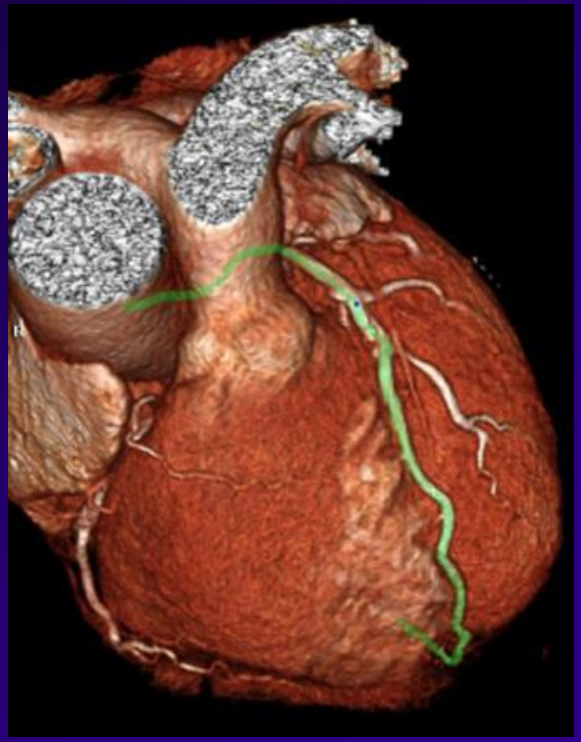
The 24th Annual Diagnostic Imaging Symposium

KAISER PERMANENTE®

# Fundamentals of Cardiac CT



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

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# Course Objectives

*To understand*

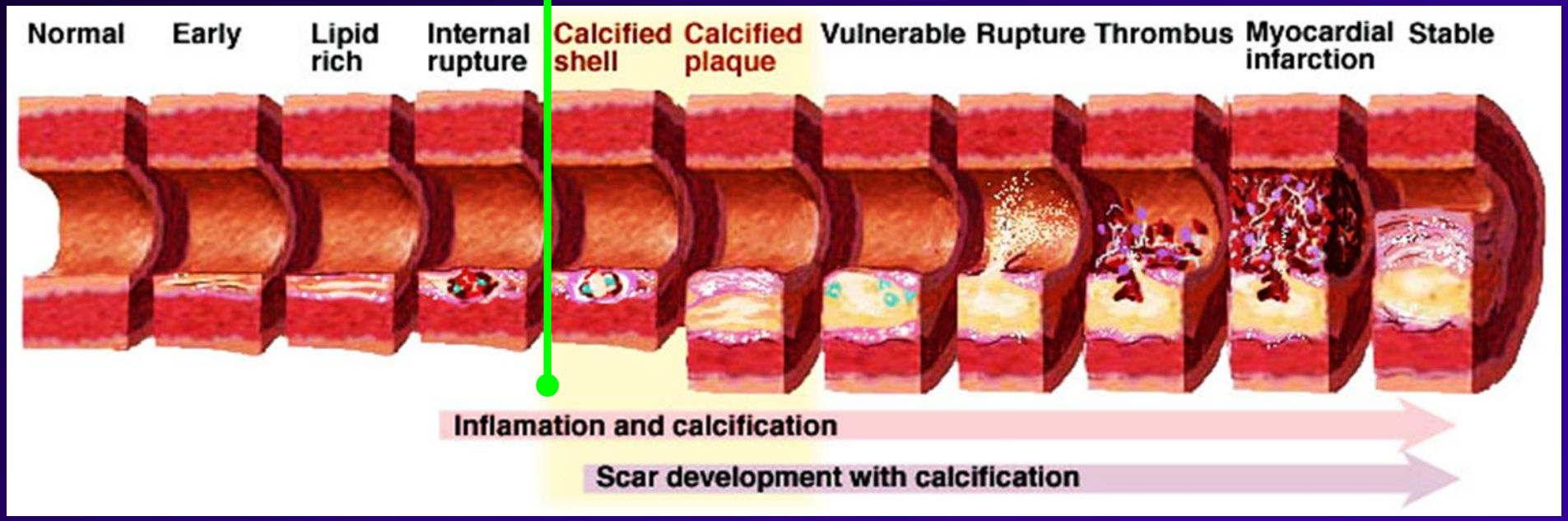
- How cardiac CT is integrated with Nuclear Cardiology
- How to prepare for cardiac CT exams
- Technical aspects of cardiac CT

# 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

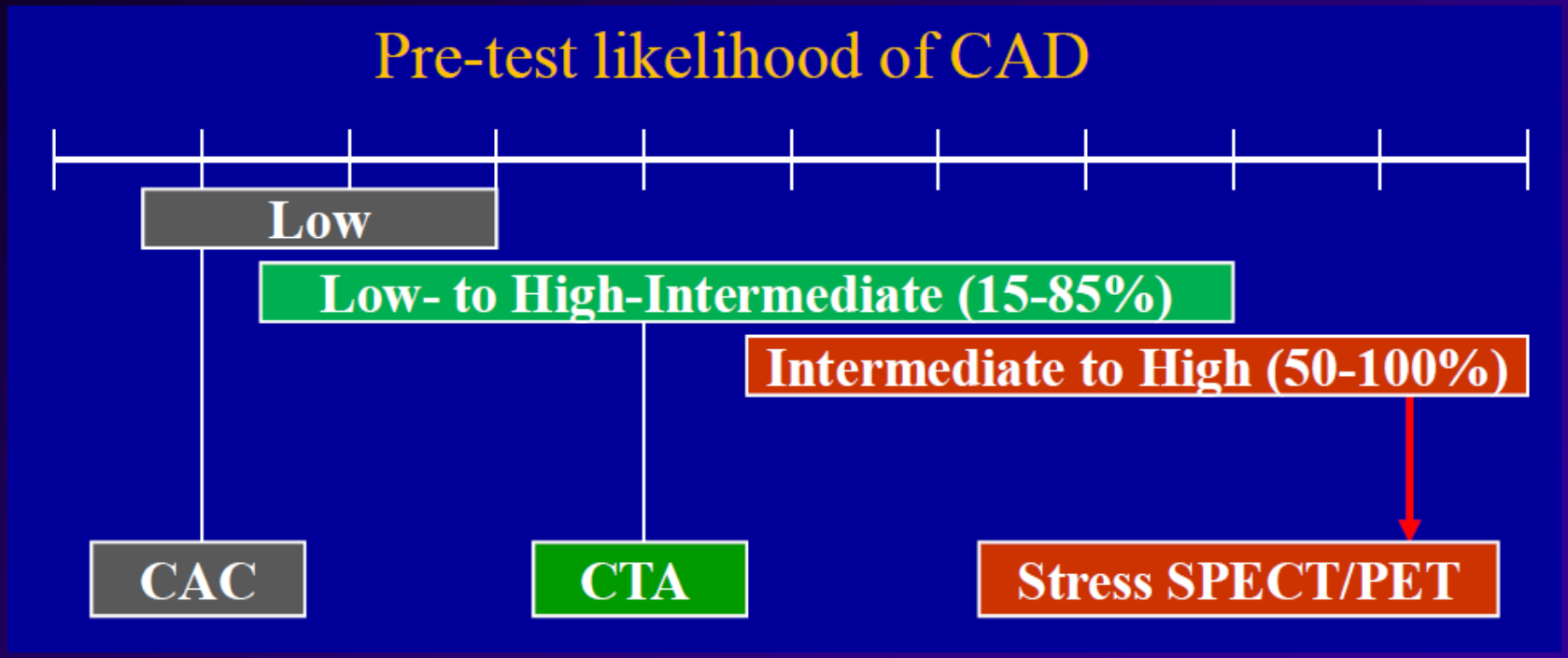
Calcified Plaque Detected by CT




? Role for CTA

>60% stenosis (+) stress/imaging

# Cardiac CT vs Nuclear Cardiology




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

# Cardiac CT

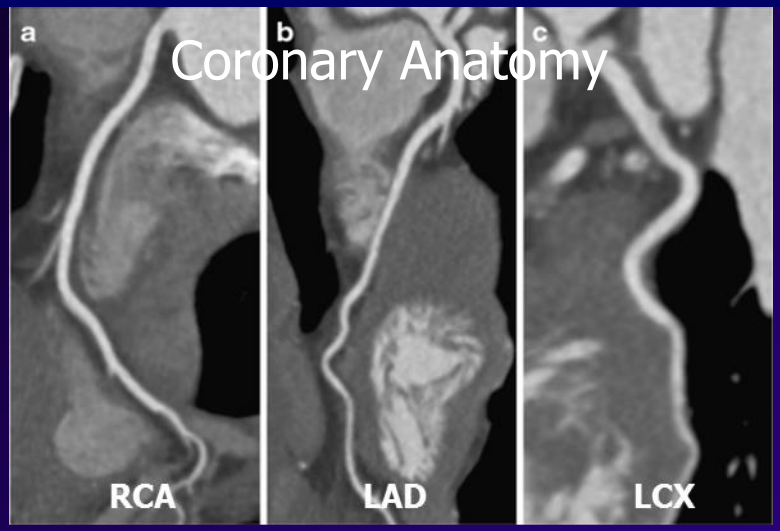
***Strengths:***

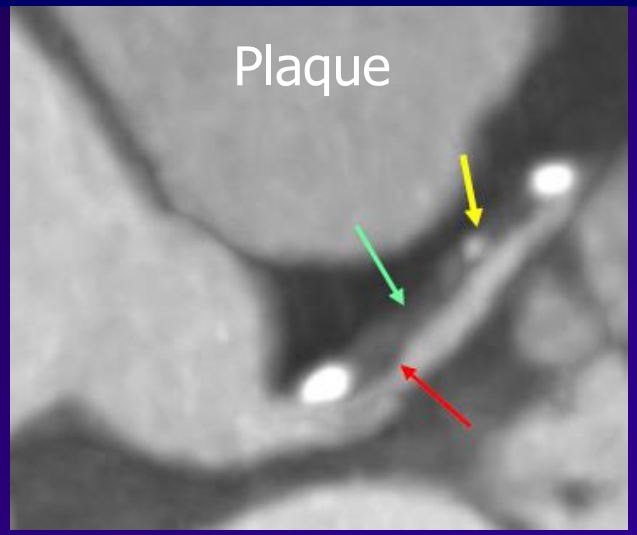
- Non-invasive, rapid, easily performed
- 3D high spatial resolution
- Non-contrast: proven role of CAC for prevention
- Contrast: CCTA
  - Highest sensitivity & specificity for CAD
  - Potential for comprehensive cardiac assessment
  - Function, perfusion, infarct, plaque
  - Strong prognostic value

***Weaknesses;***

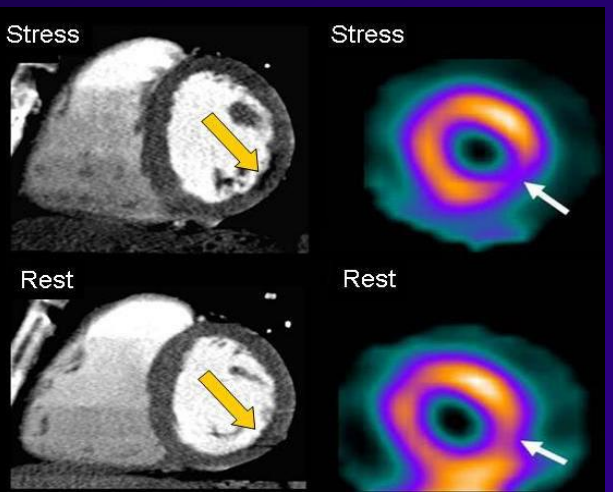
- Densely calcified plaques: non-diagnostic
- Dependence on how HR and regular rhythm
- Iodinated contrast

# Cardiac CT

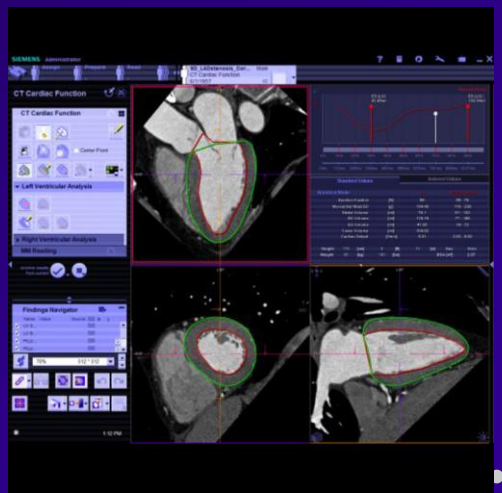


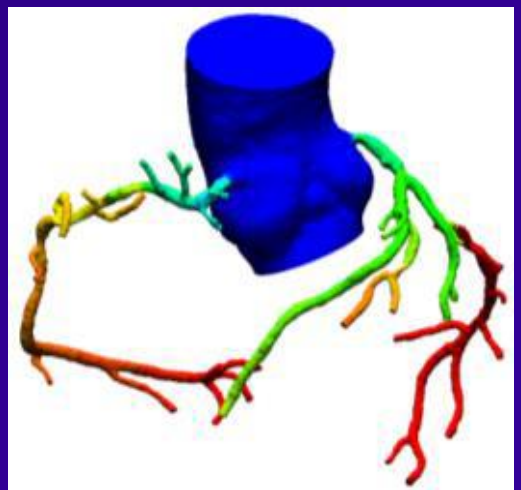

Perfusion




Function



Flow



# Myocardial Perfusion SPECT/PET

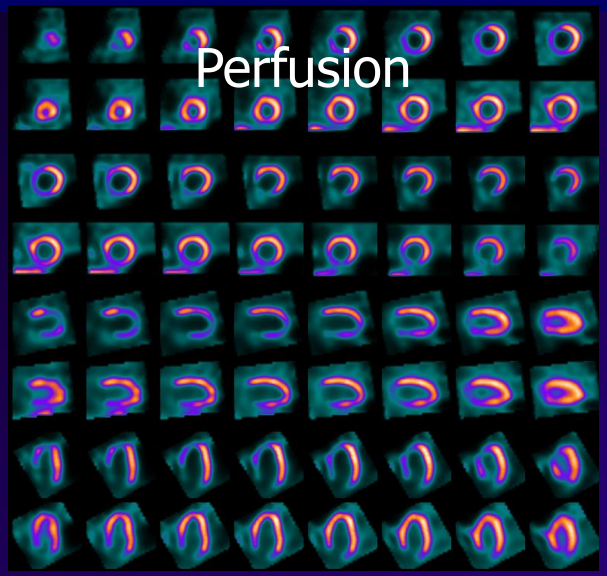
***Strengths:***

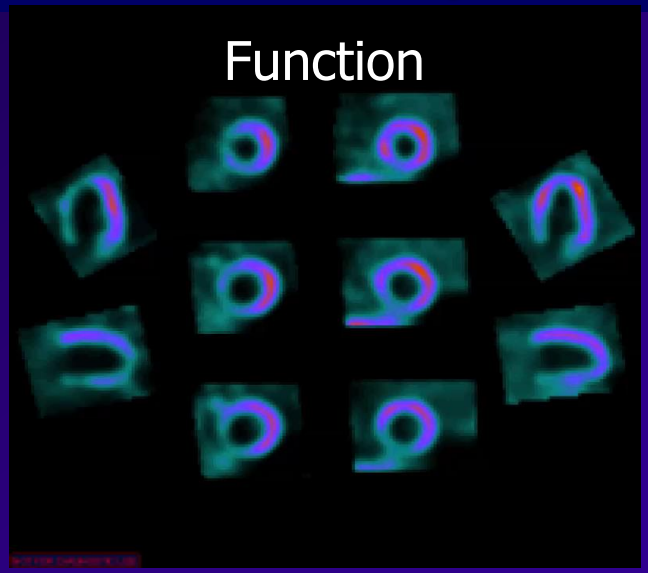
- High technical success rate
- Objective measurements of perfusion & function
- Documented for risk-stratification/management
- Validated for myocardial viability
- Promising new PET tracer

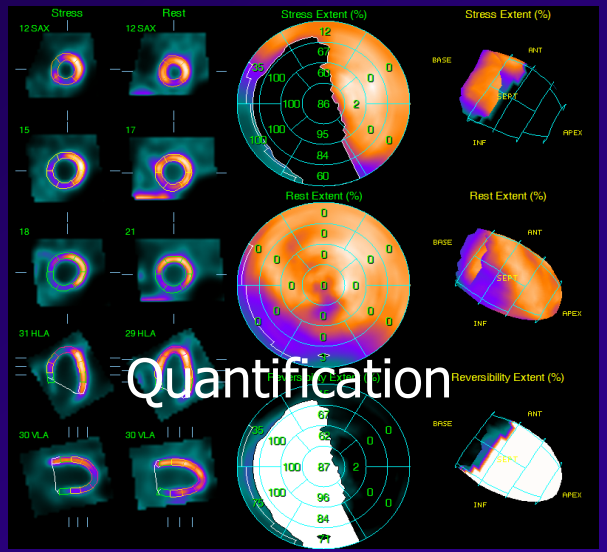
***Weaknesses;***

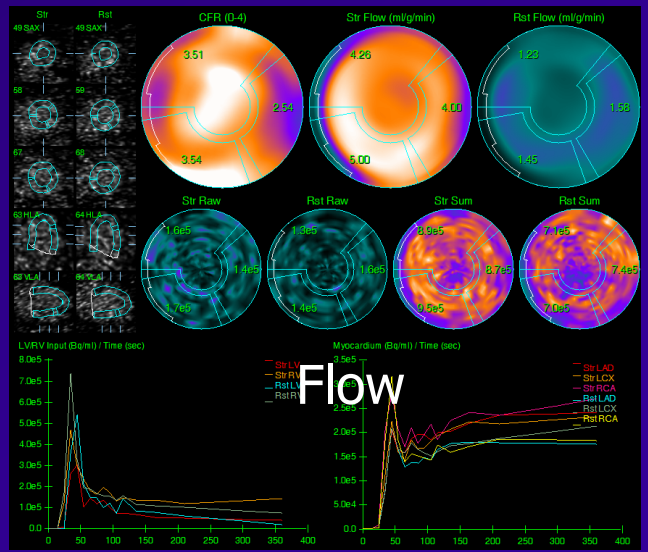
- No detection of early atherosclerosis
- Frequently underestimates extent of ischemia/CAD

# Myocardial Perfusion SPECT/PET

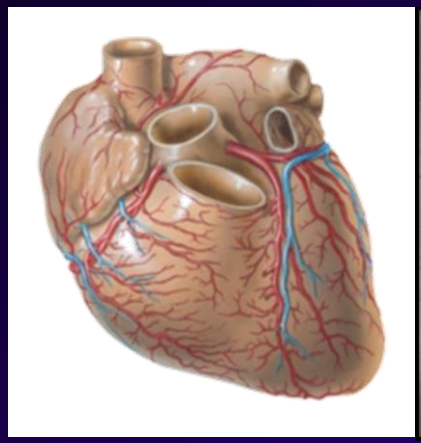


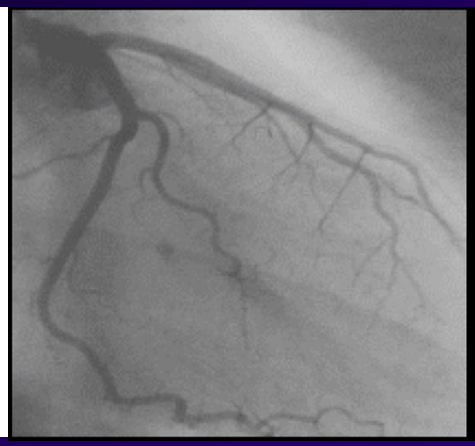



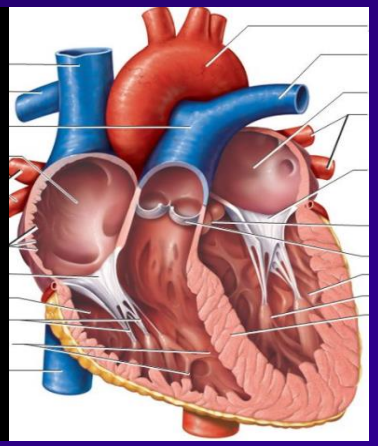



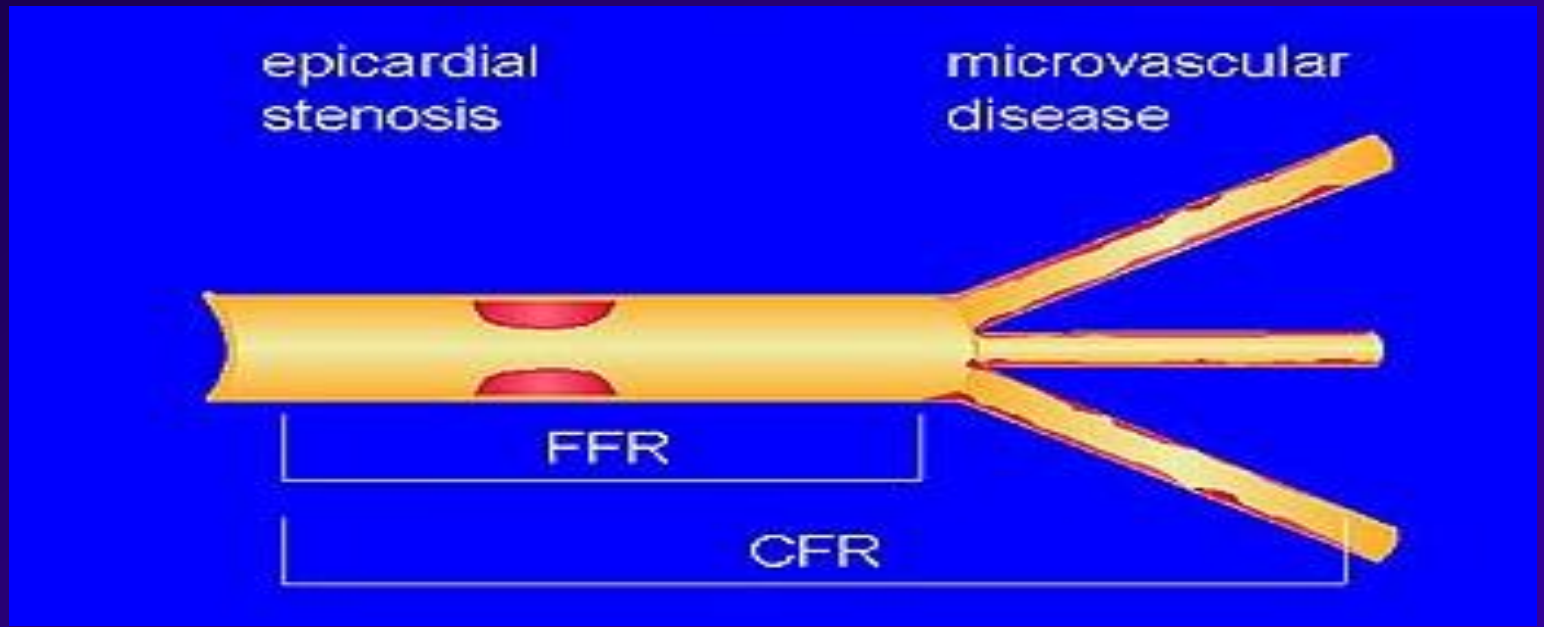



# Epicardial vs Microvascular Disease









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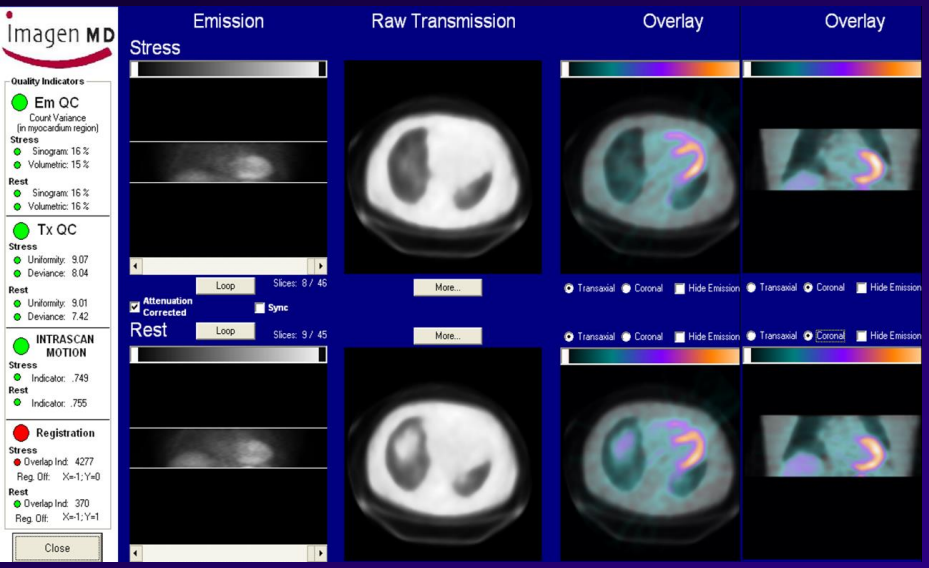
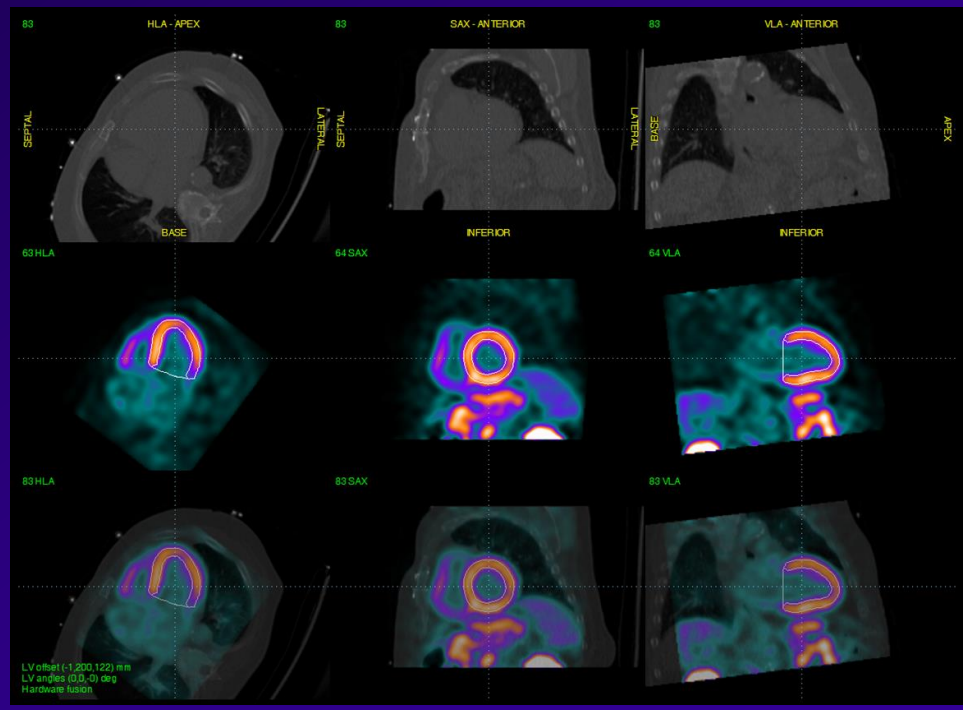
# Attenuation Correction

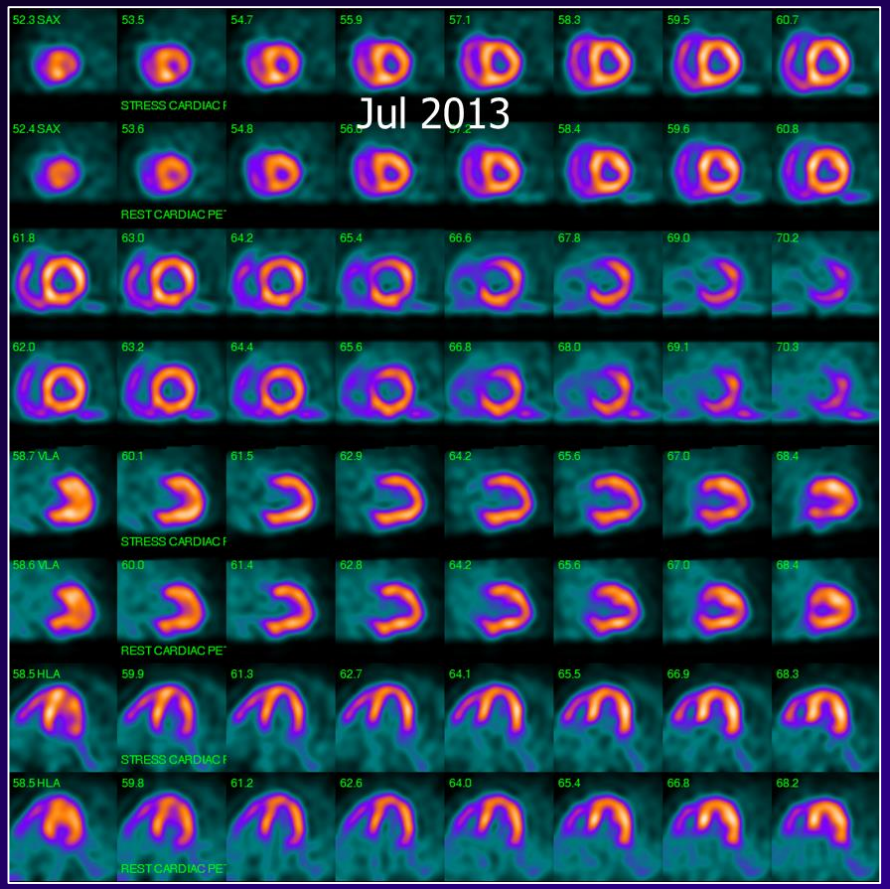



Tx AC

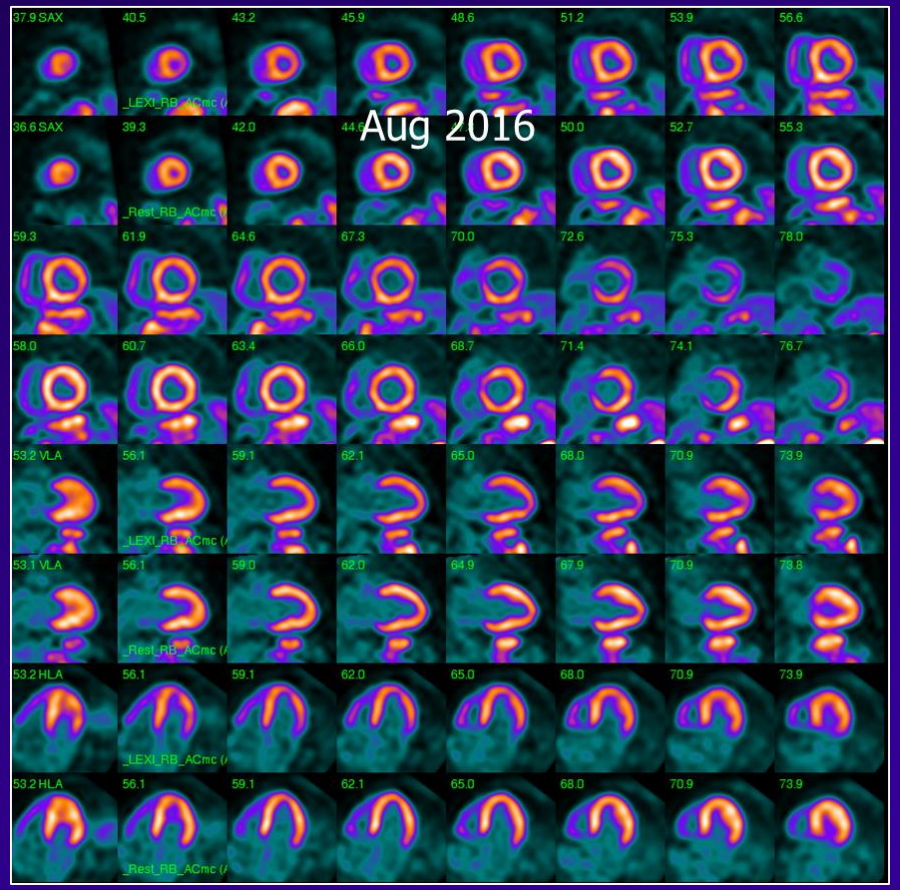



CTAC

# Attenuation Correction



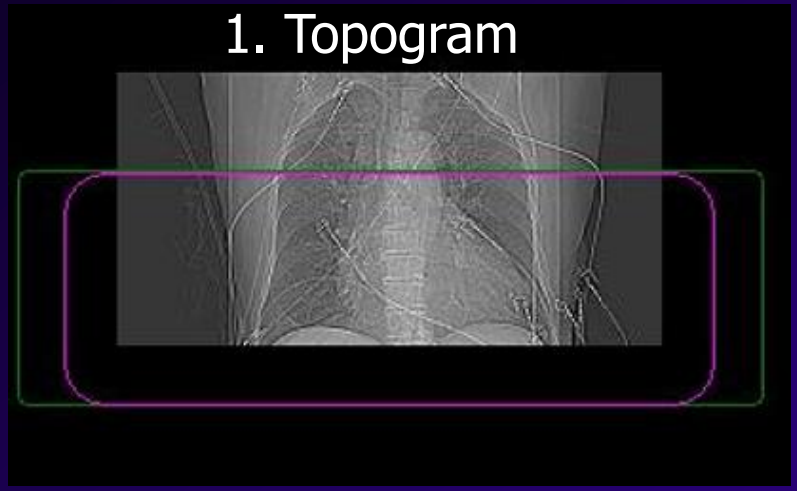

Tx AC



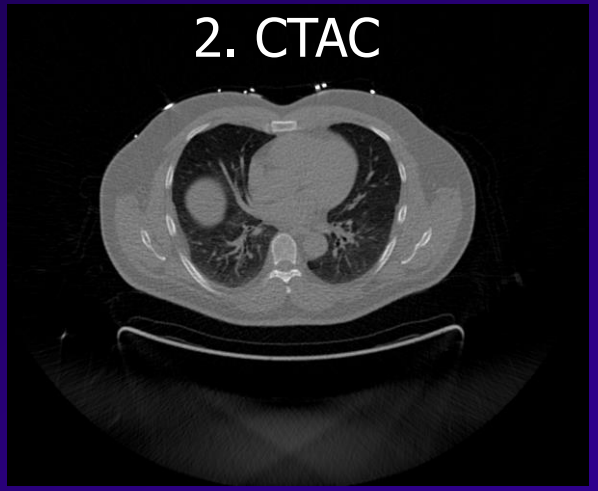

CTAC

# CTAC

1. Topogram

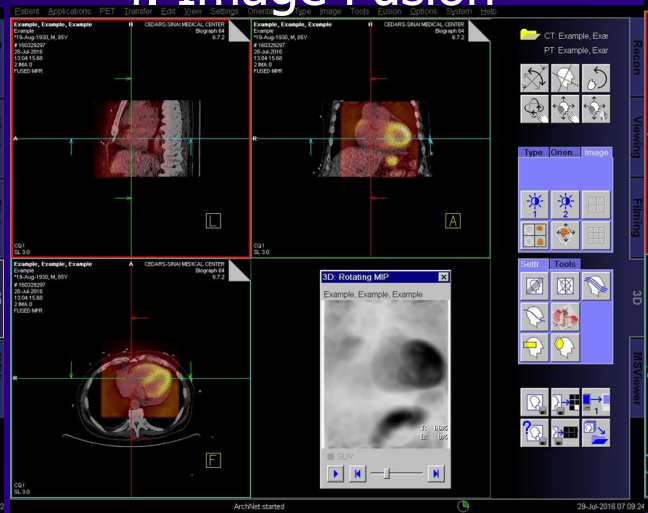


2. CTAC



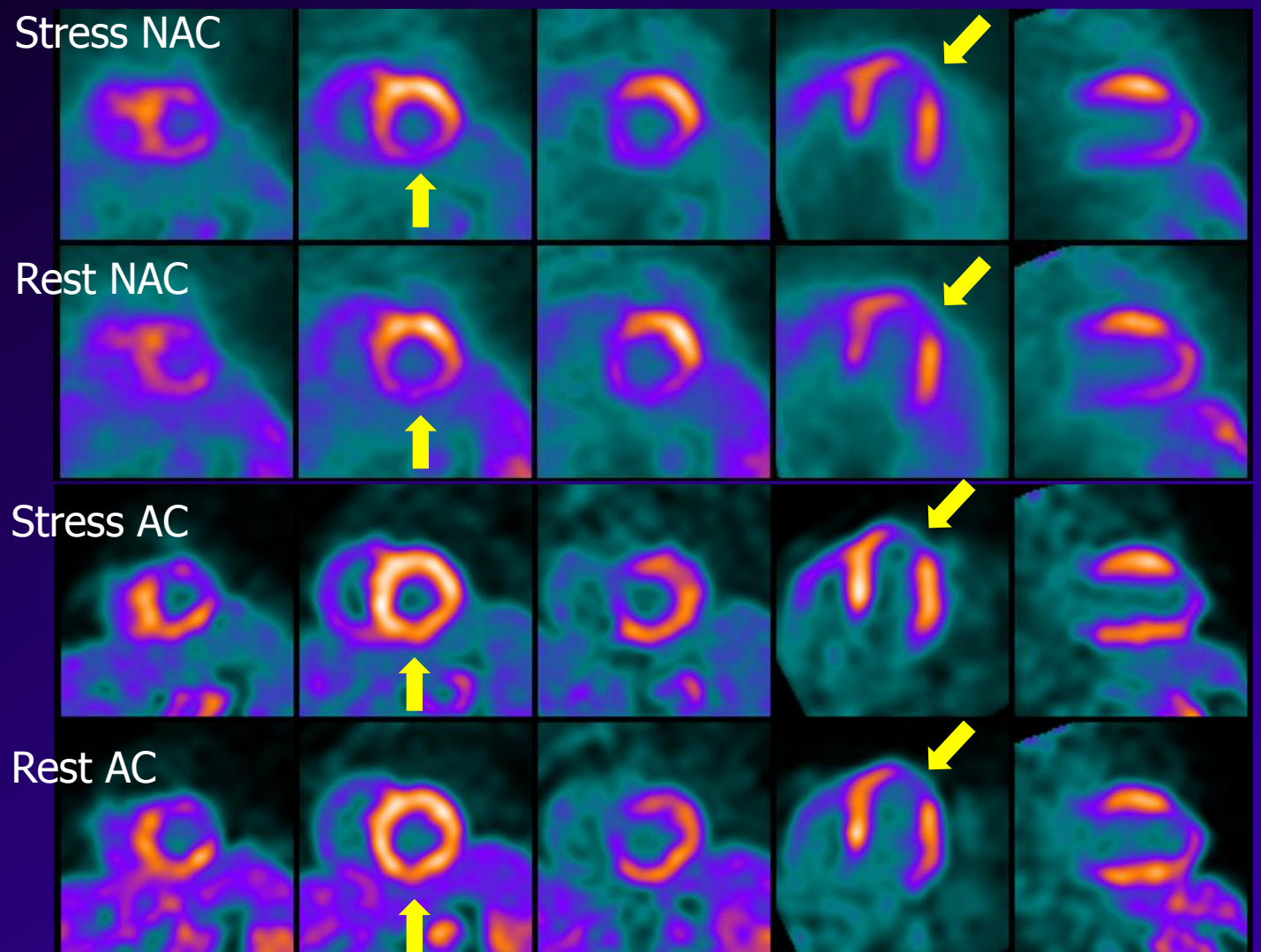
3. Image Reformat

4. Image Fusion




5. Image Registration

# Attenuation Correction



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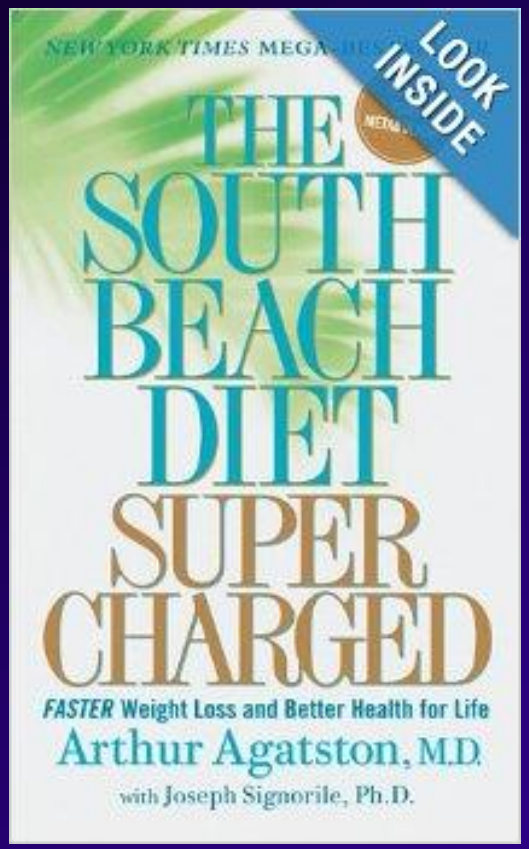
# Coronary Artery Calcification (CAC)

*If we can see it*

*We can measure it…*

# Agatston and Janowitz… AJ score





**Originally published:** 2003

# CAC Score Scale

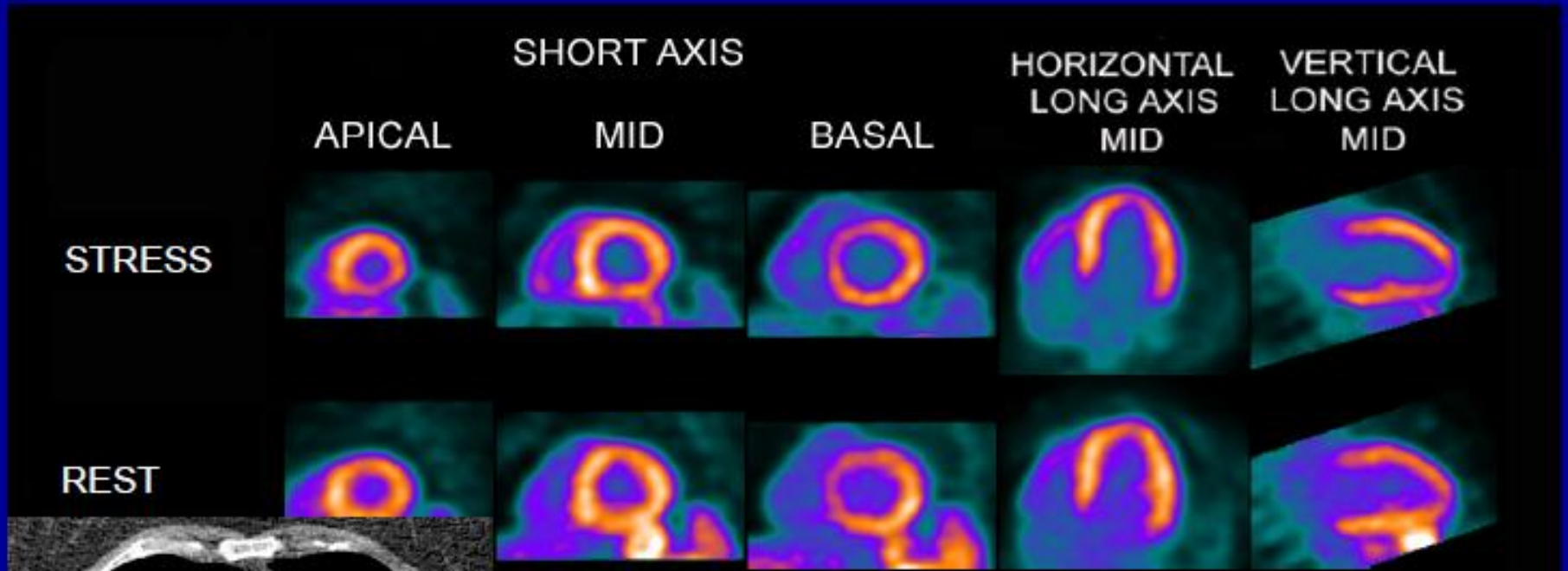
| Score | Category |
|---|---|
| 0 | None/Normal |
| 1 – 10 | Minimal |
| 11 – 100 | Mild |
| 101 – 400 | Moderate |
| 401 – 1000 | Extensive/Severe |
| > 1000 | Very Extensive/Severe |

Coronary artery calcium score directly correlates with risk of events and likelihood of obstructive CAD

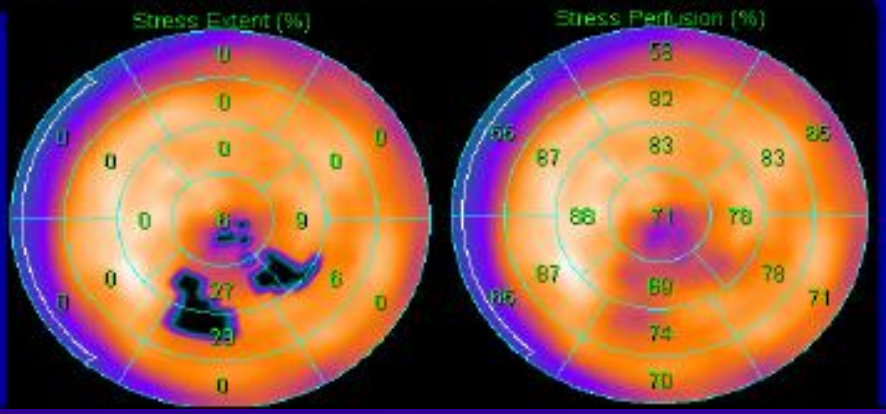
# 5 USES OF CAC Scan (CCS)

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

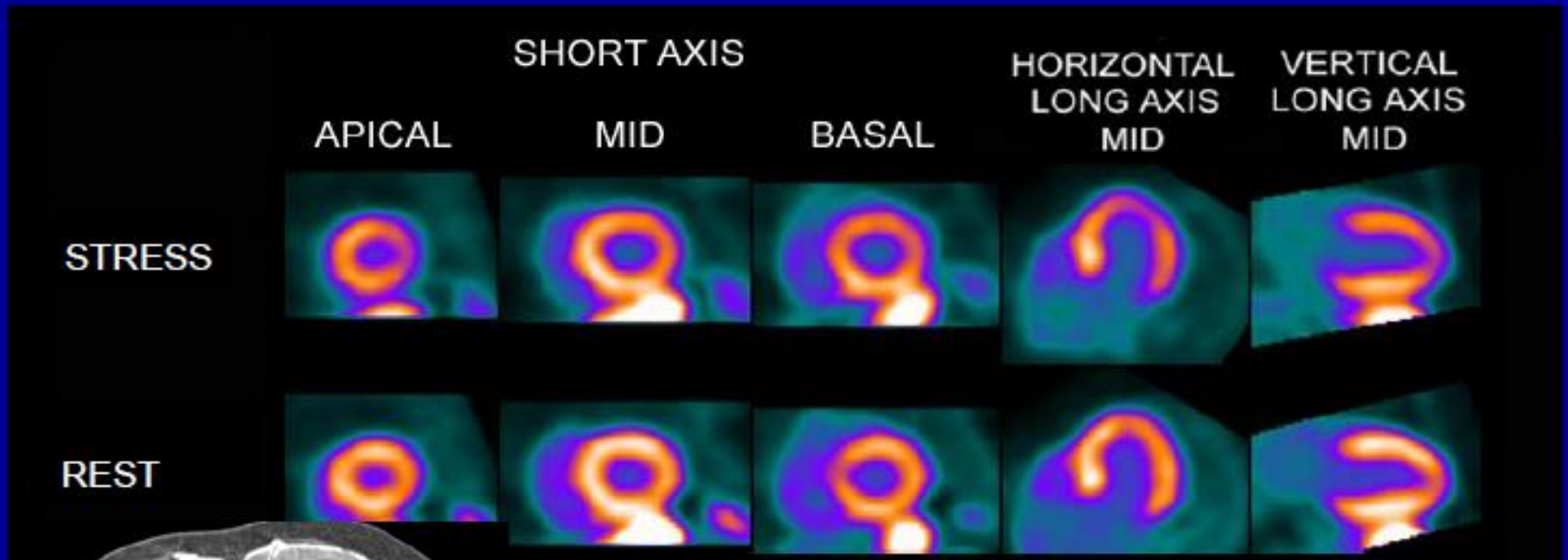
# FO 60 M ATA, HF, no walk adeno, normal ST response



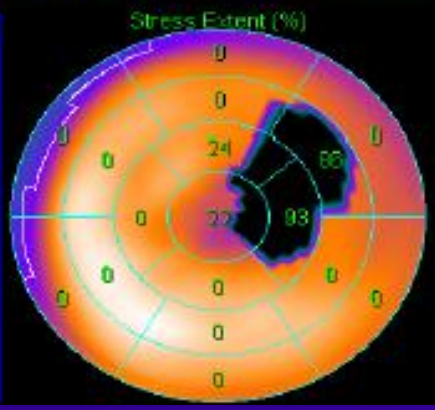

CAC 0

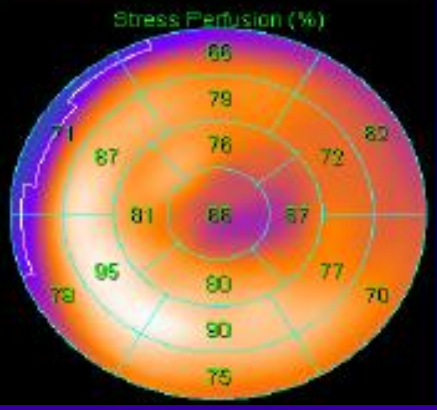


# RJ 75 F ATA, DM, no walk adeno/ normal ST response

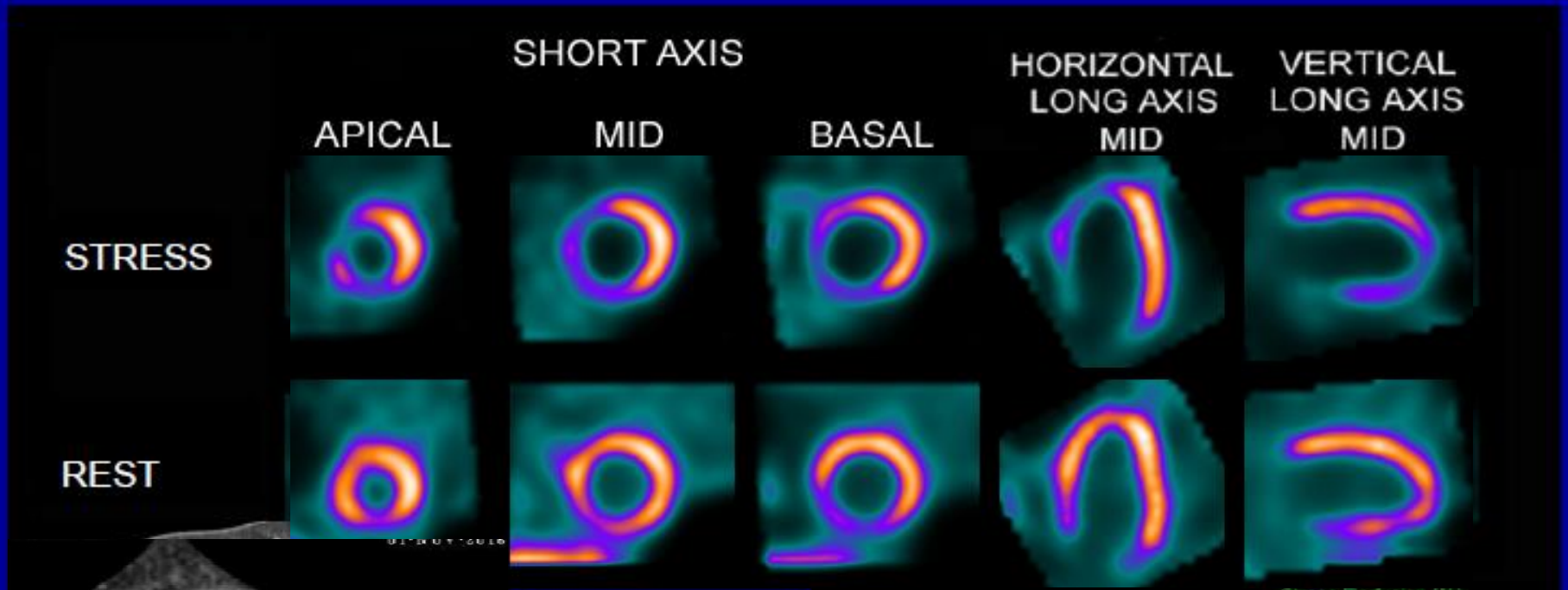



CAC 1463
(97th %)



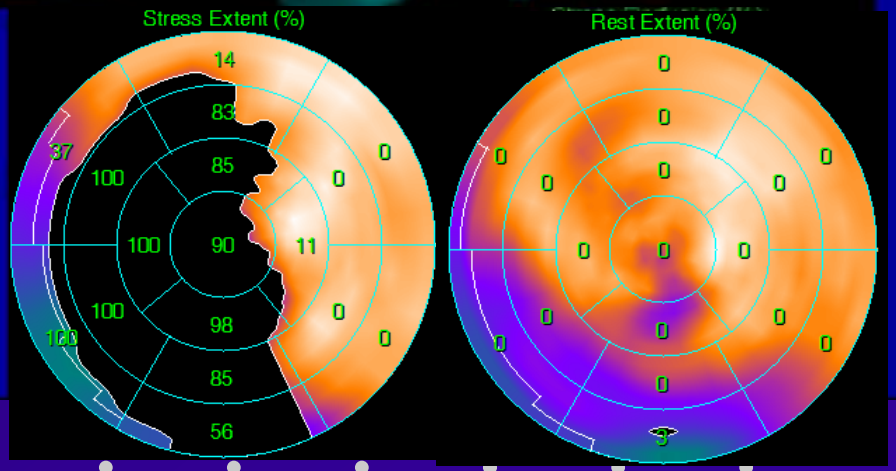



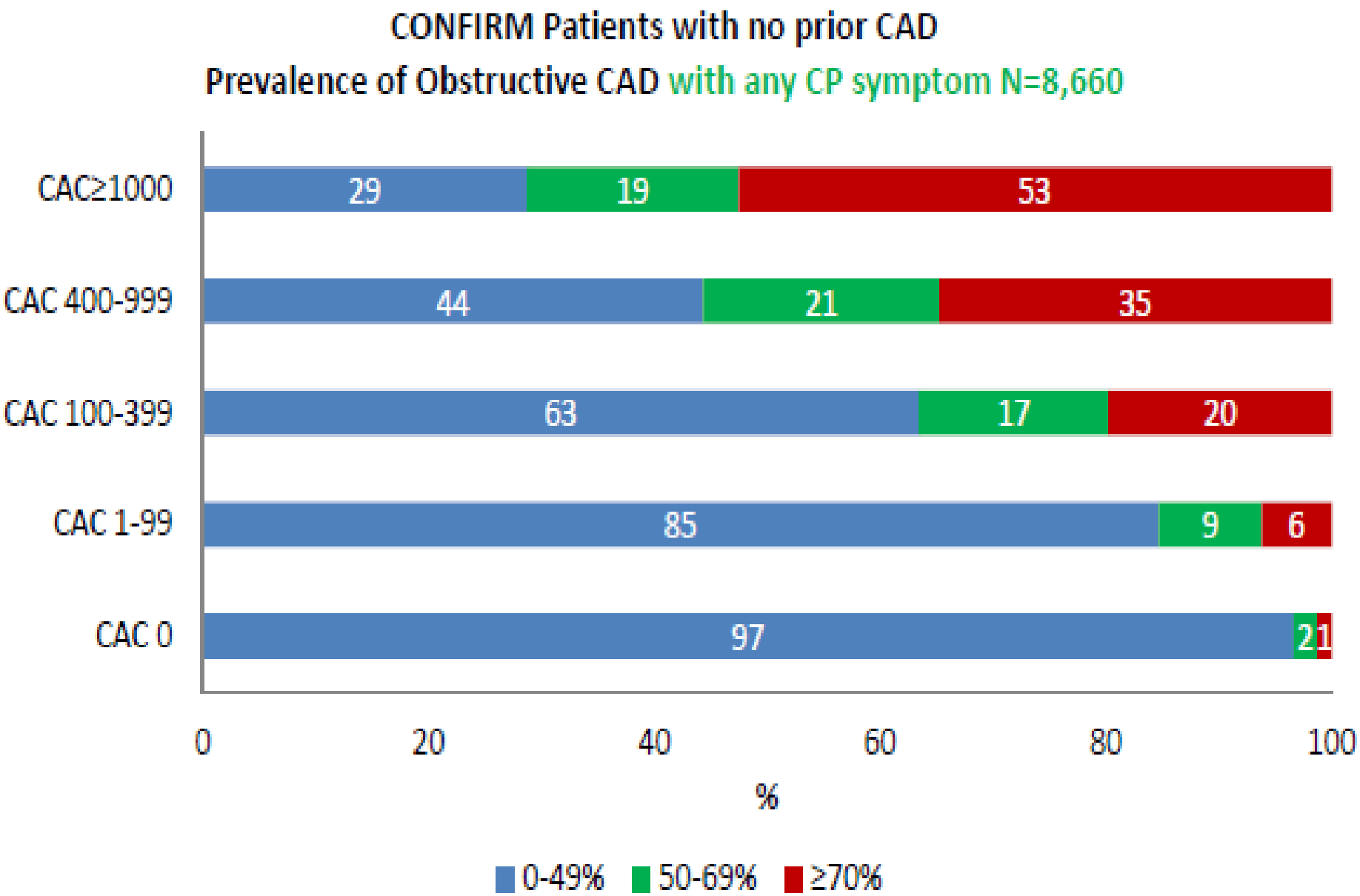
# BB 62 M AS, HLD, 13.5 min EX, 95% MPHR, ST dep





CAC 682
(89th %)






CONFIRM, unpublished, 2016

# Coronary Calcium Scan (CCS)

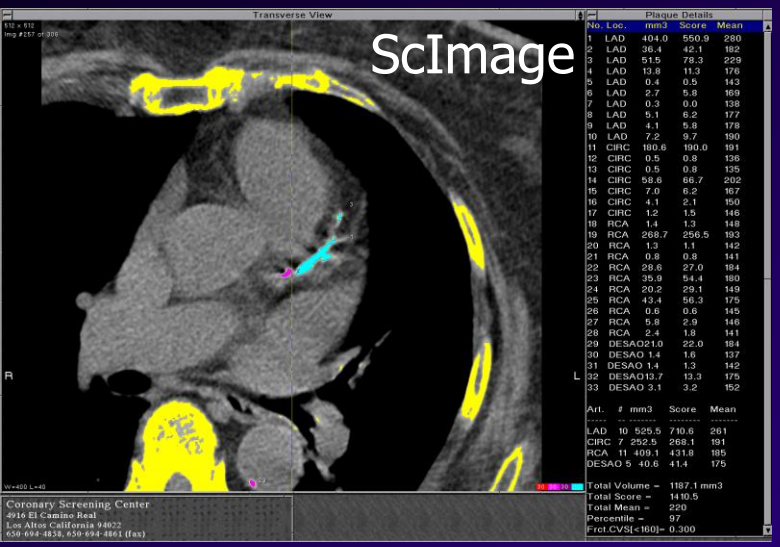
## *Acquisition*

- 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

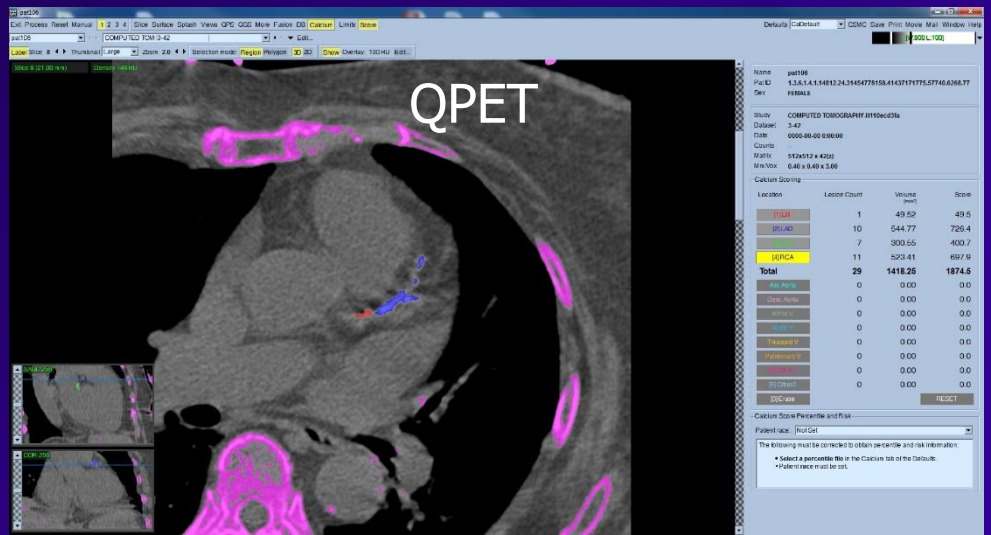
## *CT CAC Quantification*

- Density of calcification: >130 HU
- Measurement of area: >1 $mm^3$

# Calcium Scoring Software







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


Mark C. Hyun, Frances Wang, Heidi Gransar, Norman Gellada, Serge D. Van Kriekinge, Piotr Slomka, Damini Dey, Parker Waechter, Sean W. Hayes, Louise E.J. Thomson, John D. Friedman, Daniel S. Berman.

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

CS Cedars-Sinai Medical Center.



## BACKGROUND

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

## METHODS

- We studied 94 consecutive p CAC scanning (age of 67.9±11. a 64-slice cardiac PET/CT syste source 128 slice CT scanner were analyzed using all three s
- Regression analyses were us the strength of the correlation plots were used to assess bias
- The distribution of the CAC standard CAC categories was none; 1-9, minimal; 10-99 moderate; ≥400, severe). (Figu

## RESULTS

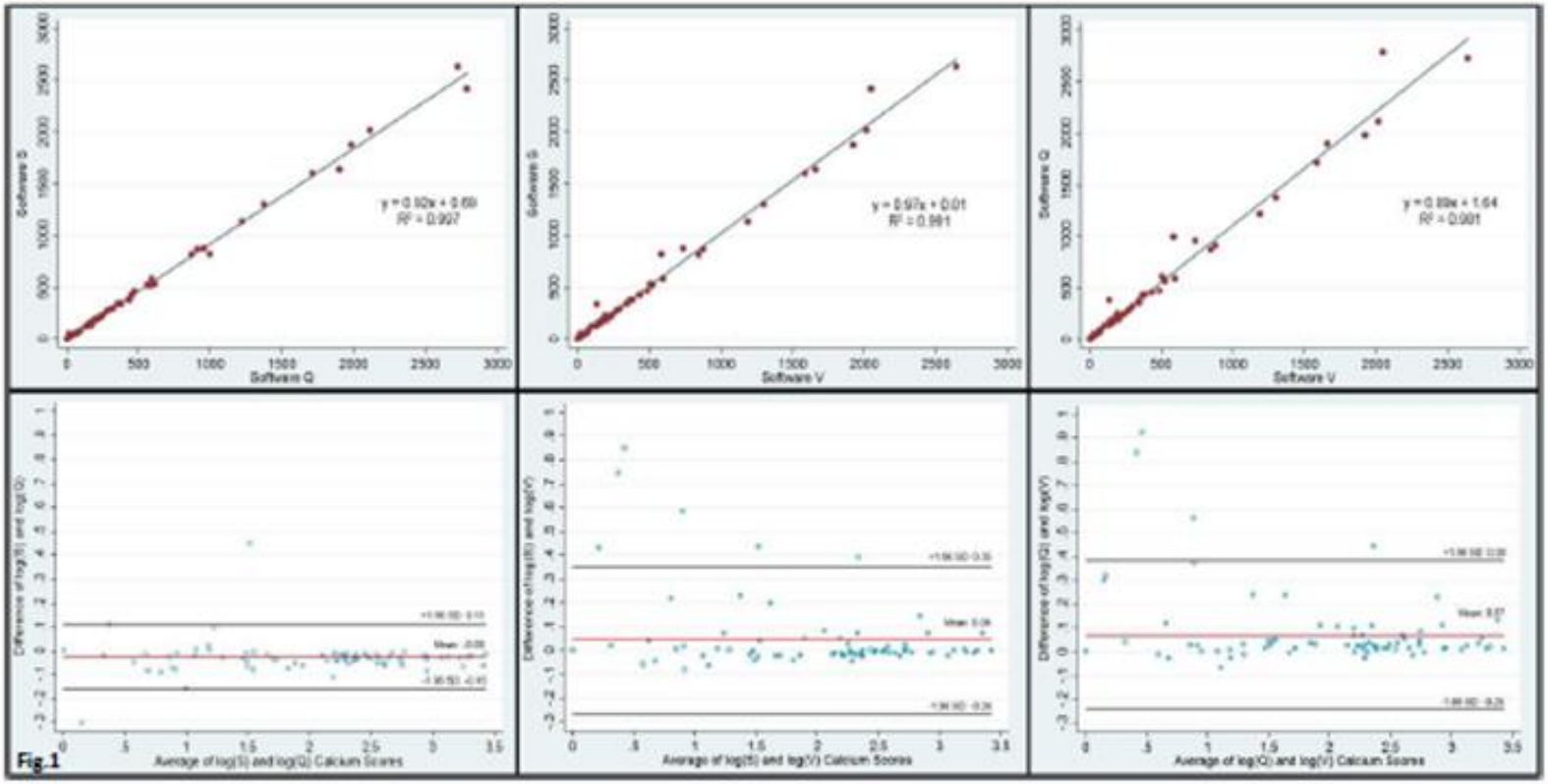



Fig 1

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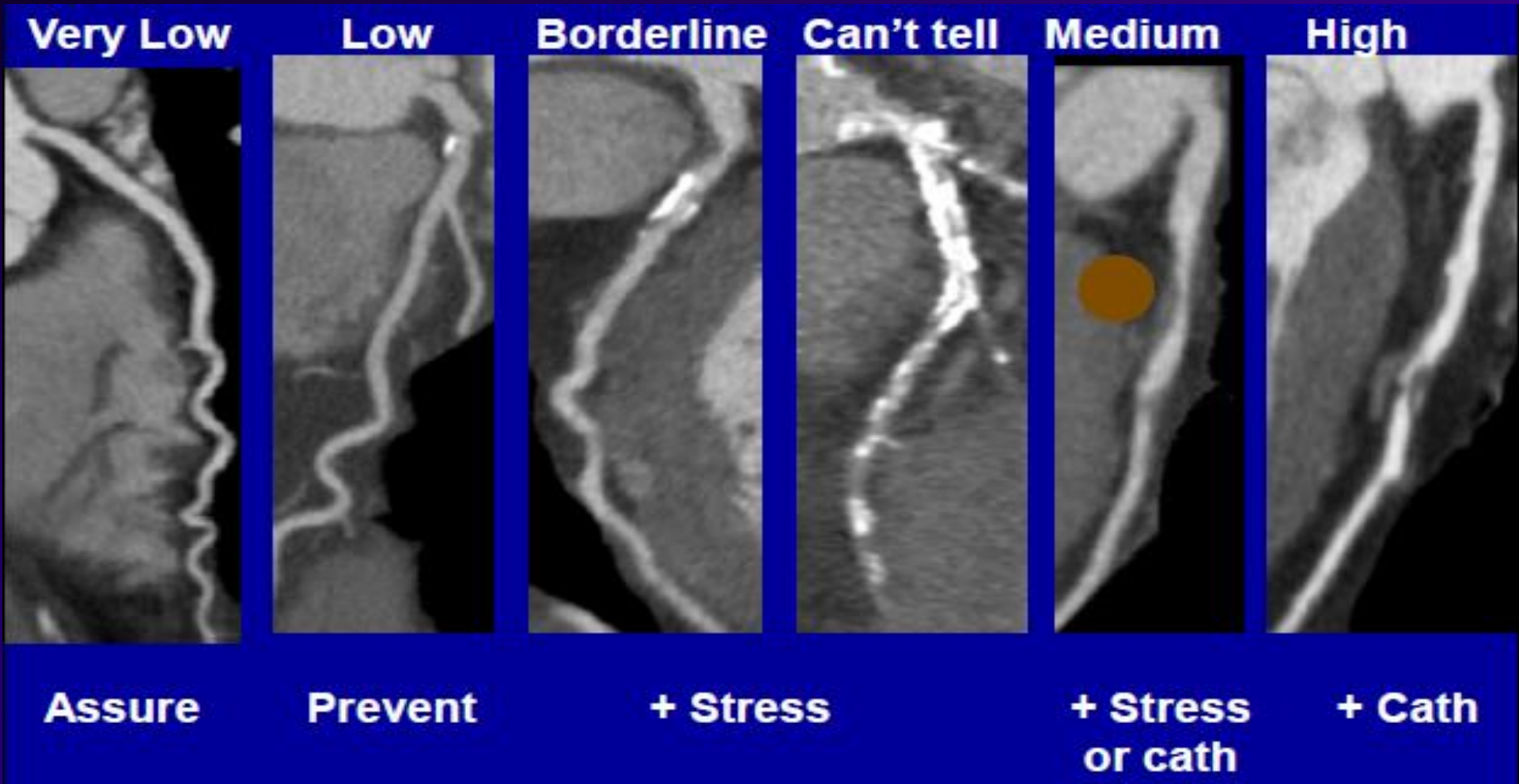
# Coronary CT Angiography


- Sensitivity & Specificity: ~ 95% / 90%
- Higher than all other modalities
- Very unlikely to miss high risk disease

# Coronary CT Angiography

Level of Risk



# Coronary CT Angiography

*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

# Coronary CT Angiography

*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:

| | | |
|---|---|---|
| A. | Prednisone: | 50 mg. PO at 13 hours prior to exam |
| B. | Prednisone: | 50 mg. PO at 7 hours prior to exam |
| C. | Prednisone: | 50 mg. PO at 1 hour prior to exam |
| D. | Diphenhydramine: | 50 mg. PO in Imaging, approximately 30 minutes prior to exam |

IV Protocol:

| | | |
|---|---|---|
| A. | Hydrocortisone: | 200 mg. IV at 13 hours prior to exam |
| B. | Hydrocortisone: | 200 mg. IV at 7 hours prior to exam |
| C. | Hydrocortisone: | 200 mg. IV at 1 hour prior to exam |
| D. | Diphenhydramine: | 50 mg. IV in Imaging, approximately 30 minutes prior to exam |

# 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*

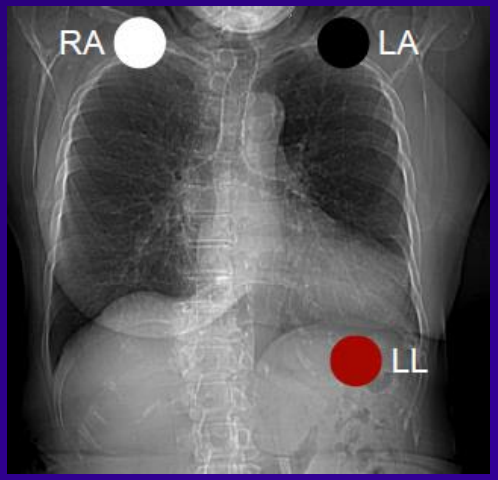
- Clinical History
- Scheduling & Screening
- Education & Consent
- Monitoring of Vital Signs (HR & BP)
- Management of Medical Devices
- Lab Values (Renal Function)
- Medication & Dosage

# 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

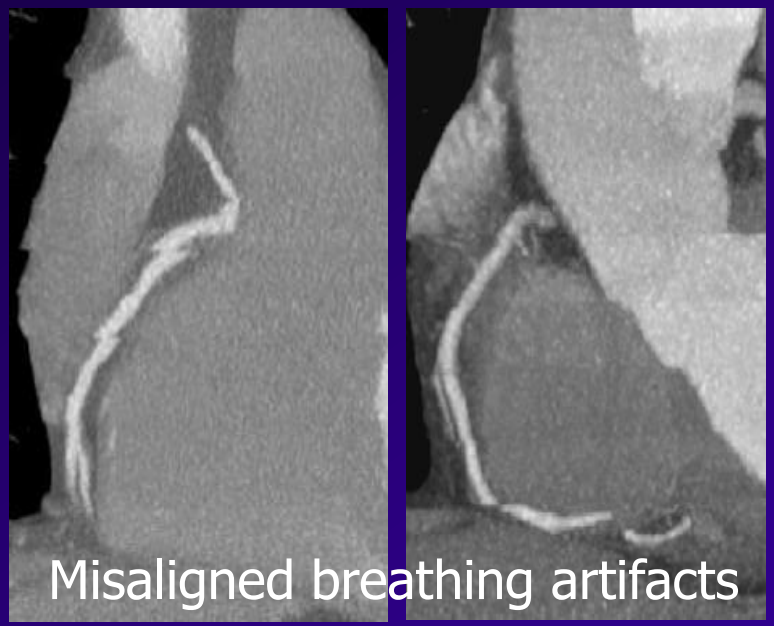
- No caffeine x 12 hrs prior to CCTA
- NPO x 4 hrs prior to CCTA
- No cardiovascular activity prior to CCTA
- Patient education to minimize anxiety
  - Holding breath & motion
  - Contrast effects
  - Beta-blockers & NTG

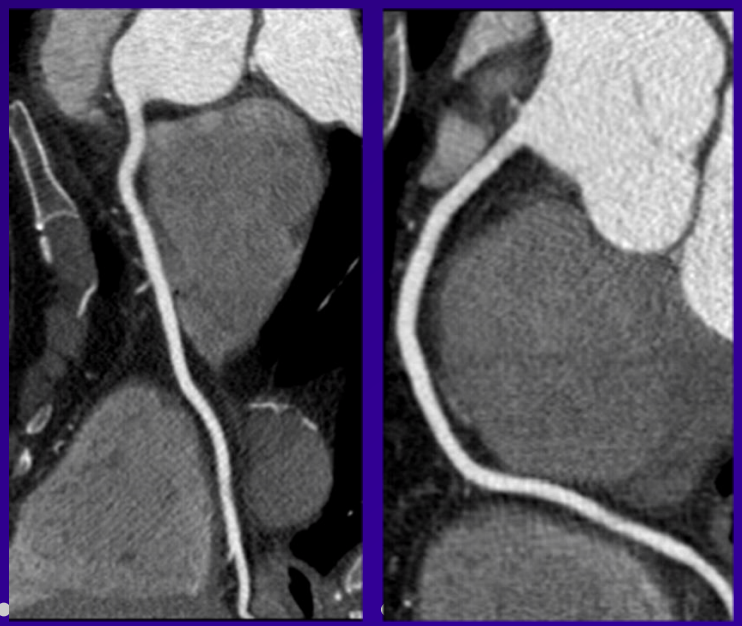



- ECG placement
- IV access
  - Antecubital vein, 18g IV angiocath
  - Injection rate of ≥5 cc/sec

# Breathing

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



# 5 Steps to Optimal CCTA

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3. CT Setup and Contrast
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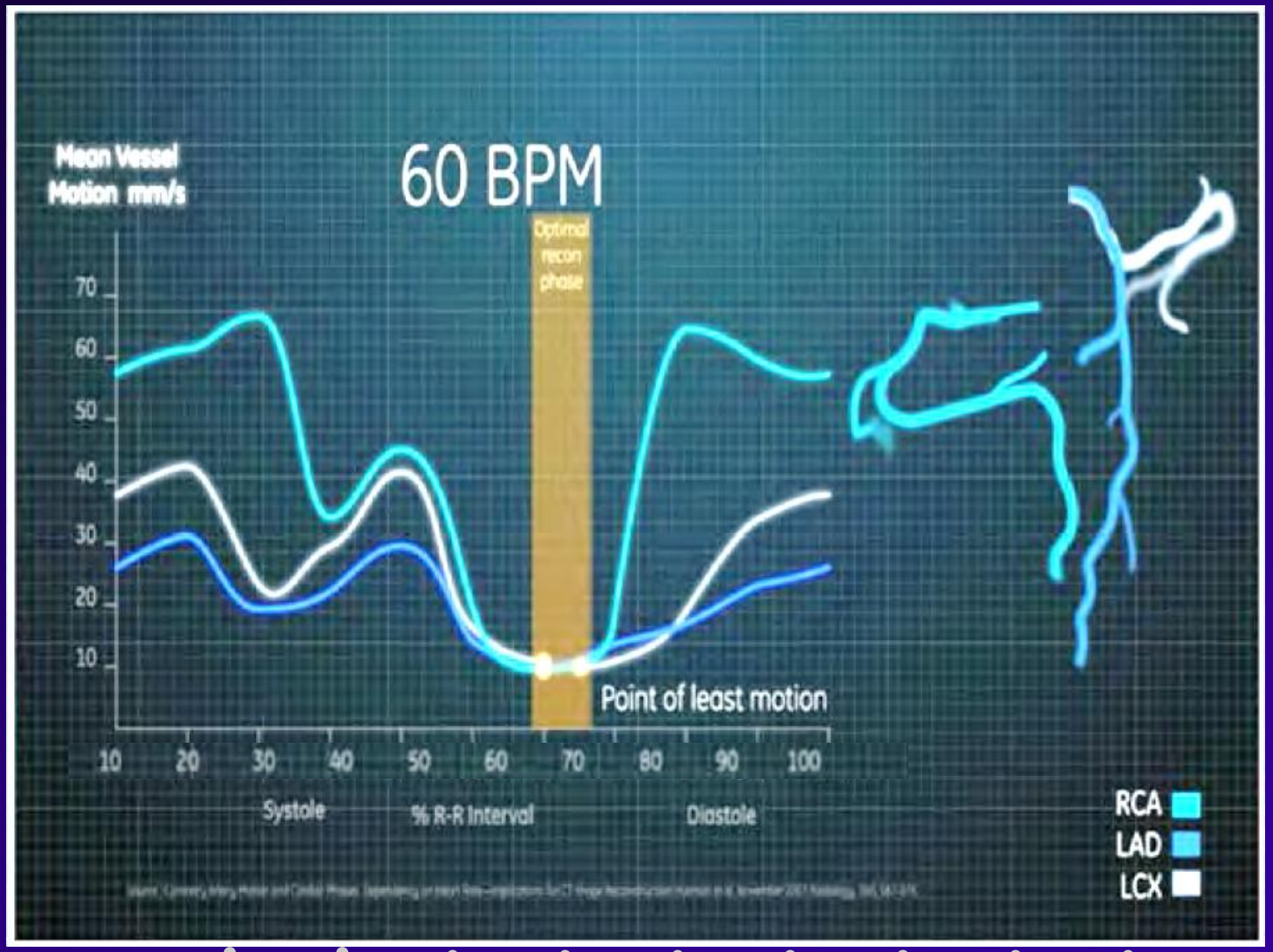
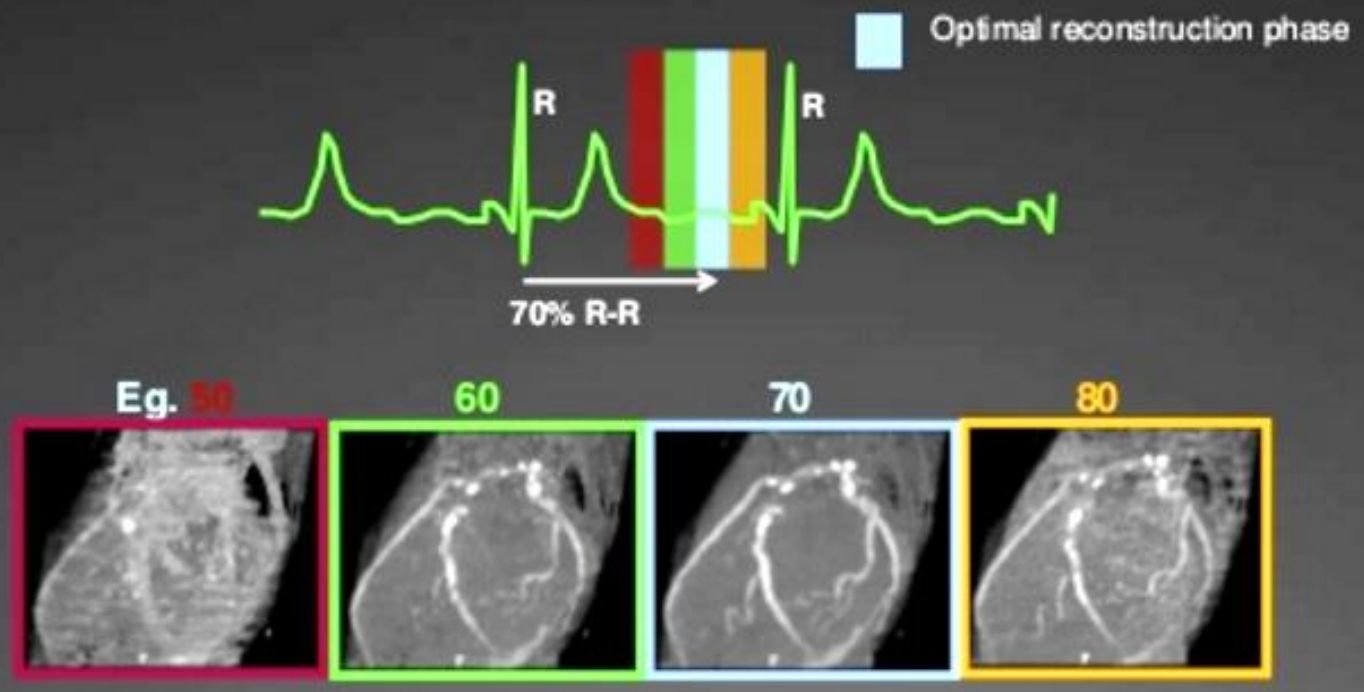
5. Reconstructions

# Heart Rate & Coronary Motion

# Cardiac CT – ECG phases

* Optimal phase for reconstruction for CTA
  * diastole @ ~ 70 %



# Oral Beta-Blocker Protocol

**Metoprolol Administration**

| YES | NO | | |
|---|---|---|---|
| ☐ | ☑ | Iodinated Contrast Contraindications | |
| ☐ | ☑ | Previous hypersensitivity to beta blocker | |
| ☐ | ☑ | Asthma / Uses Inhaler | If yes: How often? _____ |
| ☐ | ☑ | Takes Diltiazem | If yes: Last time taken and dosage? _____ |
| ☐ | ☑ | Takes Beta Blocker | If yes: Last time taken and dosage? _____ |
| ☐ | ☑ | Abnormal ECG *(e.g. 2nd or 3rd degree heart block)* | |
| ☐ | ☑ | Aortic Stenosis | |
| ☐ | ☑ | Congestive Heart Failure | |
| ☐ | ☑ | HR < 60 bpm | |
| ☐ | ☑ | SBP < 100 mm Hg | |

***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

IV Metoprolol (MD / NP only) Pre IV Metoprolol HR ____ BP _____

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

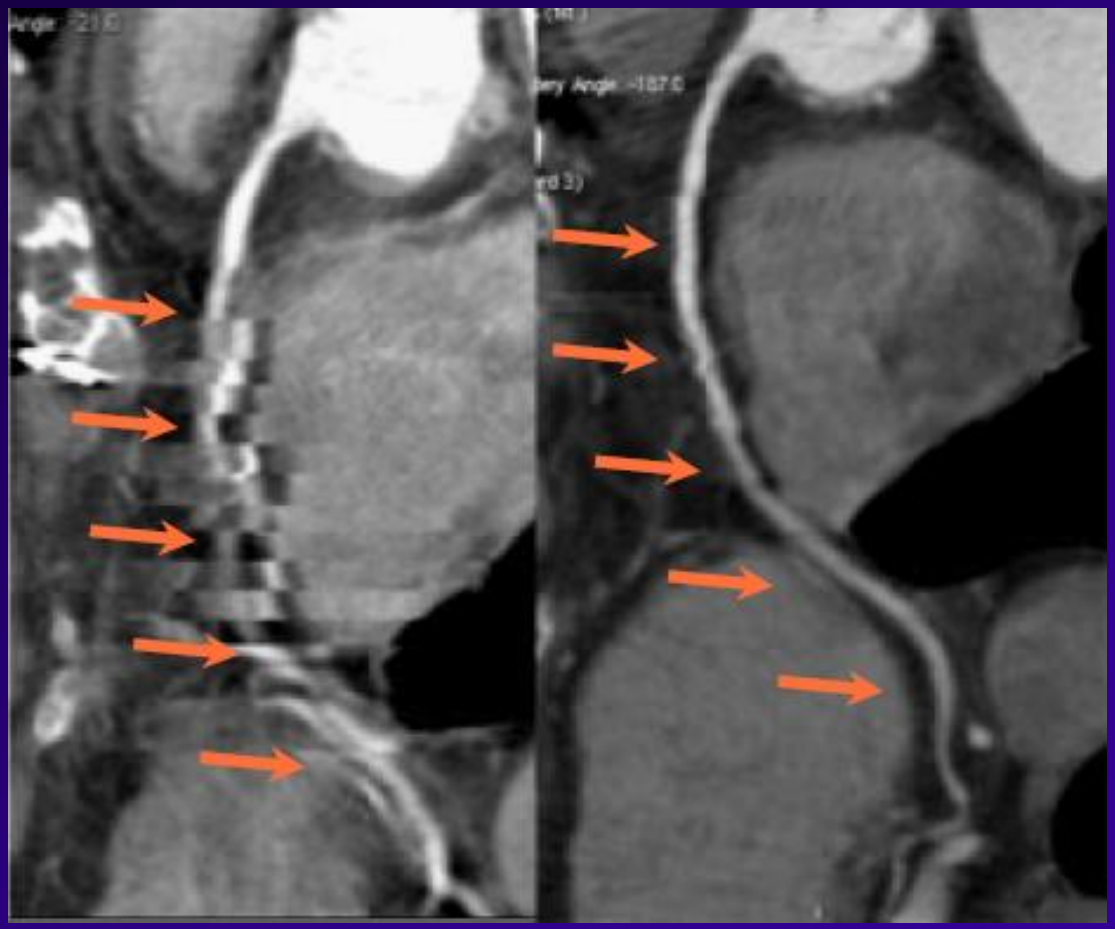
1. 5 mg Metoprolol IV HR ____ BP _____
2. 5 mg Metoprolol IV HR ____ BP _____
3. 5 mg Metoprolol IV HR ____ BP _____
4. 5 mg Metoprolol IV HR ____ BP _____
5. 5 mg Metoprolol IV HR ____ BP _____
6. 5 mg Metoprolol IV HR ____ BP _____
7. 5 mg Metoprolol IV HR ____ BP _____
8. 5 mg Metoprolol IV HR ____ BP _____
9. 5 mg Metoprolol IV HR ____ BP _____
10. 5 mg Metoprolol IV HR ____ BP _____

**Total Amount IV Metoprolol given ____ mg Time: _____**

**Administered by: _____ MD / NP**

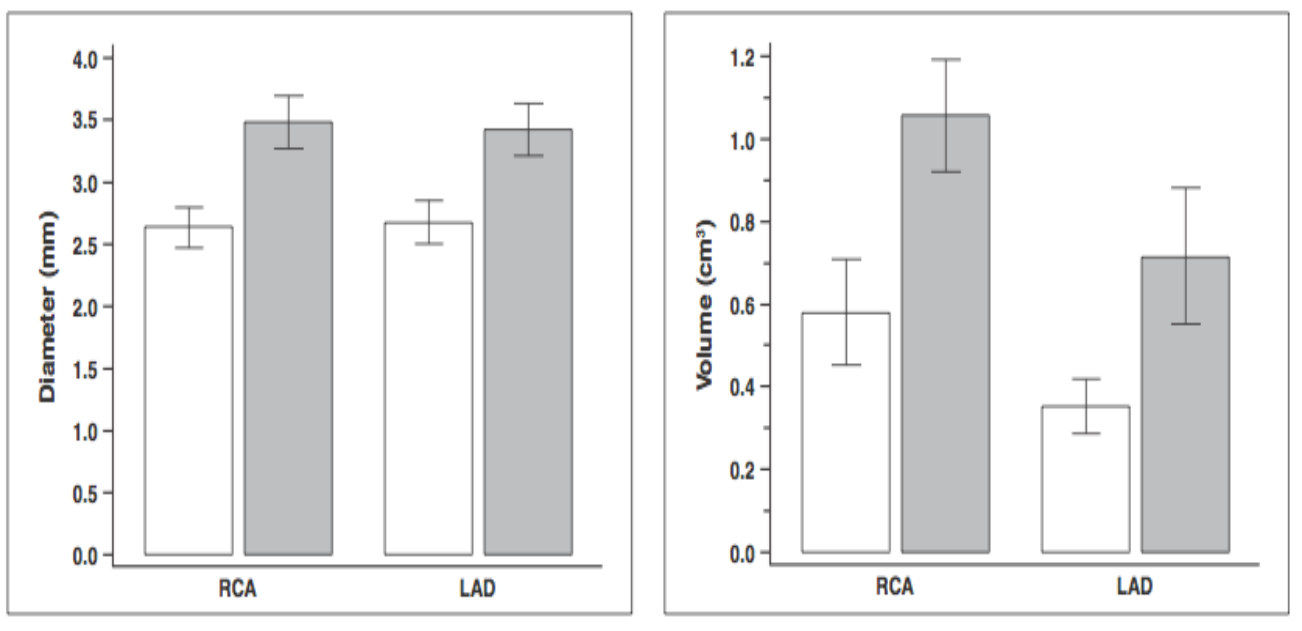
# Use of Beta Blockers in CCTA

Not used: HR 84 Used: HR 56



# Use of Nitroglycerin in CCTA






Decramer, AJR 2008

42 patients randomized to NTG or no NTG

# Nitroglycerin Protocol

**Nitroglycerin Administration**

| YES | NO | |
|---|---|---|
| ☐ | ☑ | Symptomatic cardiomyopathy |
| ☐ | ☑ | Severe aortic stenosis |
| ☐ | ☑ | Takes erectile dysfunction meds. |
| | | If yes: name of med, dosage, last time taken? _____ |
| ☐ | ☑ | SBP < 100 mmHg |
| ☐ | ☑ | Patient experiencing dizziness, syncope, nausea or vomiting |

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 & Range

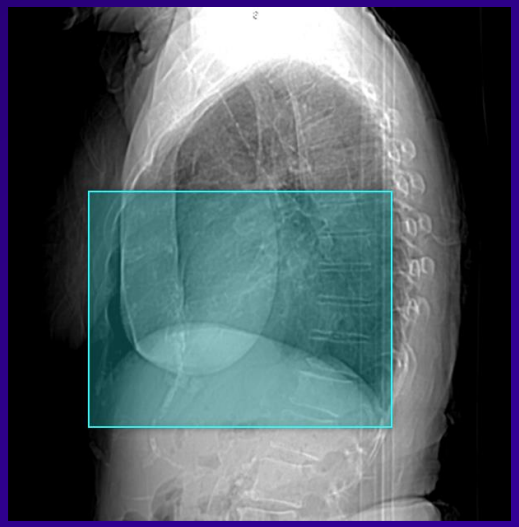
*Scan Field of View (FOV)*

- 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

AP

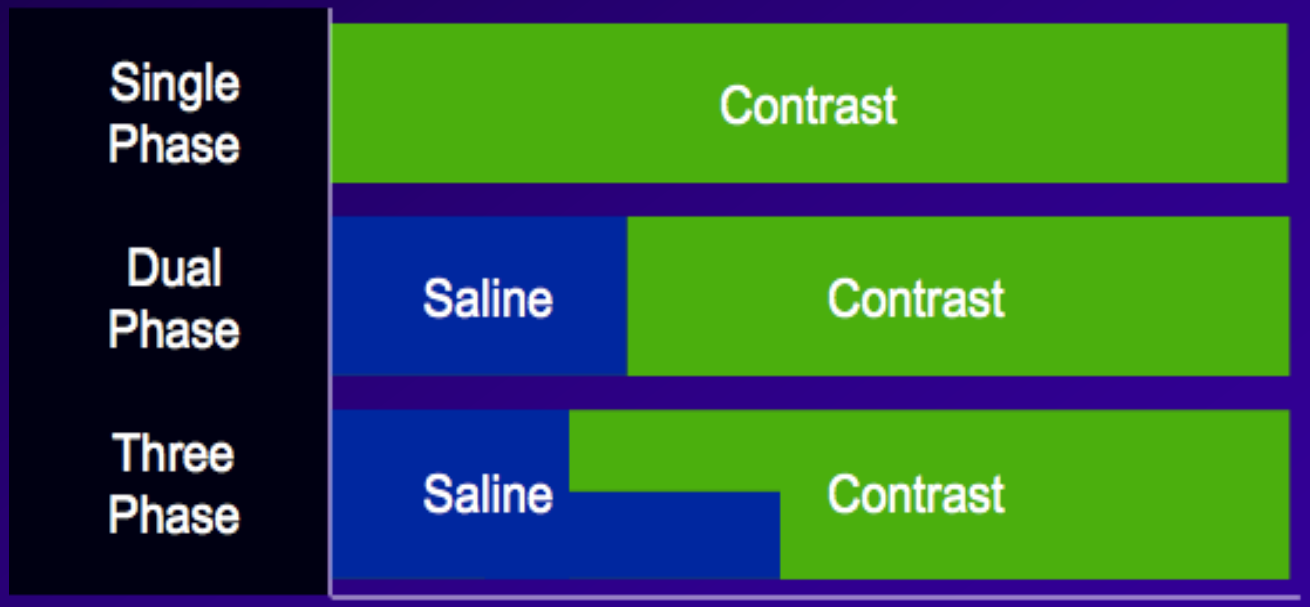


Lateral

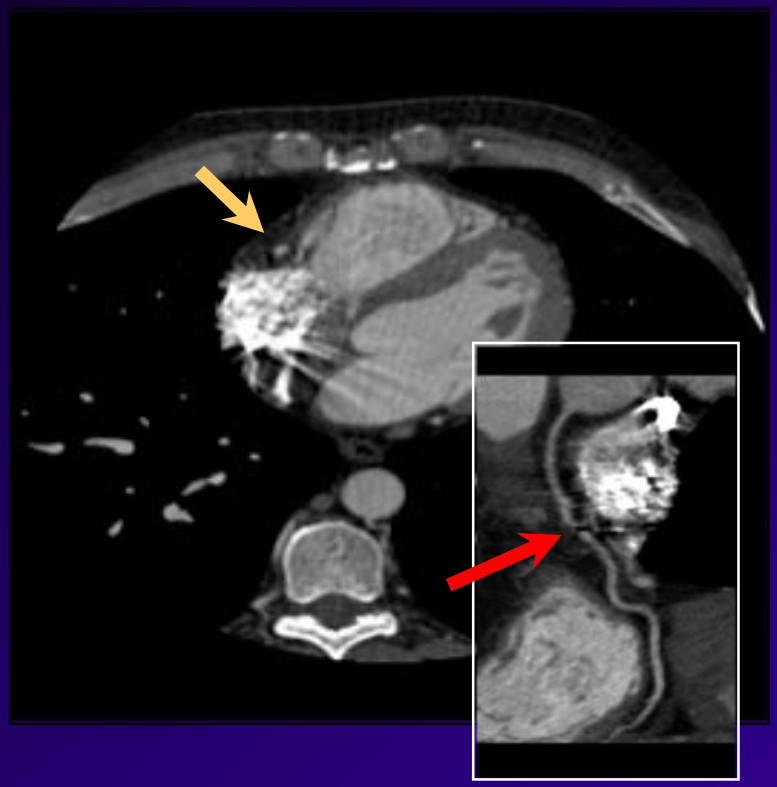
# Dual Syringe Injection System

# Contrast Protocols

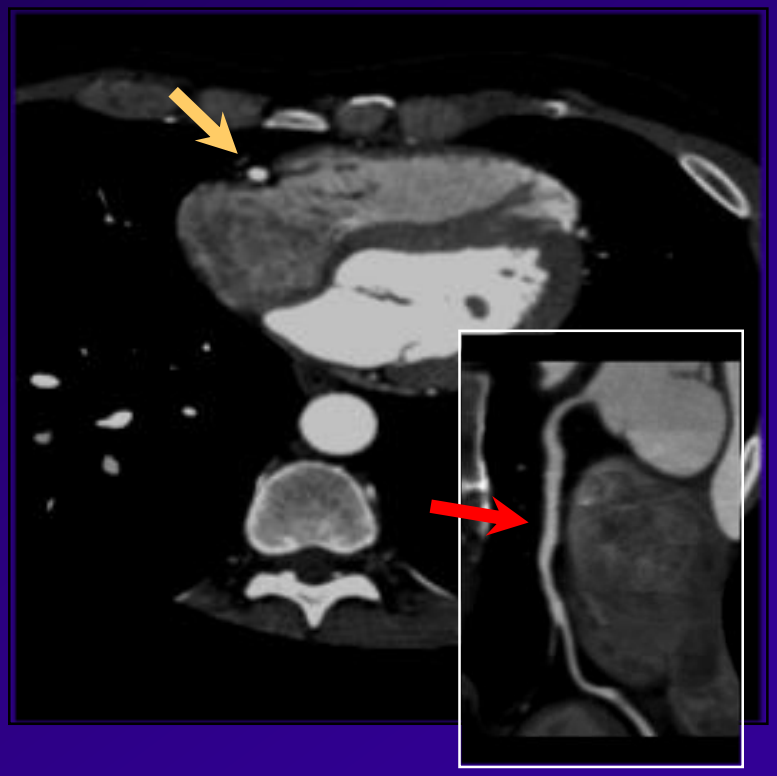
- Injection rate is important
- Dual- or triple-phase protocols generally preferable (less contrast volume, less artifact)



# Contrast Protocols



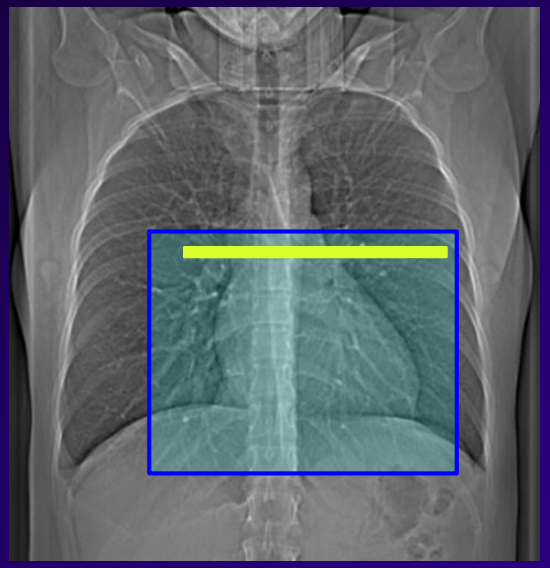
Single-Phase
Contrast Protocol

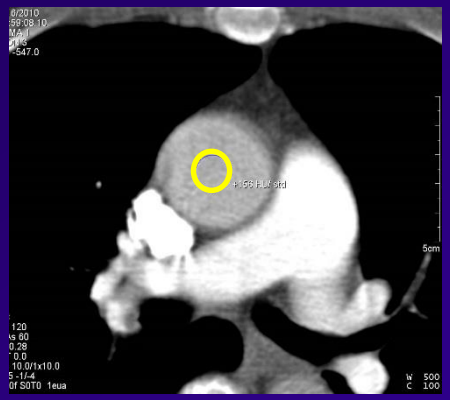


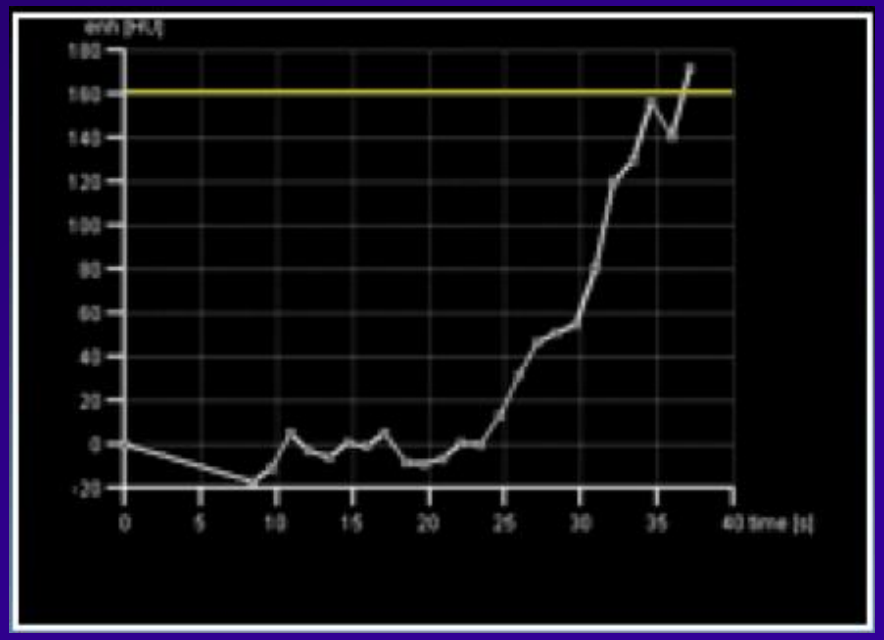
Multi-Phase
Contrast Protocol

# Bolus Tracking

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

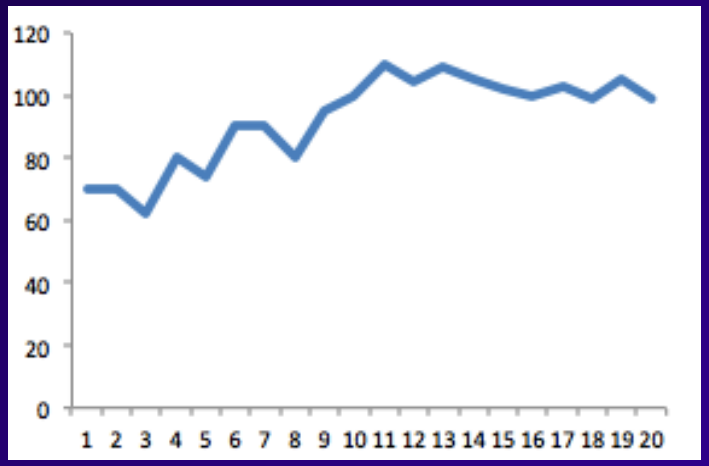




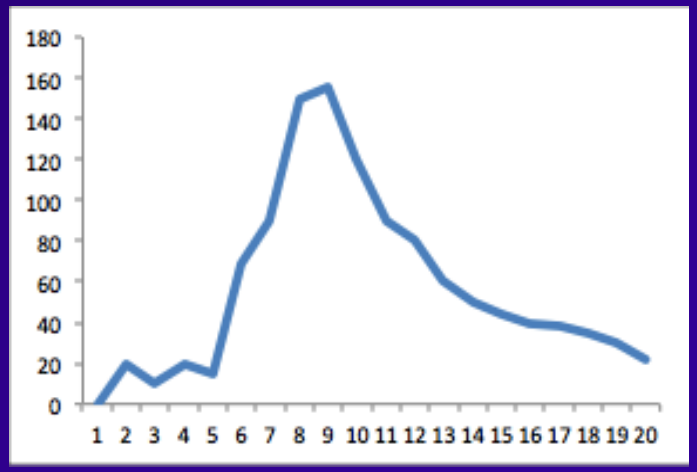


# Timing Bolus

- 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)

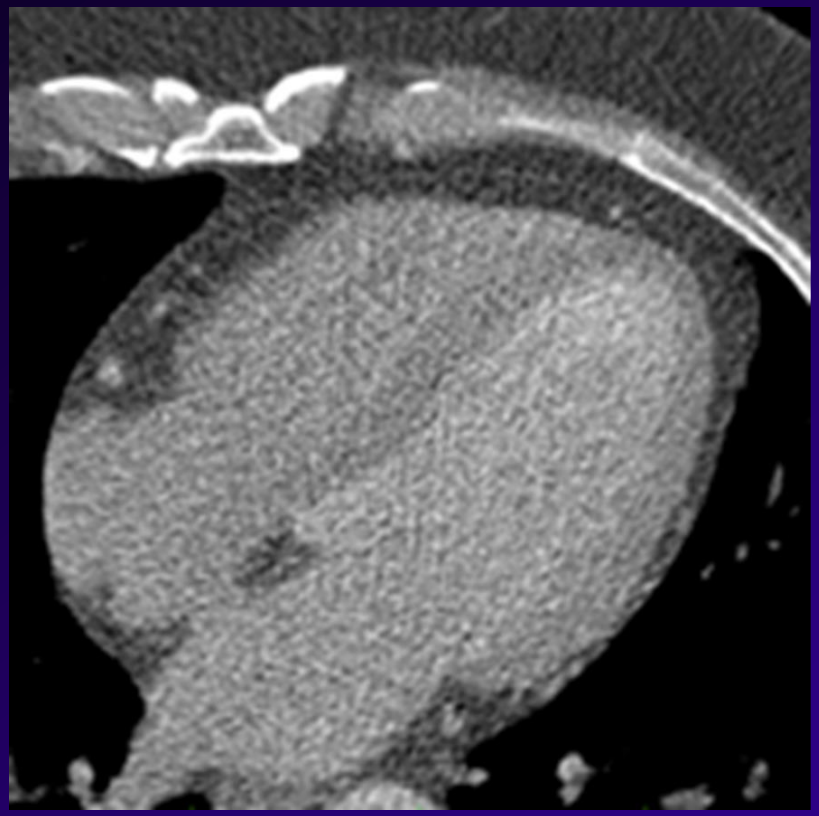



Poor Peak

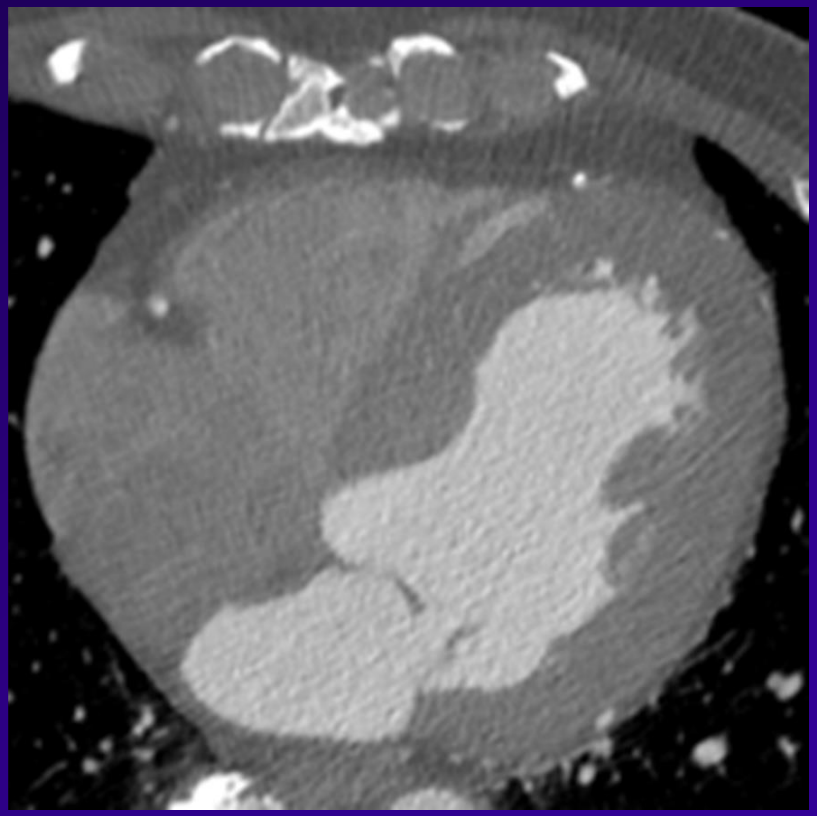



Good Peak

# Contrast Opacification



Poor Contrast



Good Contrast

# 5 Steps to Optimal CCTA

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

# Scan Mode Comparison

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

# Gating: General Principles

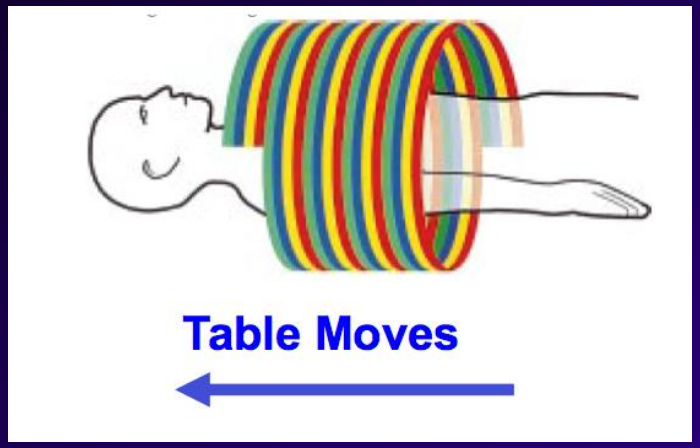
***Retrospective ECG gating best for:***

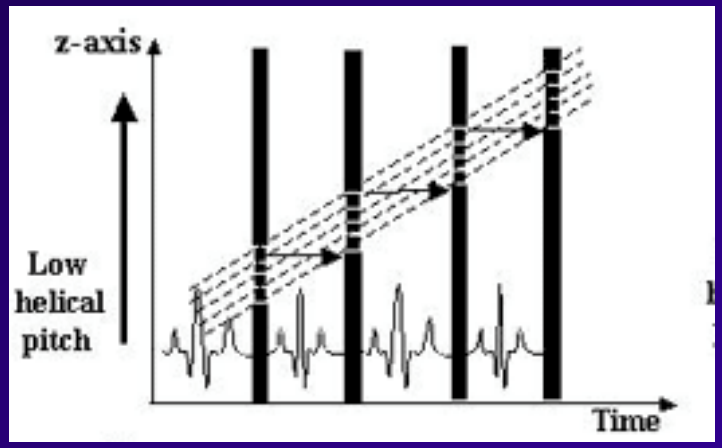
- Higher heart rate
- Irregular rhythm
- Known CAD or higher probability of CAD

***Prospective ECG gating best for:***

- Well-controlled heart rate (generally <60-65 bpm)
- Regular rhythm
- Low-probability of CAD

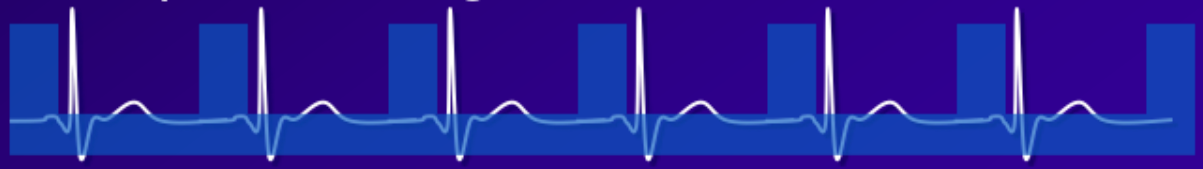
# Retrospective ECG Gating



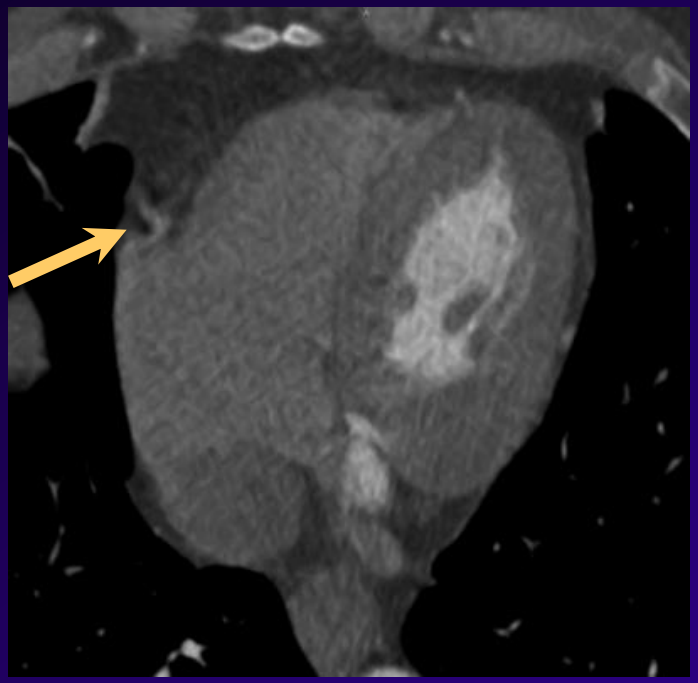

Retrospective Gating

Retrospective Gating with Dose Modulation

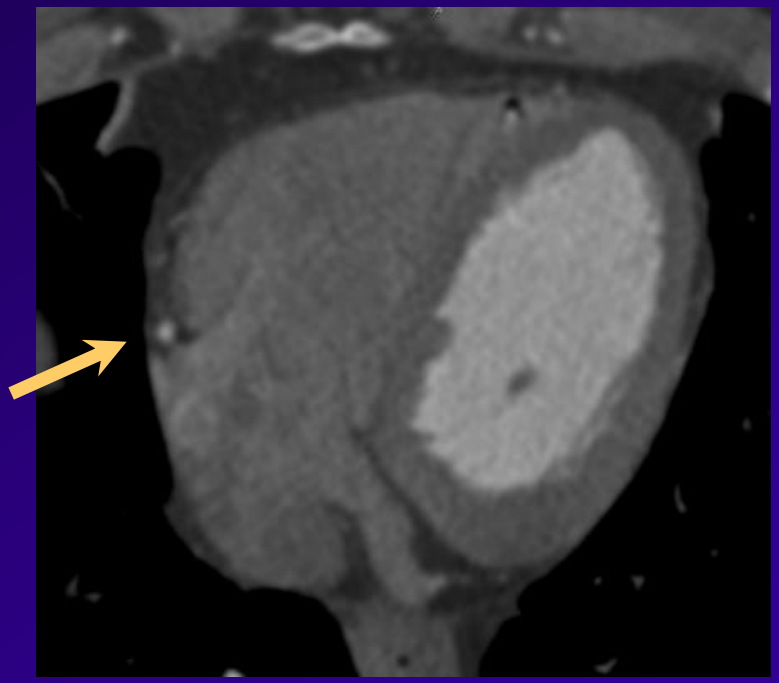


-25%

# Benefit of Additional Phases



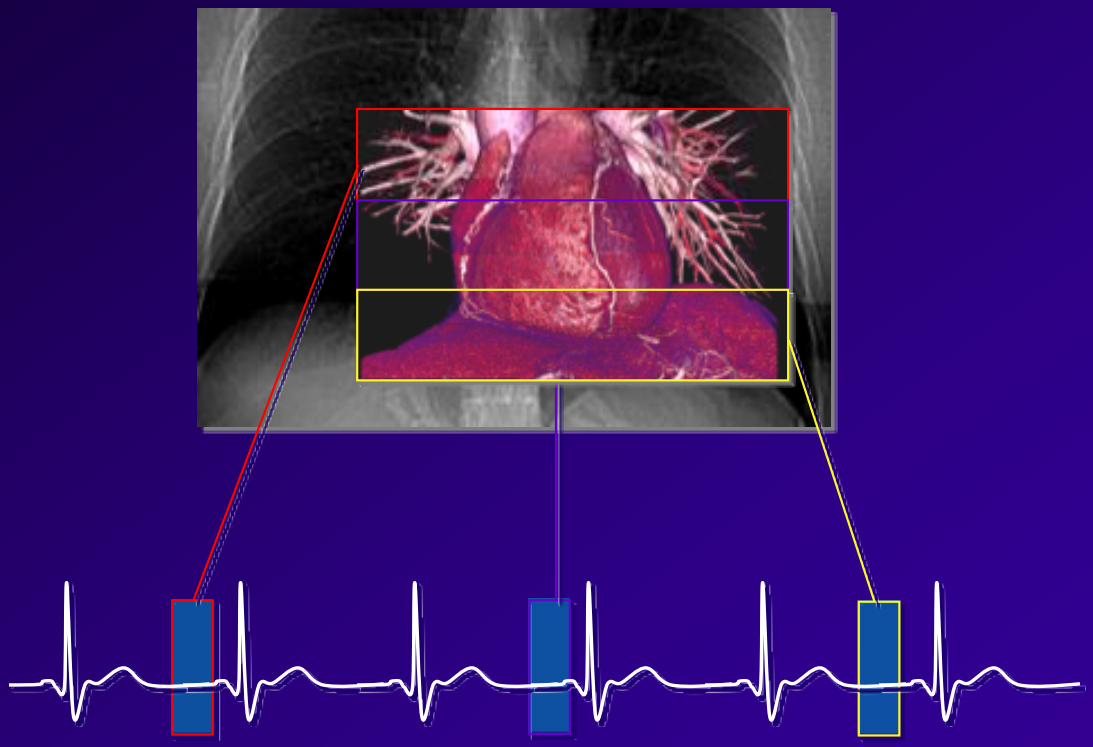
65% Phase



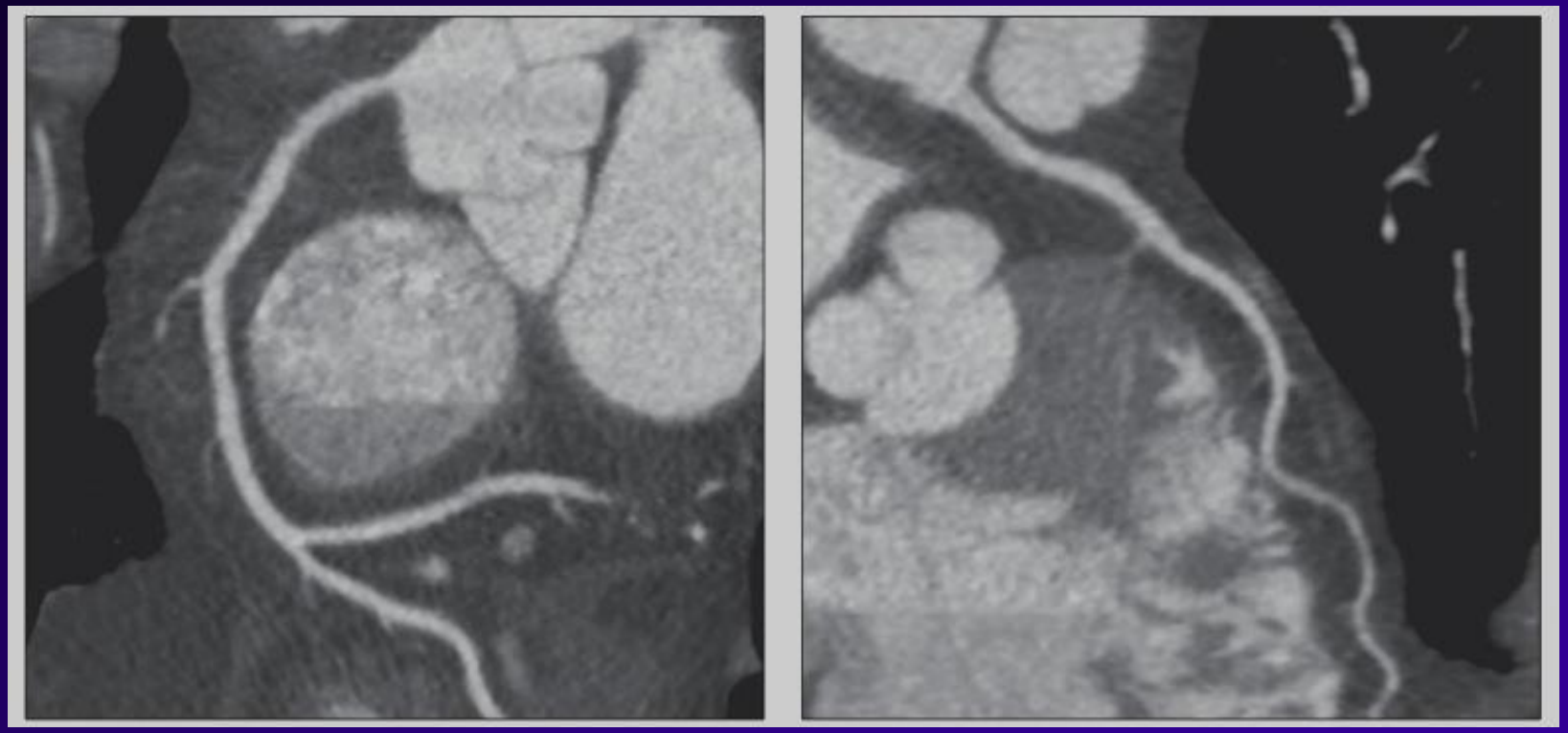
80% Phase

Having multiple phases may reduce the number of non-interpretable studies!!

# Prospective ECG Gating



# Benefit of Prospective ECG Gating

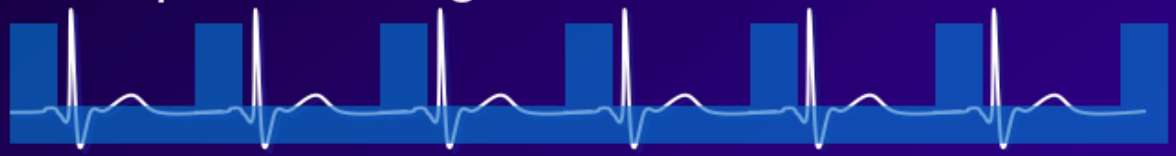


59 yo female with chest pain
Prospective ECG gating with no padding (0.64 mSv)

# Gating Methods in CCTA

Retrospective Gating

Retrospective Gating with Dose Modulation



-25%

Prospective Gating

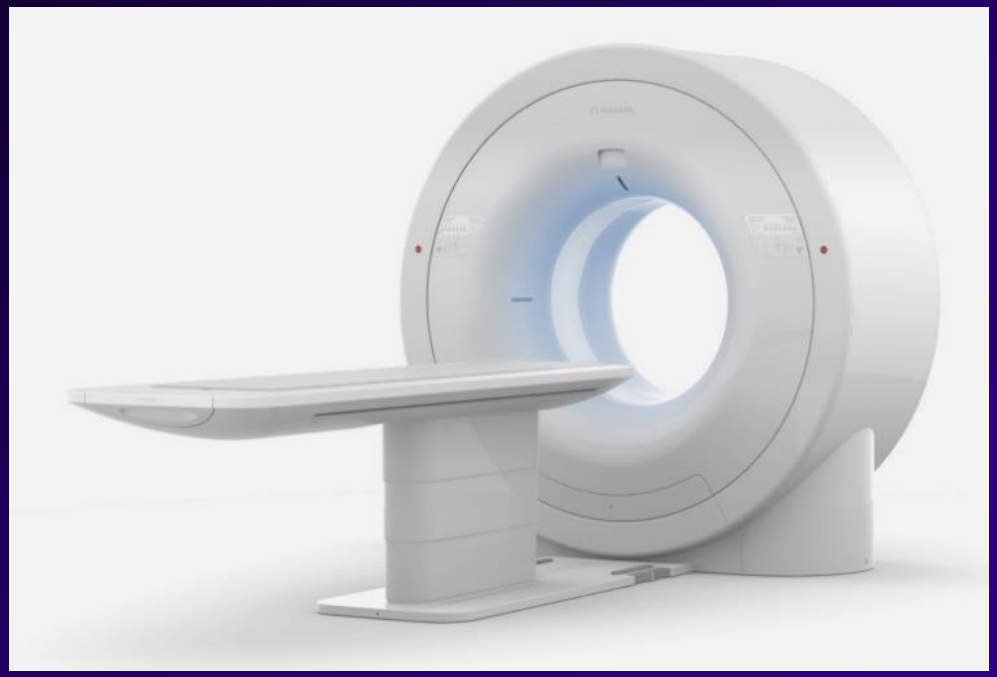
-78%

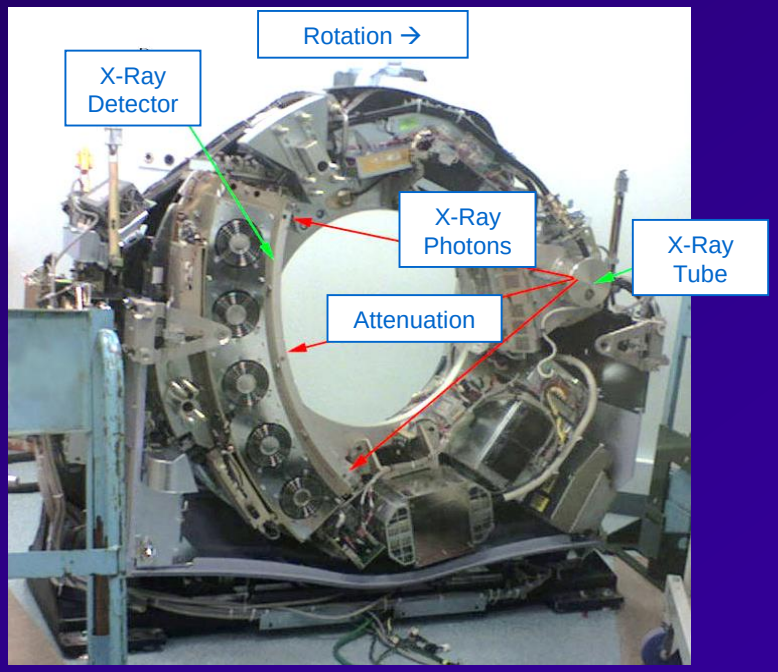
Prospective Gating with Reduced Padding

-91%

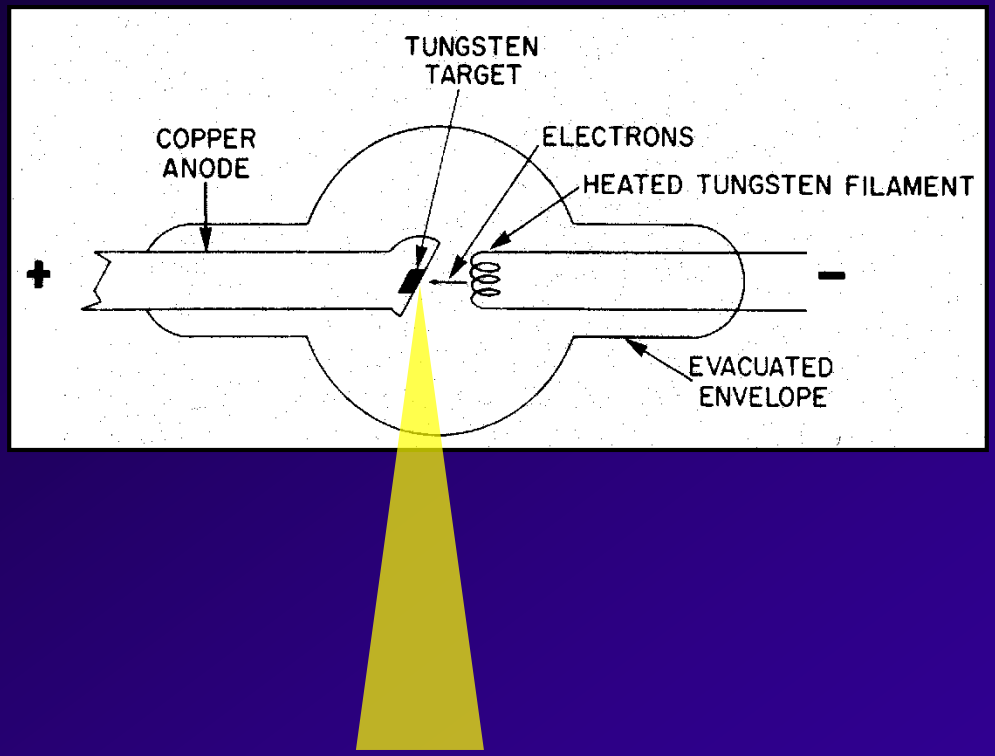
LaBounty, AJC 2010, AJR 2010

# Tube Current and Voltage





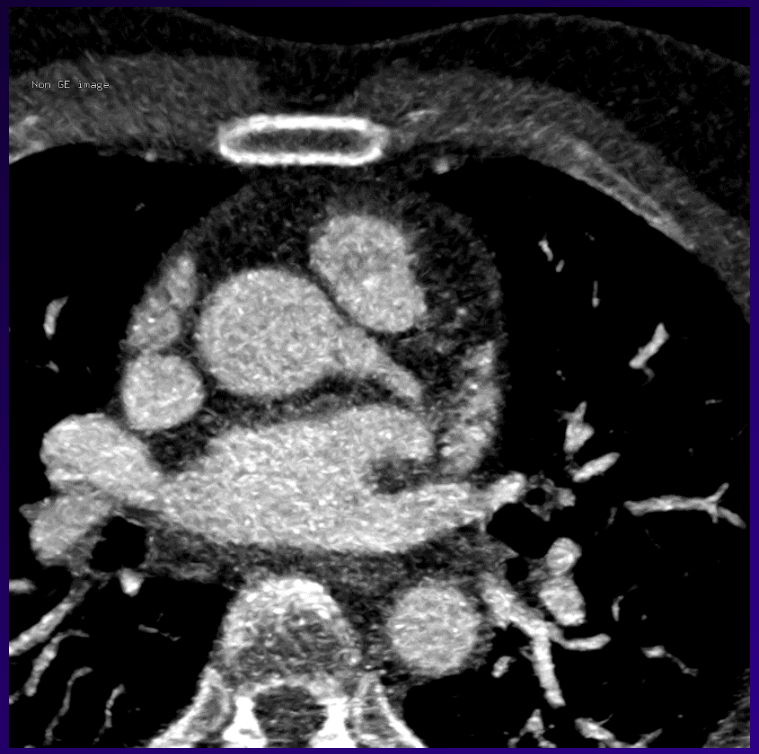
# X-Ray Tube



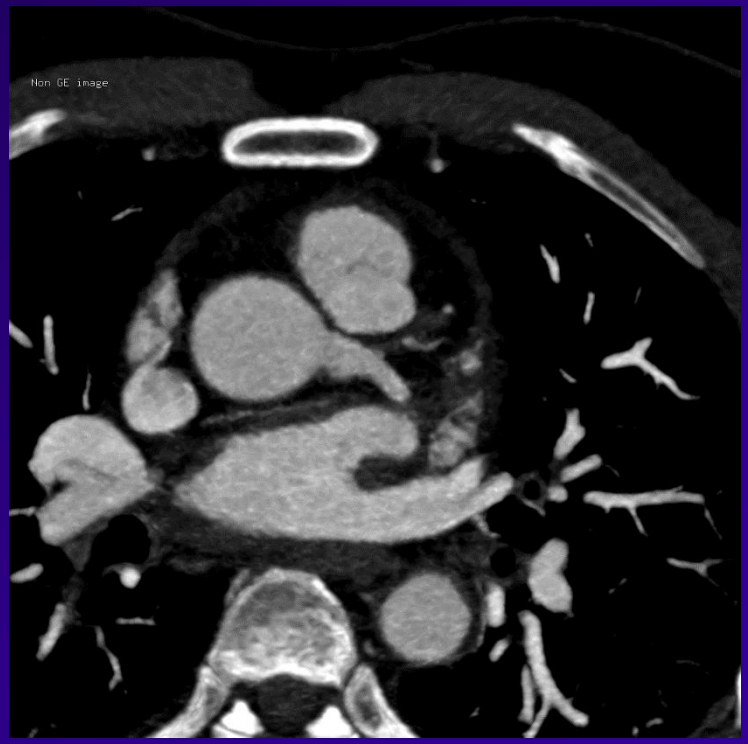

Electrons accelerated at tungsten target;
when they hit the target, x-ray photons are produced

# Tube Current (mA)

Lower Current

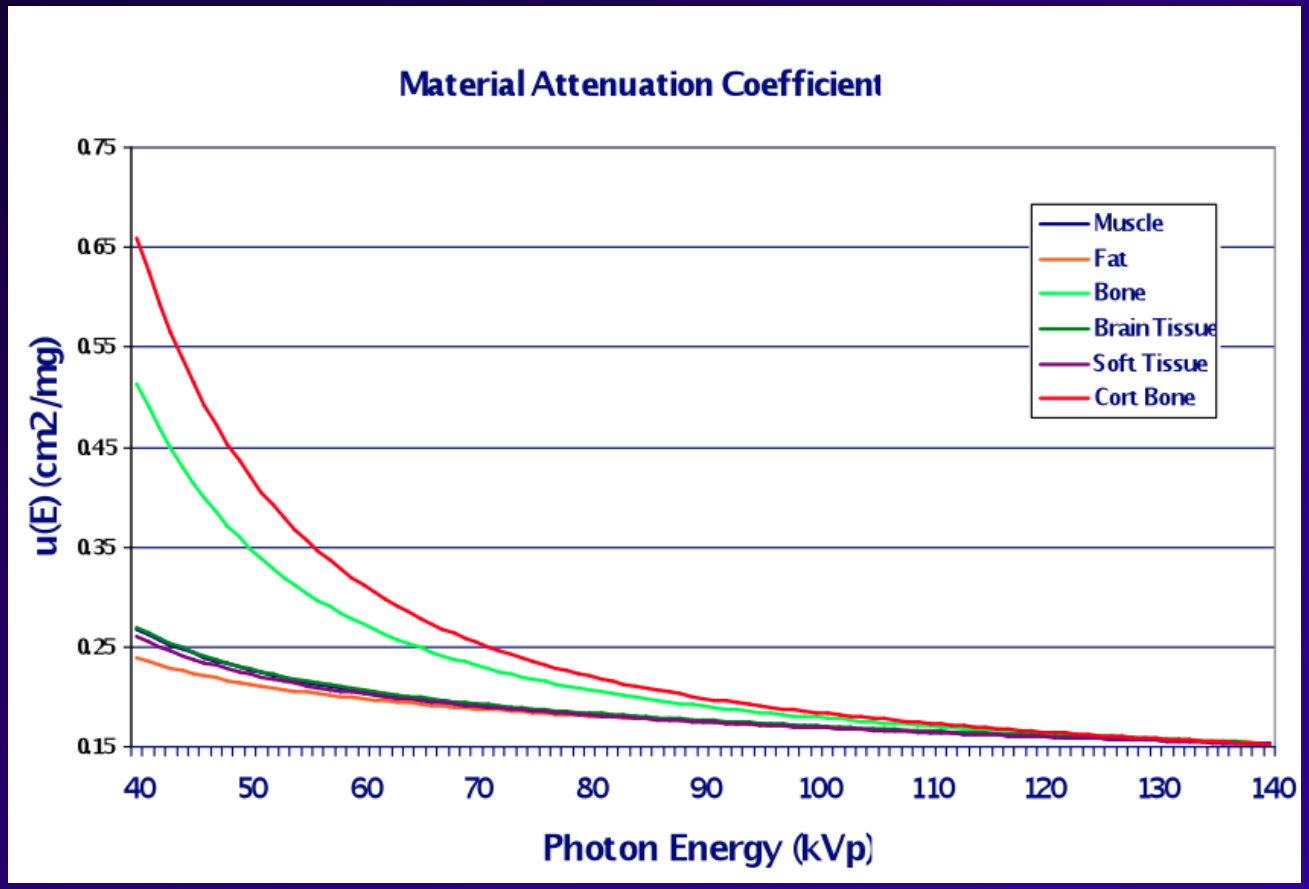



Higher Current




- Higher current = more photons = less noise
- Larger patient = need more photons

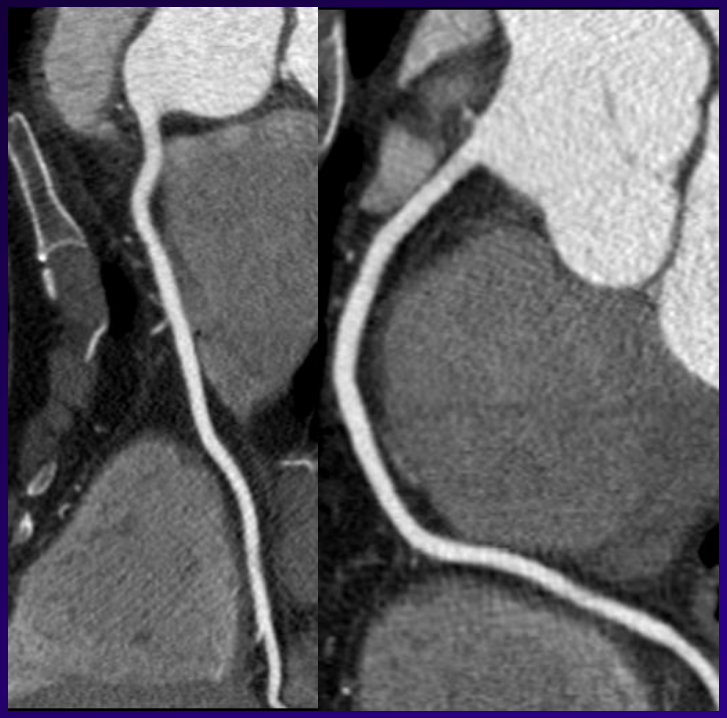
# X-Ray Attenuation



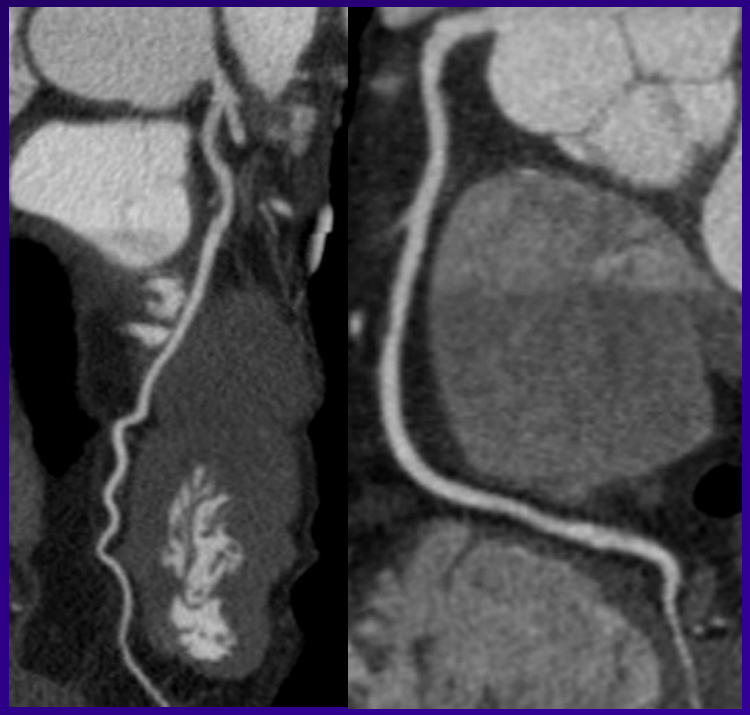

Photon attenuation by a given material is affected by the potential energy (voltage) of the photons

# Tube Voltage (kV)

Higher voltage = higher photon energy = less noise
(but lower signal and contrast)



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 1
Standardized coronary computed tomographic angiographic protocol

| BMI (m/kg$^2$) | Tube Voltage (kV) | Tube Current (mA) |
|---|---|---|
| <25 | 100 | 275–450 |
| 25–29.9 | 100 | 325–550 |
| 30–33.9 | 120 | 375–625 |
| ≥34 | 120 | 500–800 |

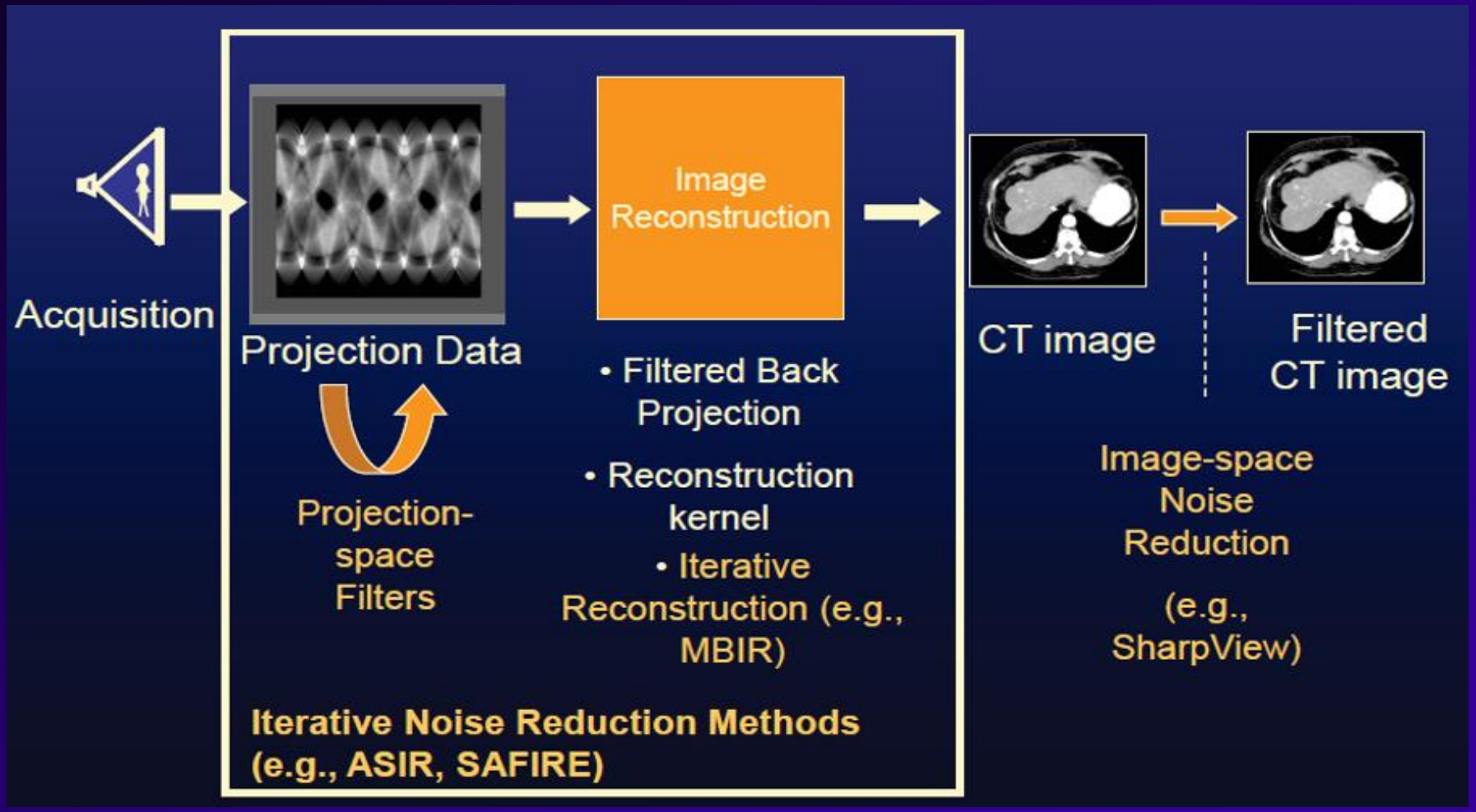
Prospective ECG gating was assigned to all patients with regular heart rates <65 beats/min unless the ordering physician specifically requested retrospective gating. Scan length was minimized in all patients.

LaBounty, AJC 2010

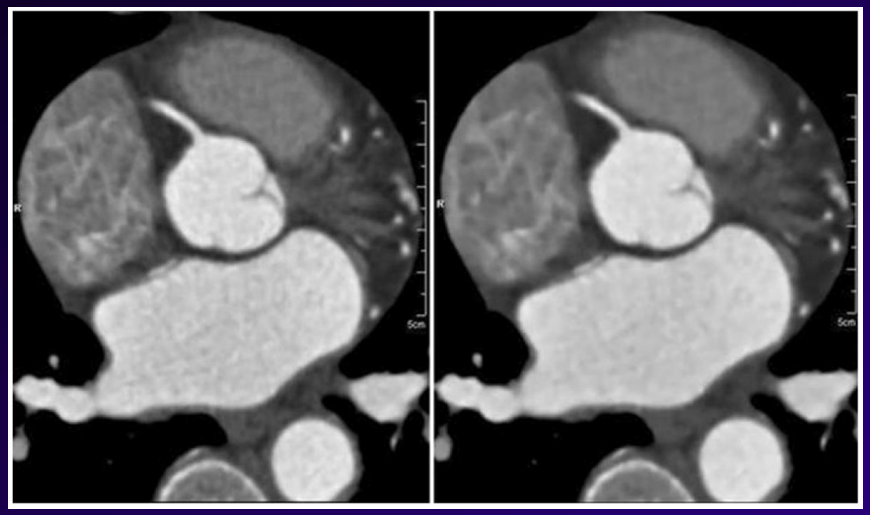
# 5 Steps to Optimal CCTA

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

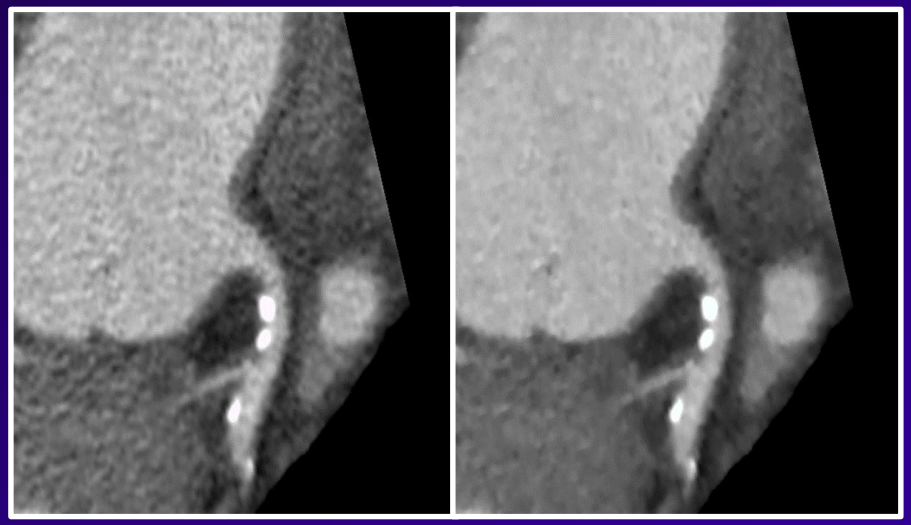
# Reconstructions



# Iterative Reconstruction



FBP Iterative

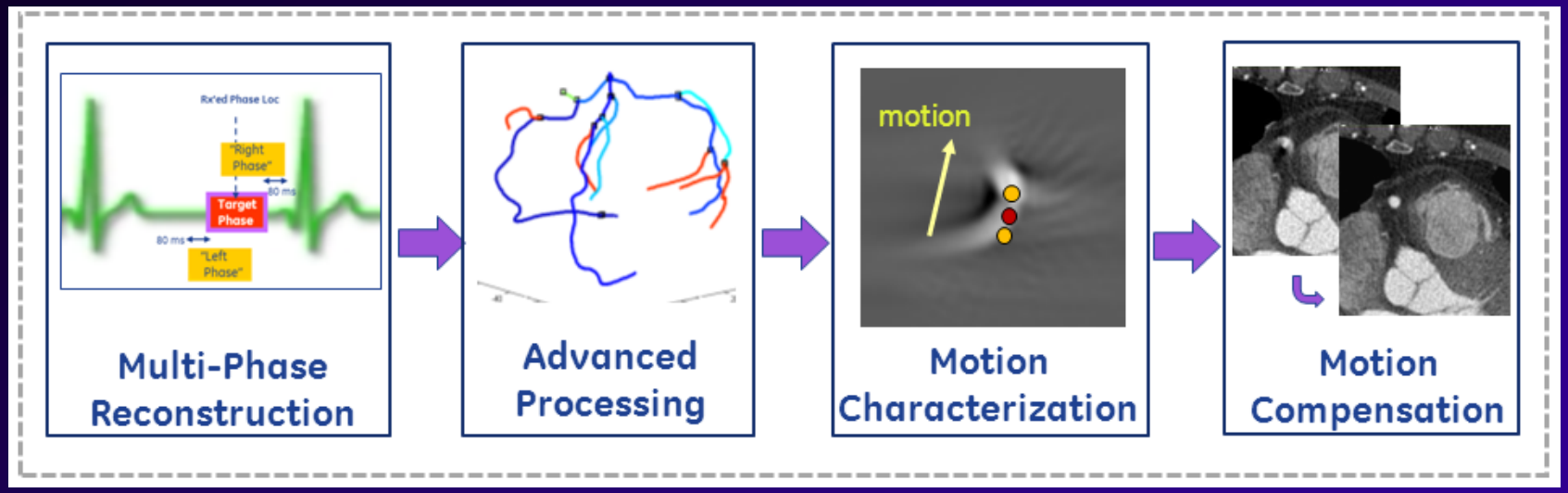


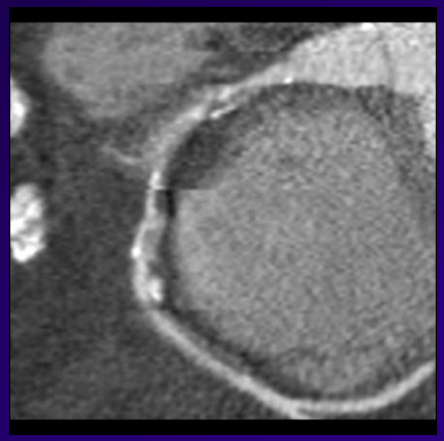
FBP Iterative

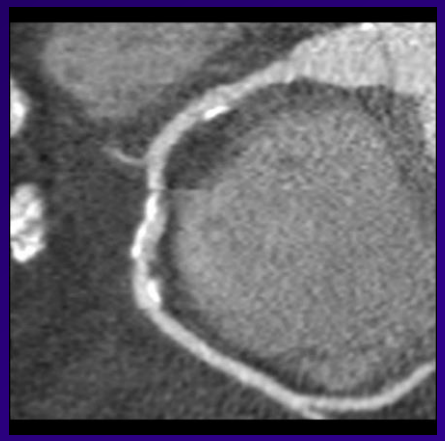
Iterative reconstruction lowers image noise:

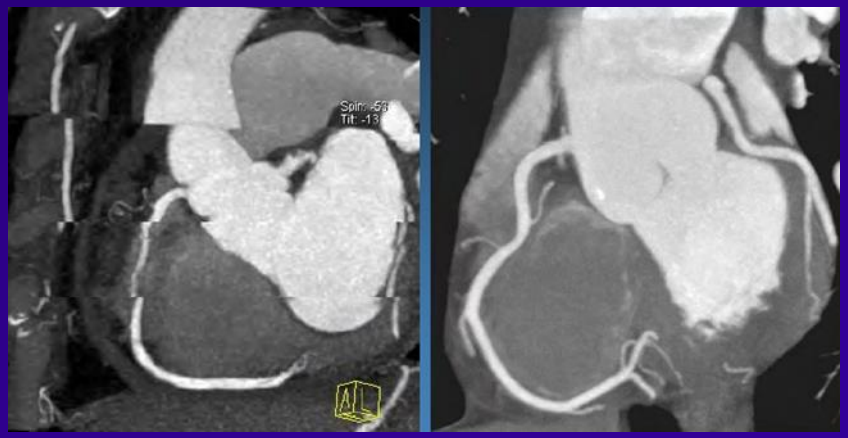
1. May permit reduced radiation dose by permitting the use of lower current
2. May improve image quality of noisy studies

# Motion Correction Algorithms



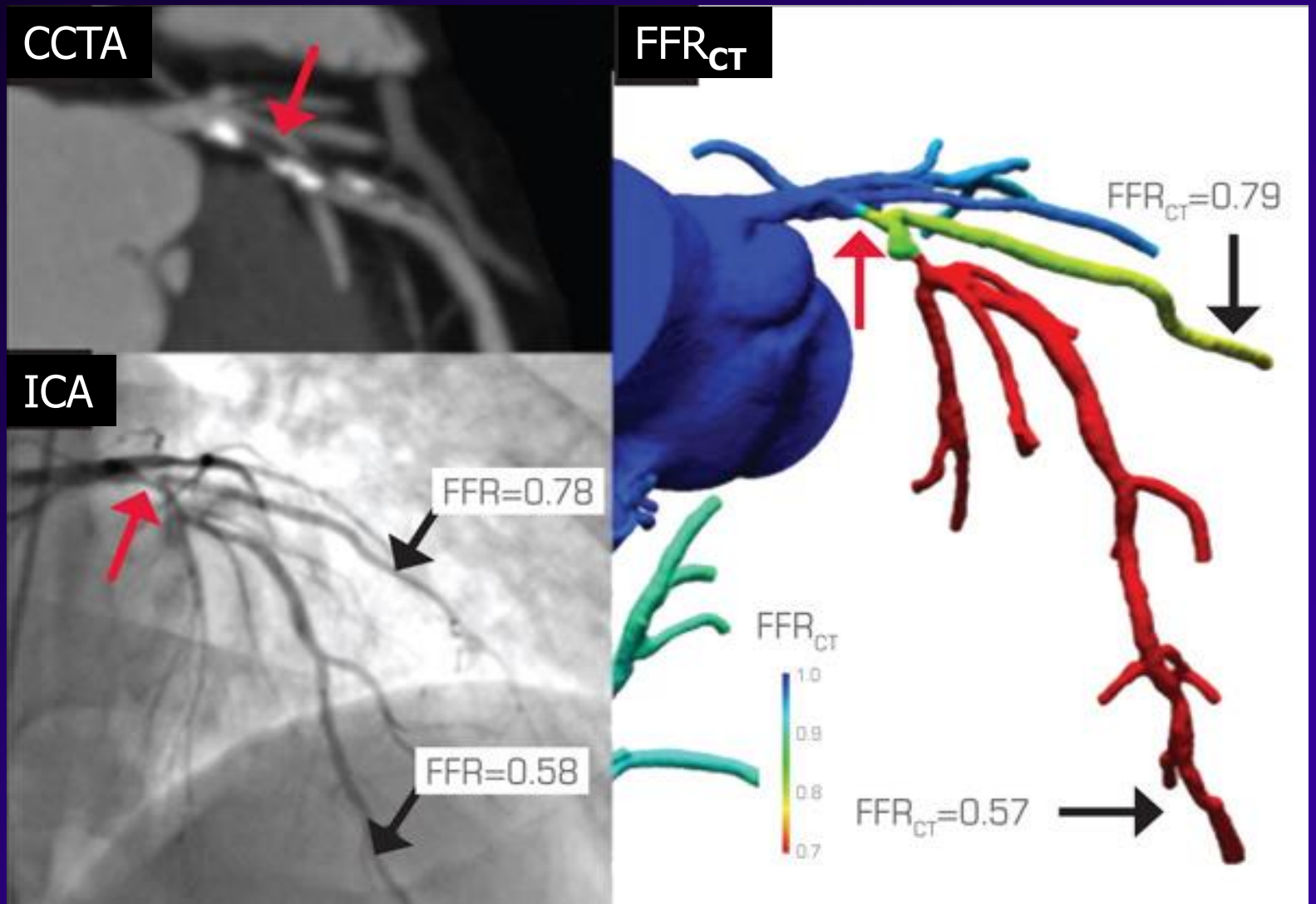







Courtesy of Dr. Jonathon Leipsic

# Coronary CT Flow ($FFR_{CT}$)



# 5 Steps to Optimal CCTA

1. Patient Preparation
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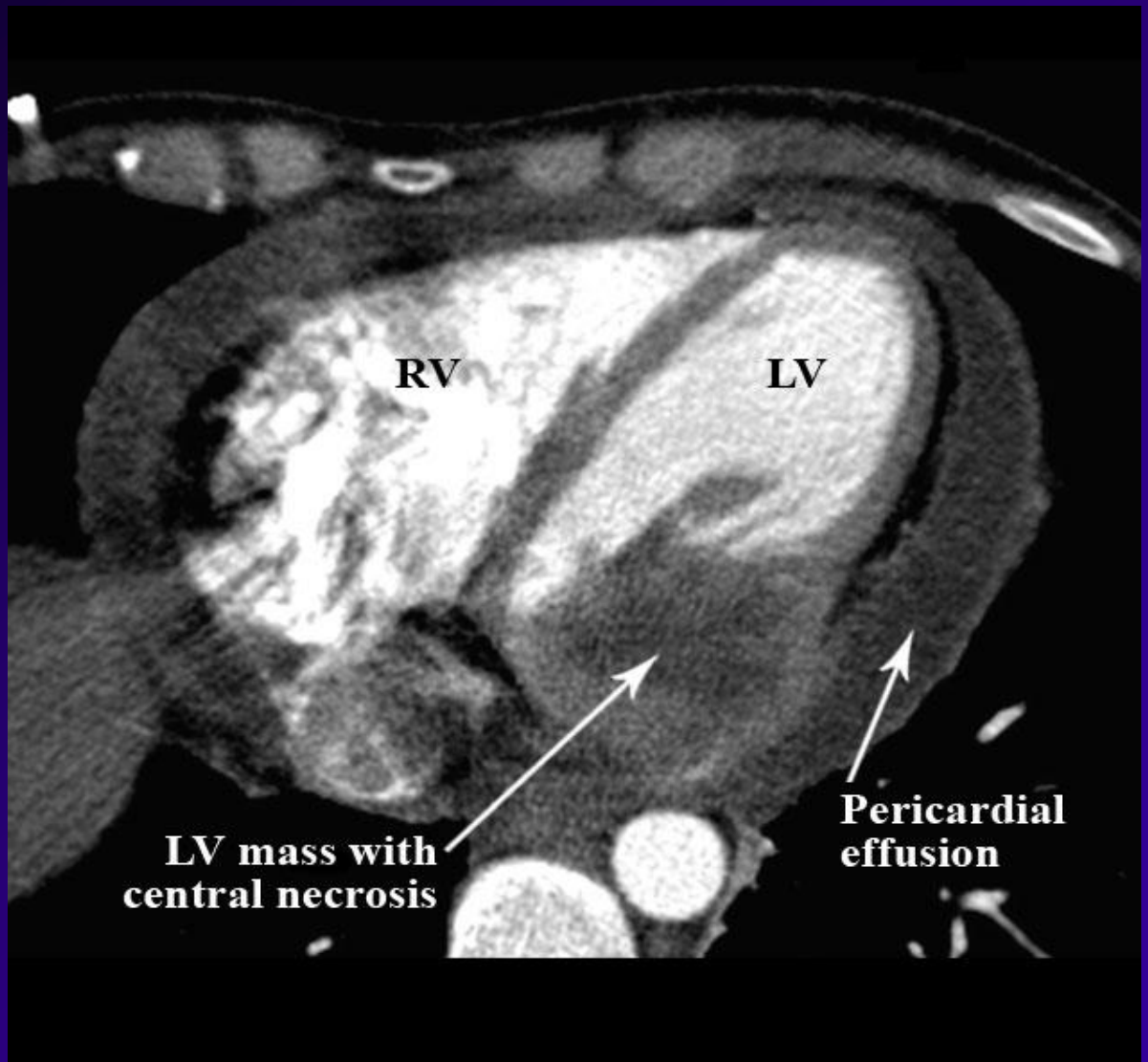
**OVERALL GOAL:**

**Best Image Quality with Highest Patient Safety**

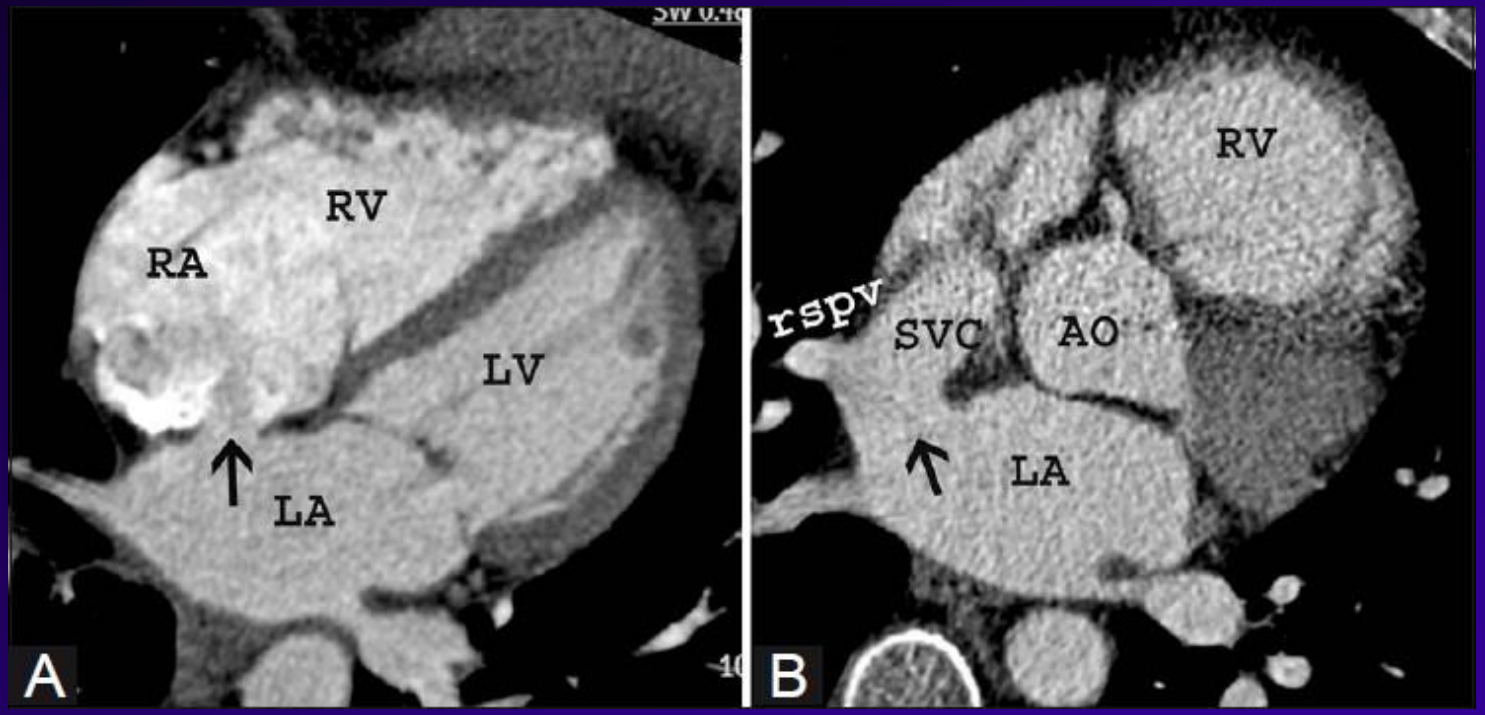
# Non-Coronary Cardiac CT

- 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



# Congenital Heart Disease

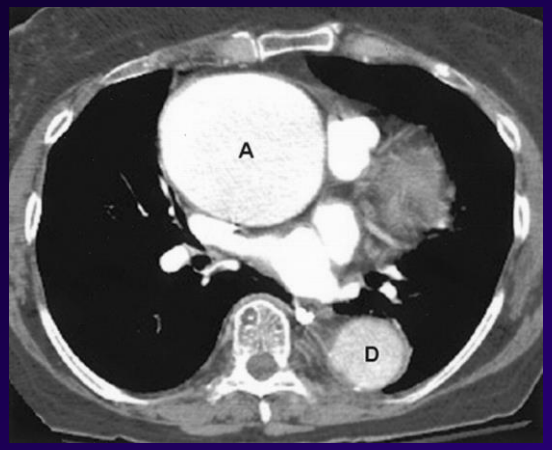


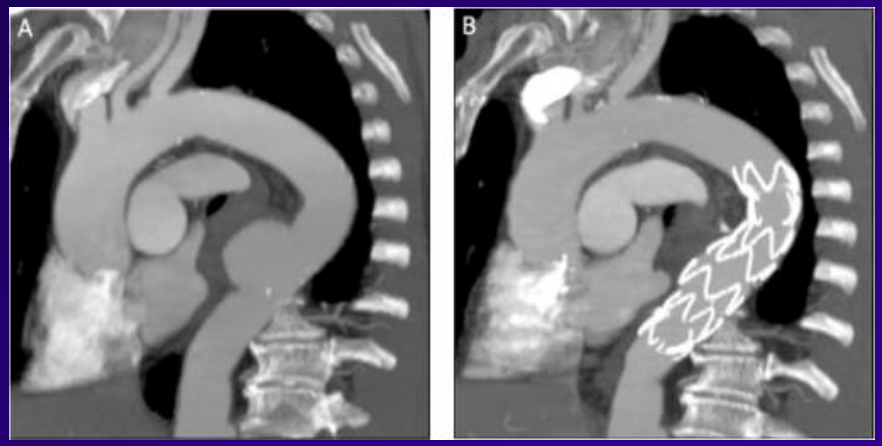

Atrial Septal Defects (ASD)

Sinus Venous/Coronary Sinus Defects

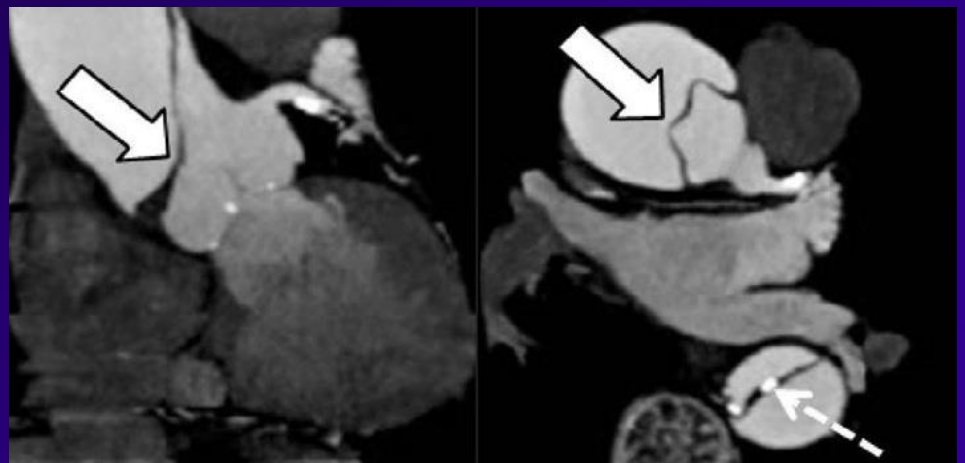
# Aortic Disease

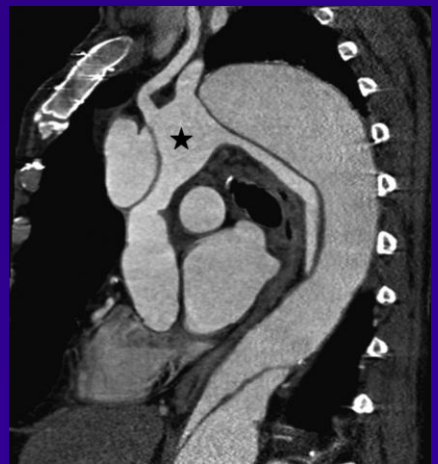
Aortic Aneurysm



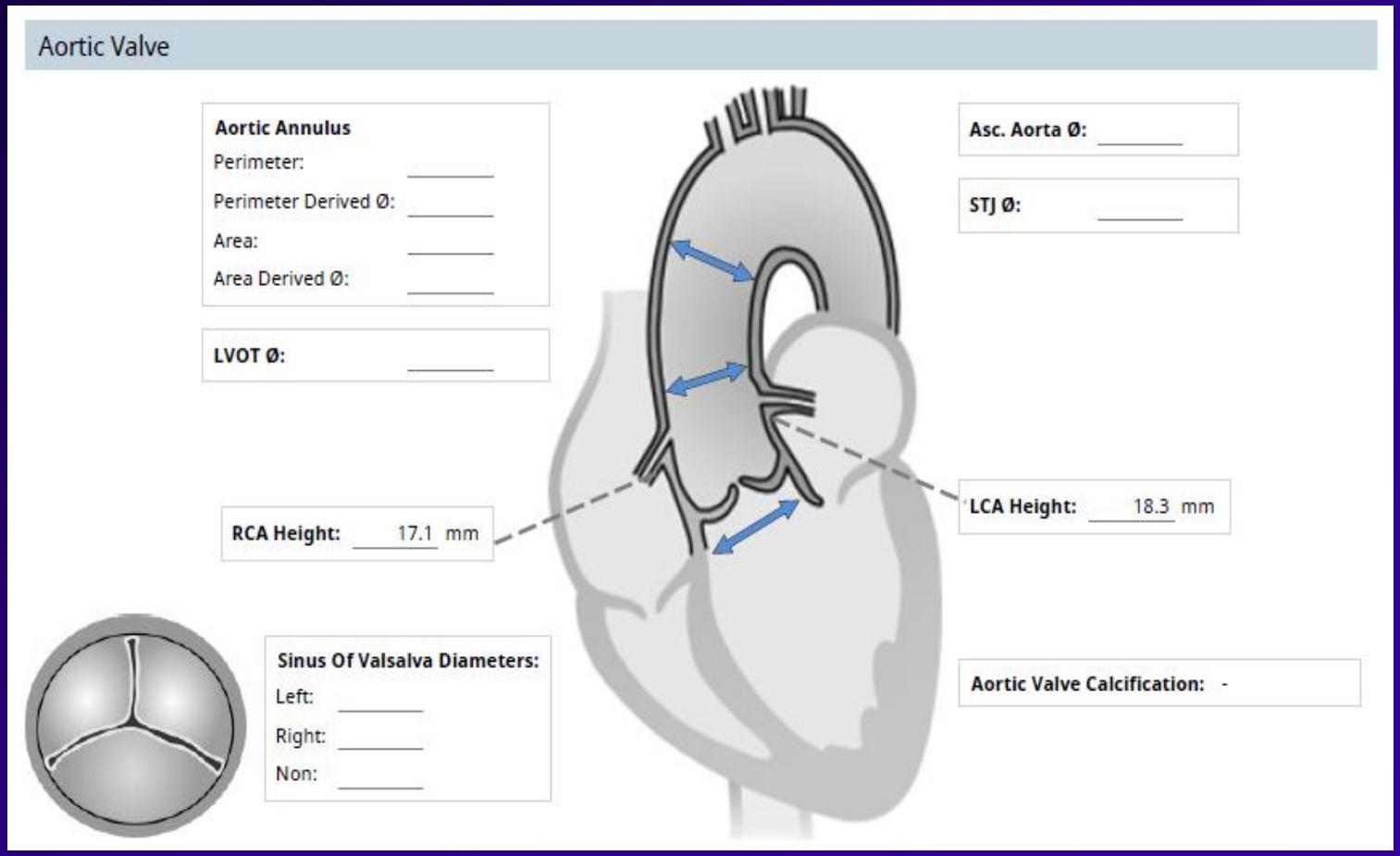

Aortic Dissections





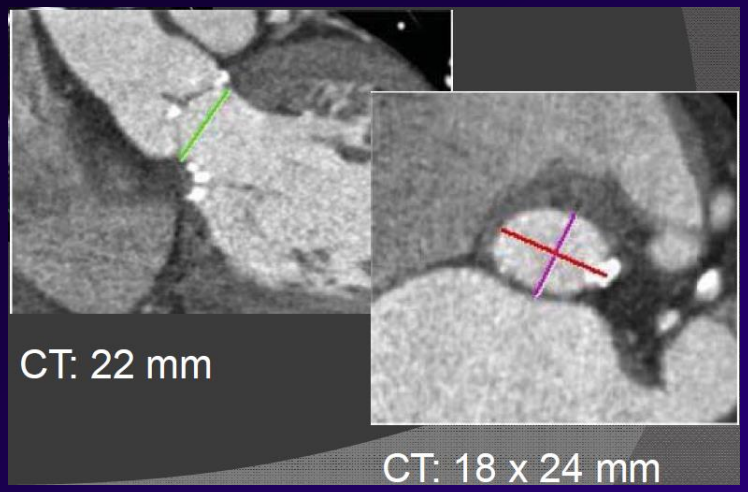
# CT Assessment of Annular Sizing

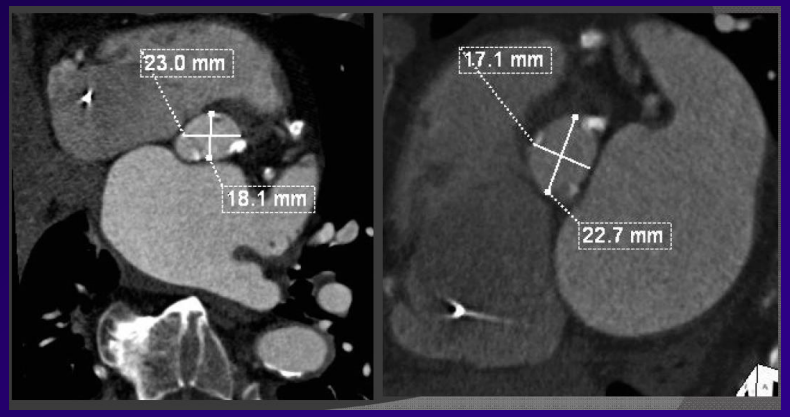
## Pre-TAVR

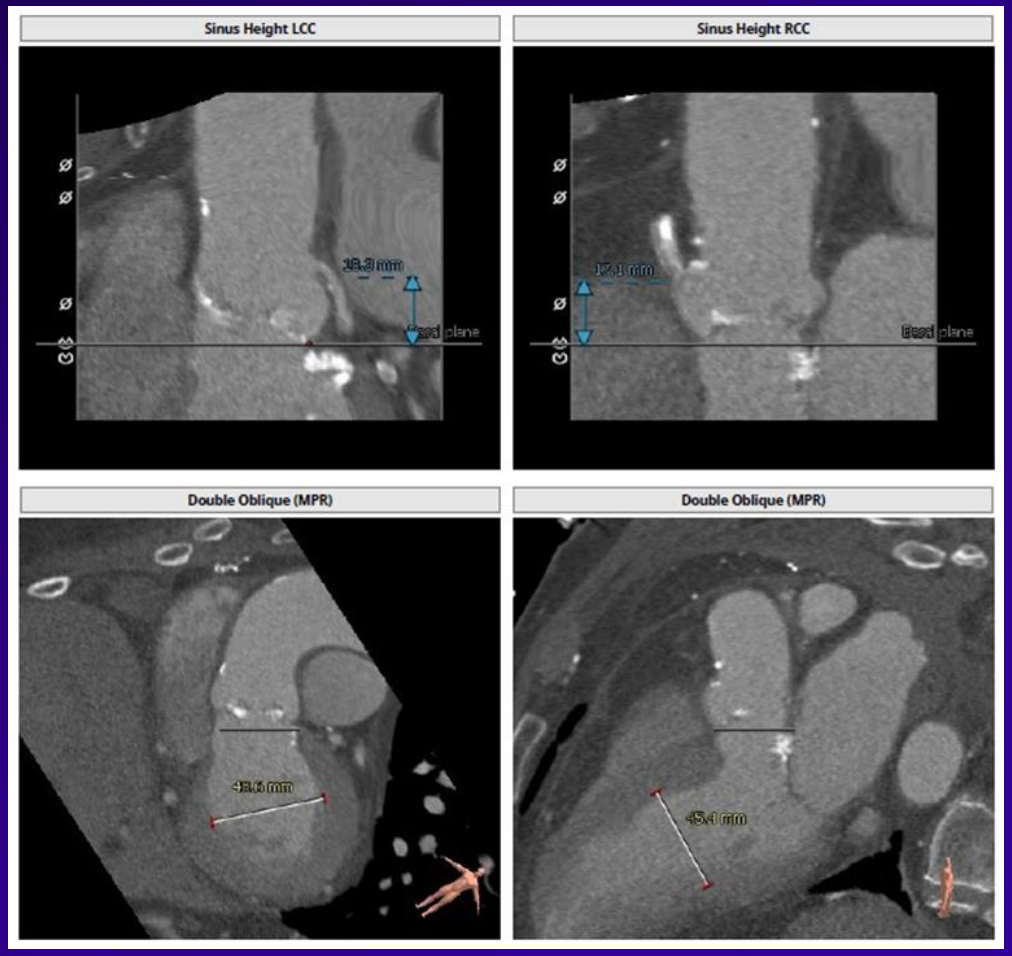


# CT Assessment of Annular Sizing

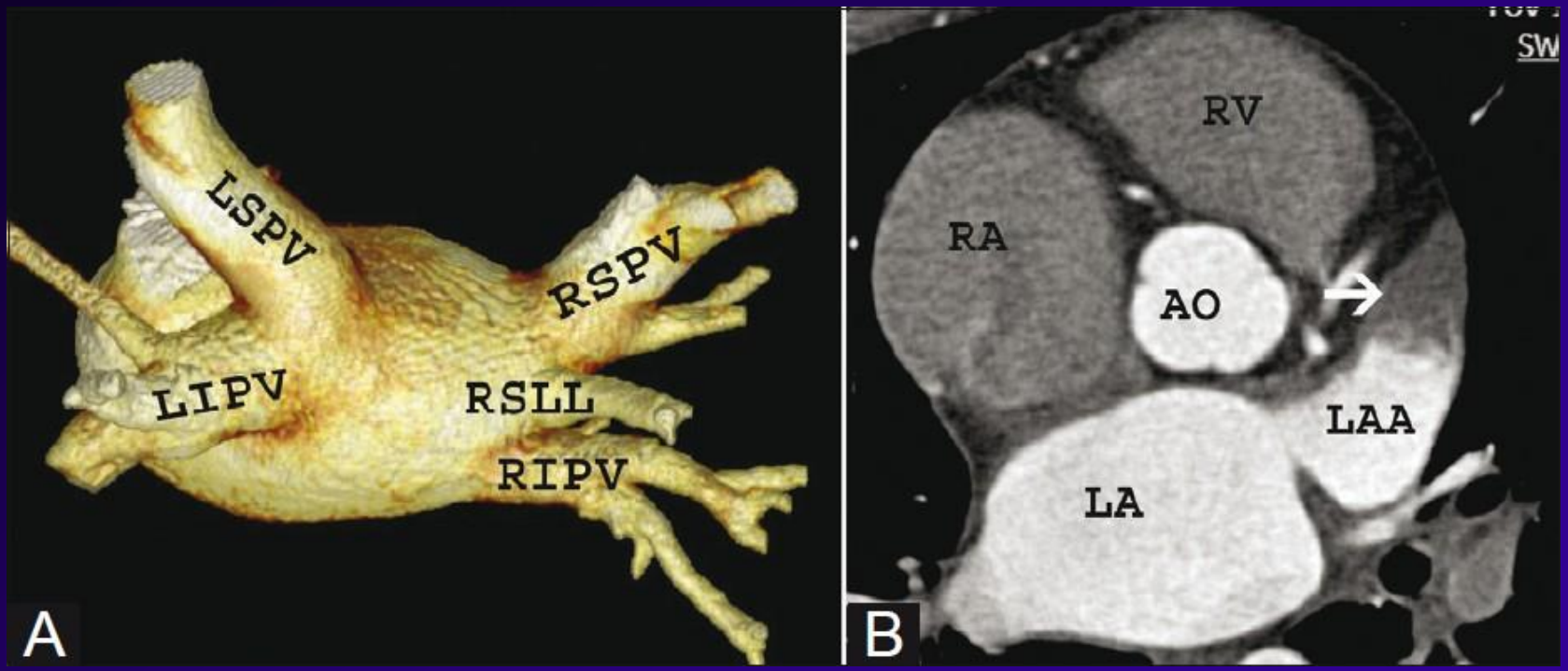
## Pre-TAVR

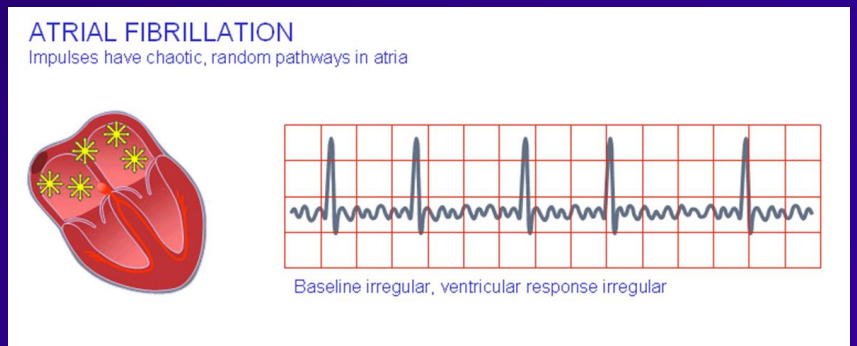


# LAPV

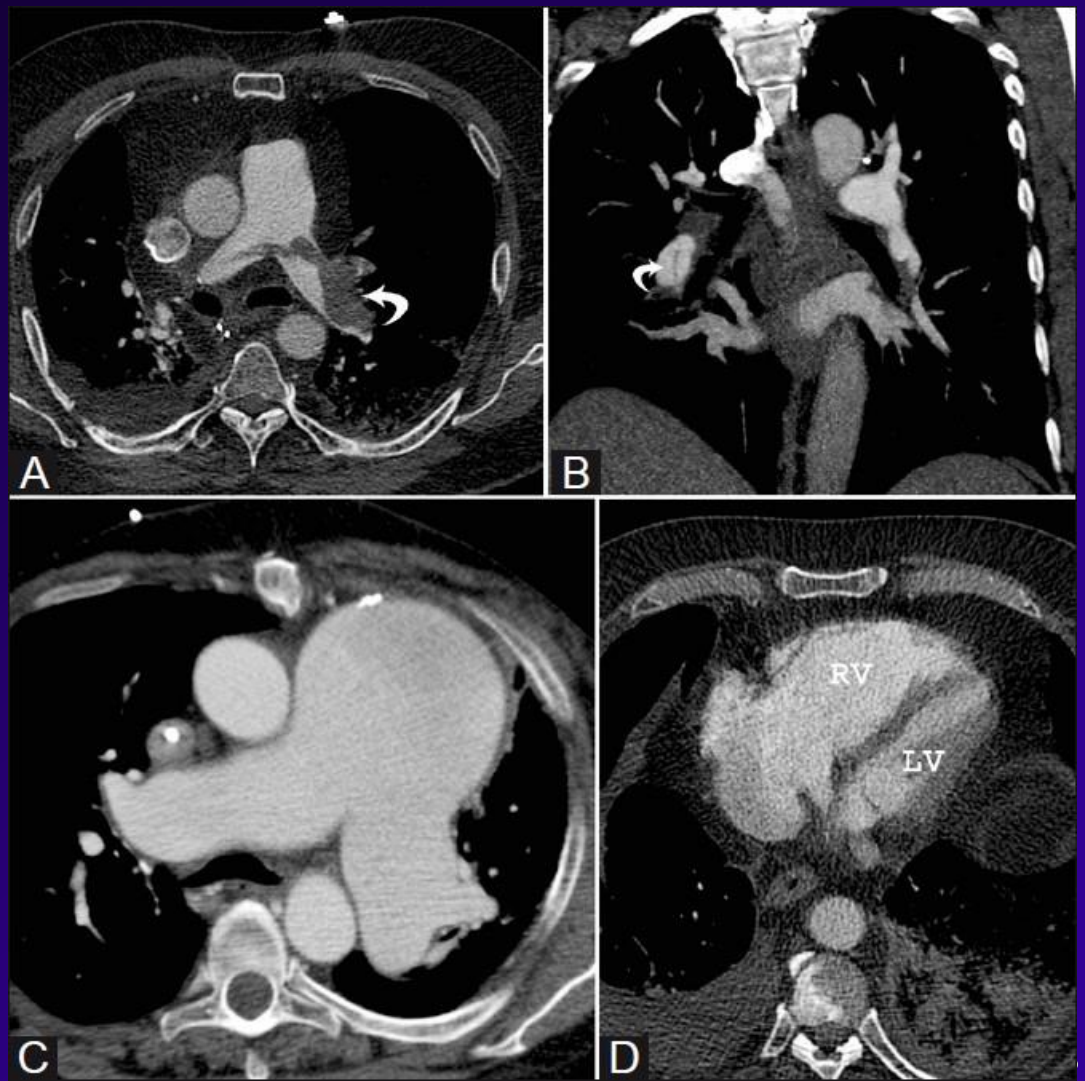

LSPV
RSPV
LIPV
RSLL
RIPV
A
RV
RA
AO
LAA
LA
B


ATRIAL FIBRILLATION
Impulses have chaotic, random pathways in atria
Baseline irregular, ventricular response irregular

# Pulmonary Arteries

PE

PE

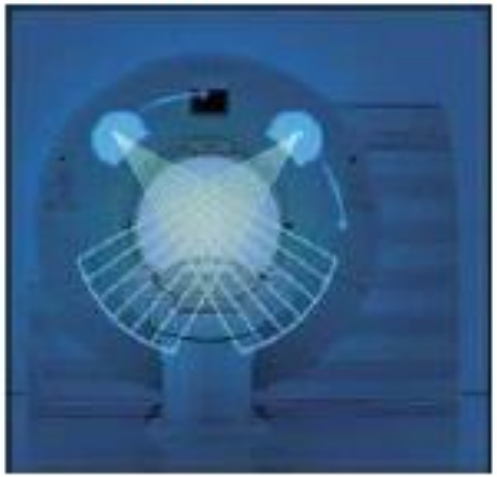



Pulm HTN

RV Strain

# New Technologies in Cardiac CT

## Temporal resolution



**Dual-source/ Flash CT**

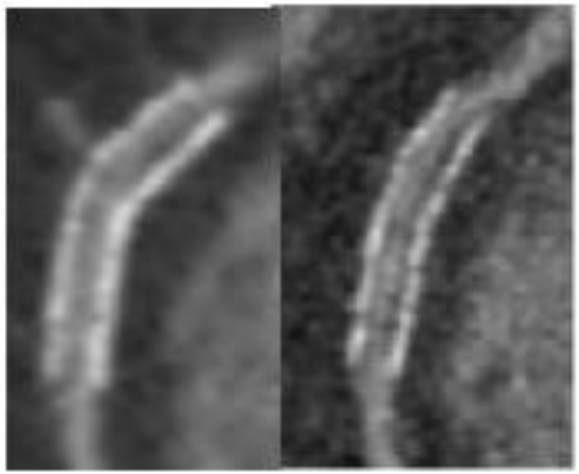
- Faster gantry rotation
- 83 ms resolution
- Reduced need for beta blockers

## Volume coverage

**320-slice MDCT**

- Increased z-axis coverage /gantry rotation
- Whole heart acquisition in 1 beat
- Perfusion?

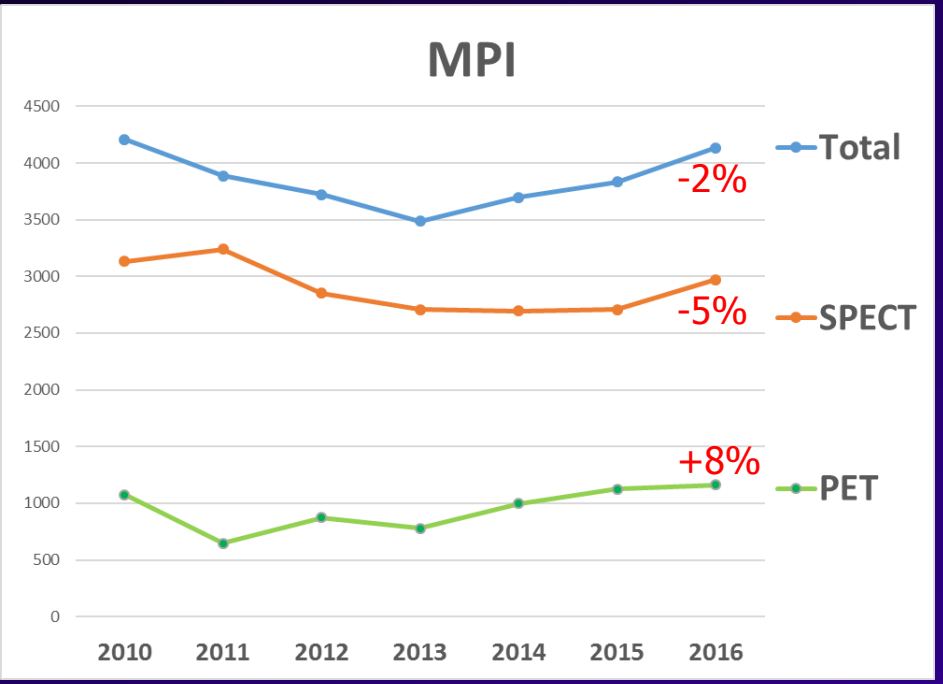
## Spatial resolution

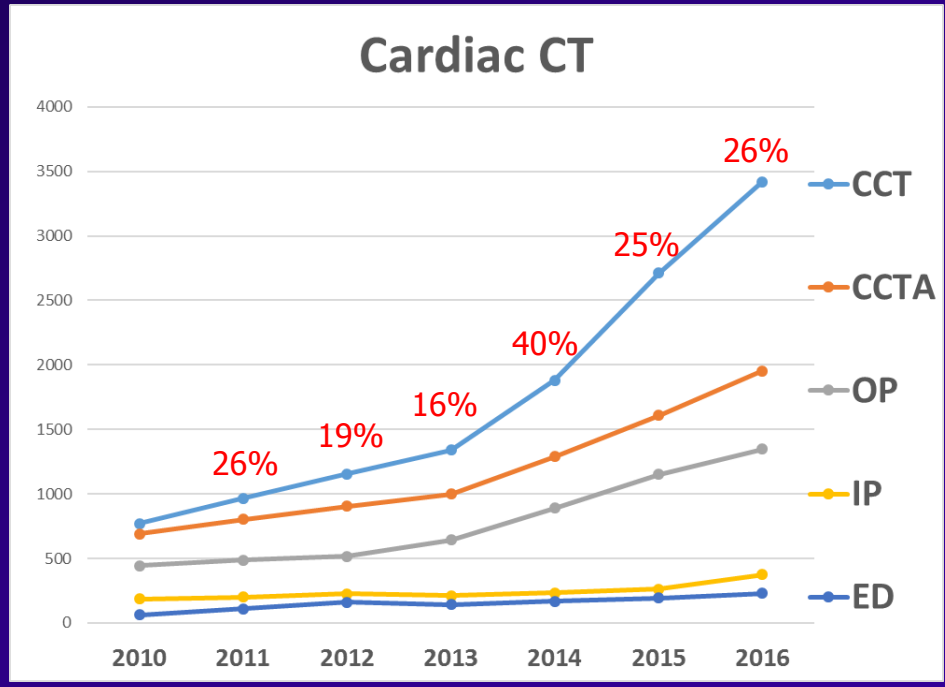


**High Definition CT**

- Improved spatial resolution
- Improved reconstruction (SNR)
- Reduced radiation
- Enhanced Ca2+ and stent imaging, stenosis severity

# MPI vs Cardiac CT Volume



# 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!