 1000
  - 2016: 1100
  - Increase: 40%
Conclusion

- Cardiac CT offers complimentary role to nuclear MPI (SPECT/PET)
- Cardiac CT is rapidly growing in assessing CAD
- CAC scan is an excellent screening tool for CAD
- Radiation risk is real, but is comparable to nuclear MPI
- Cardiac CT is an excellent tool for non-coronary findings and pre-/post-surgical evaluation
Thank You!