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Cardiac Stress Testing

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Who is appropriate for stress testing?

1. Symptomatic patients with suspected CAD
-Chest pain, anginal equivalents or exertional dyspnea
-New or worsening symptoms in patients with known CAD
-New onset heart failure
2. Pre-operative Evaluation
-Especially if they have poor functional capacity (<4METS)
-Prior to organ transplant
-Stress testing not indicated for patients with good functional capacity (>4 METS), prior normal testing within 1 year or low risk surgery
3. Post-Revascularization or known CAD

-Rarely appropriate within 2 years of PCI or 5 years of CABG

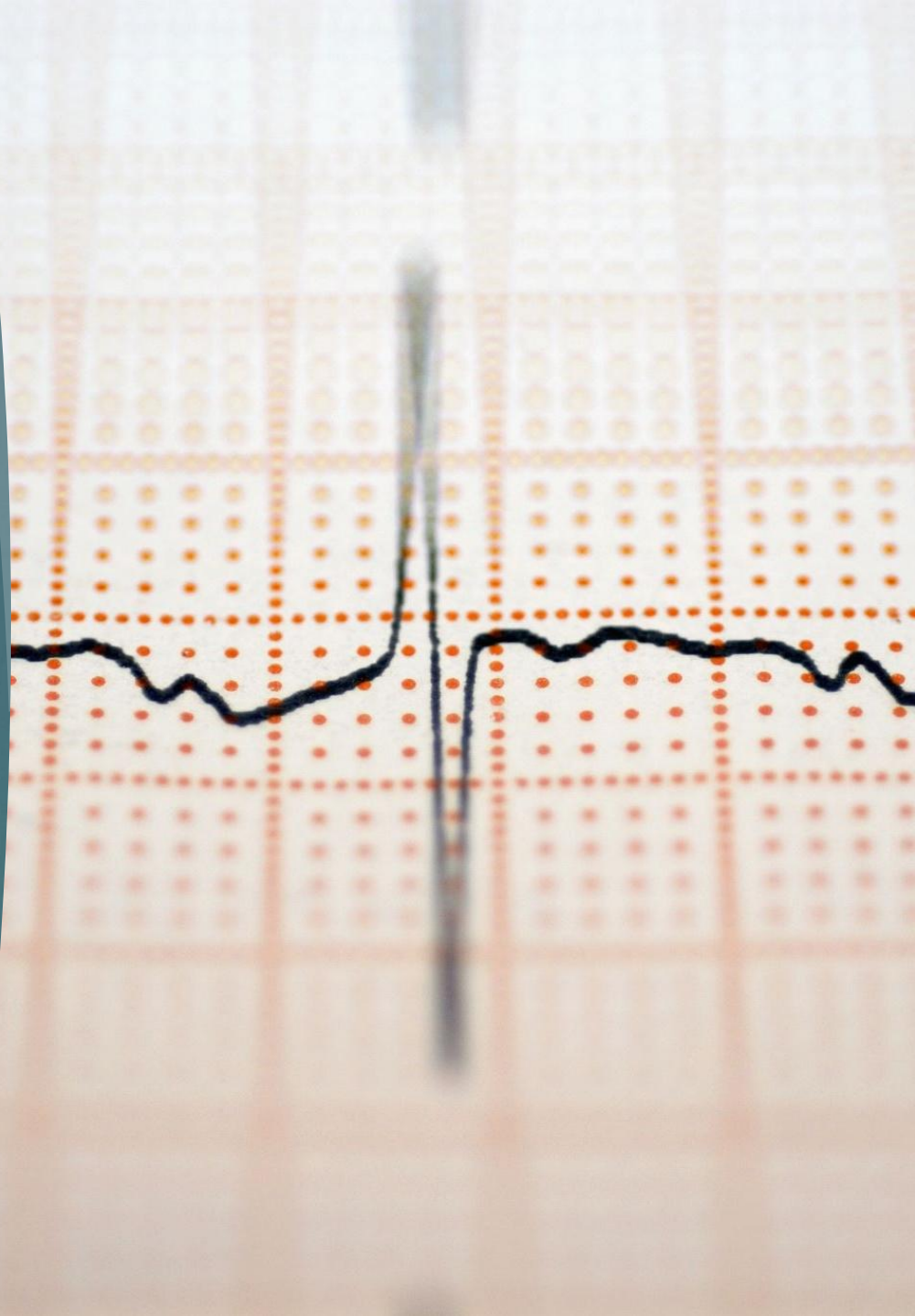
4. Asymptomatic patients generally not indicated

-Coronary artery calcium score >400

-Asymptomatic with diabetes, peripheral vascular disease or strong family history of CAD

Who is not appropriate for stress testing?

- 1.Patients with active acute coronary syndrome (ACS)
- 2.Decompensated heart failure
- 3.Symptomatic severe aortic stenosis
- 4.Uncontrolled arrhythmias (SVT, VT, AF, 2/3 degree HB, HR <45)
- 5.Acute aortic dissection
- 6.Myocarditis/pericarditis
- 7.Resting hypertension >200/110 mm Hg



Which stress test do I order?

- Factors to consider:
  - -Exercise capacity
  - -Resting EKG
  - -Pretest probability of CAD
  - -Age
  - -Clinical characteristics

Pre Test Probability of CAD by Symptoms, Gender and Age

Age	Gender	Typical/Definite Angina Pectoris	Atypical/Probable Angina Pectoris	Non-Anginal Chest Pain	Asymptomatic
30-39	Males	Intermediate	Intermediate	low (<10%)	Very low (<5%)
30-39	Females	Intermediate	Very Low (<5%)	Very low	Very low
40-49	Males	High (>90%)	Intermediate	Intermediate	low
40-49	Females	Intermediate	Low	Very low	Very low
50-59	Males	High (>90%)	Intermediate	Intermediate	Low
50-59	Females	Intermediate	Intermediate	Low	Very low
60-69	Males	High	Intermediate	Intermediate	Low
60-69	Females	High	Intermediate	Intermediate	Low

High = >75% **Intermediate = 15-75%** **Low = <15%** **Very Low = < 5%**

Which stress test do I order?

Step 1: Anatomic vs Functional testing

1. CCTA (coronary CT angiography)
   - -<65 years old and no known CAD
   - -Limitations: IV iodinated contrast, radiation exposure, contraindicated in pregnancy
   - -What can affect imaging: Elevated or irregular HR (Goal HR 55-65), dense calcification and obesity (BMI >40)
2. Functional stress testing
   - ->65 years old or those with a higher likelihood of ischemia (High coronary calcium burdens)

Step 2: Exercise vs Pharmacologic Stress

- -Exercise is always preferred when possible as it provides additional prognostic information (functional capacity, hemodynamic response and symptoms correlation)
- -Uninterpretable resting EKG=Pharmacological testing
  - -LBBB
  - -LVH with repolarization
  - -Paced rhythm
  - ->0.5 mm ST depressions

What stress test do I order?

Choosing the Imaging Modality

1. Exercise EKG/Exercise treadmill test (ETT)

2. Stress echocardiography

3. Stress SPECT

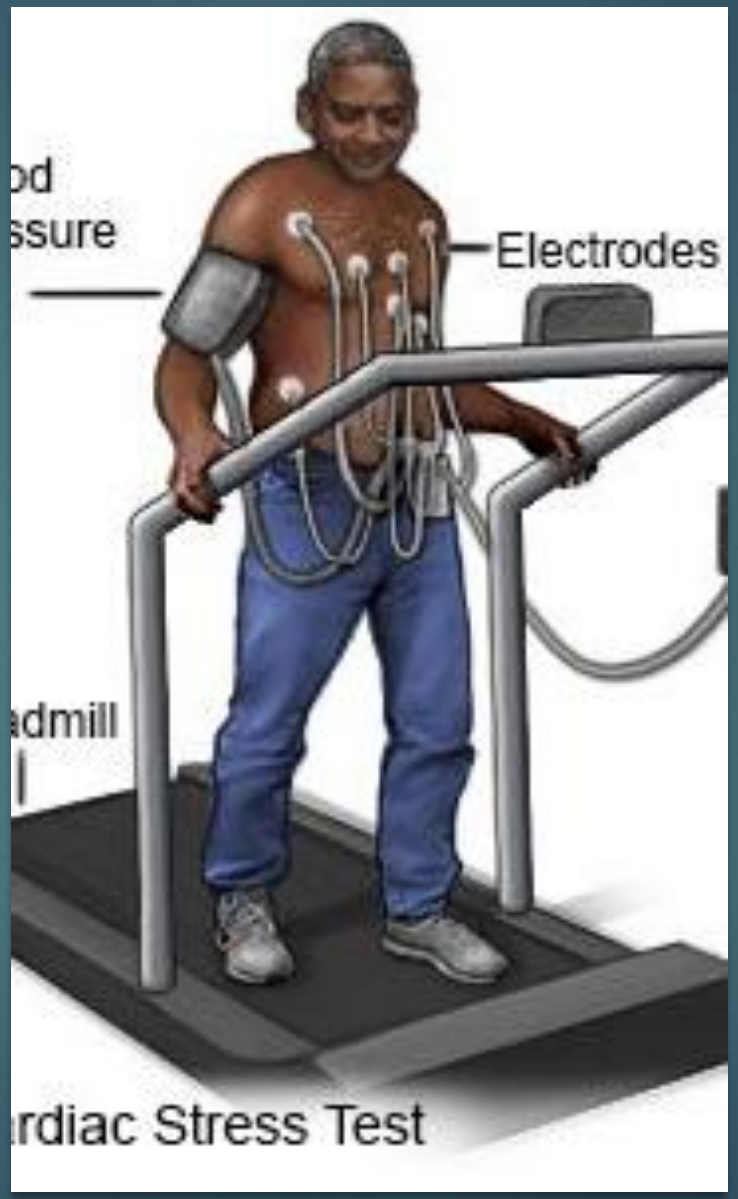
4. Stress PET

5. Stress CMR

6. CCTA

Exercise Treadmill Test/ETT

- It involves continuous EKG monitoring and periodic blood pressure measurements during graded, supervised exercise on a treadmill or cycle ergometer



Exercise Treadmill Test/ETT

Prerequisites and Preparation:

-Patient must be able to exercise safely to ≥ 5 METS (Moderate activity is 3-5.9 METS. Walking briskly at 4 mph, cycling at 10 mph, light yard work, 1-2 flights of stairs w/o stopping or doubles tennis

-Rate lowering medications are held 24 hours prior (unless goal of study is to see efficacy of anti-anginal therapy)

-Interpretable EKG (LBBB, LVH, PACED, baseline ST changes)

Exercise Treadmill Test/ETT

- Exercise protocols: Bruce and modified Bruce

Bruce Protocol for Treadmill Testing

STAGE	TIME	SPEED (mph)	GRADE (%)	METS
REST	00.00	0.0	0.0	1.0
1	03.00	1.7	10.0	4.6
2	03.00	2.5	12.0	7.0
3	03.00	3.4	14.0	10.1
4	03.00	4.2	16.0	12.9
5	03.00	5.0	18.0	15.1
6	03.00	5.5	20.0	16.9
7	03.00	6.8	22.0	19.2

Stage	Speed (mph)	Grade (%)	Duration (min)
0	1.7	0	3
0.5	1.7	5	3
1	1.7	10	3
2	2.5	12	3
3	3.4	14	3
4	4.2	16	3
5	5.0	18	3
6	5.5	20	3
7	6.0	22	3

Exercise Treadmill Test/ETT

- The modified Bruce protocol adds two initial low workload stages as a warm up, making it suitable for elderly or deconditioned patients

- A key disadvantage of the standard Bruce protocol is the large interstage workload jumps (2-3 METS per stage), which can cause premature test termination due to MSK issues rather than cardiac limitations

Exercise Treadmill Test/ETT

- How do we define an adequate stress test

-≥85% of age predicted maximal heart rate (220-age)

-Patients who achieve ≥ 10 METS have a very low prevalence of ischemia regardless of ECG findings

Interpreting Results:

-Positive test is ≥ 1 mm of horizontal or down-sloping ST segment depressions

-ST segment elevation ≥1 mm in leads without Q waves

-Exercise induced angina

-Hemodynamic response. Drop in systolic BP > 10 mm Hg suggests severe ischemia or LV dysfunction

-Chronotropic incompetence is associated with adverse outcomes

-Heart rate recovery. Failure of HR to decrease >12 bpm in the first minute of recovery reflects impaired parasympathetic tone

Exercise Treadmill Test/ETT

DUKE TREADMILL TEST (DTS)

$$\text{Duke Treadmill Score} = \text{Exercise Duration (min)} - 5\,(\text{ST Deviation (mm)}) - 4\,(\text{Angina Index})$$

Angina Index

0 – none, 1 – typical angina, 2 – angina causing test cessation

Score	Risk Group	Stenosis ≥ 75%	Multivessel Disease	1-Year Mortality
≥ **5**	Low	40.1%	23.7%	0.25%
-10 to 4	Intermediate	67.3%	55.0%	1.25%
≤ **-11**	High	99.6%	93.7%	5.25%

Exercise Treadmill Test/ETT

Indication for test termination:

-ST elevations > 1 mm

-Drop in systolic BP >10 mm Hg with other evidence of ischemia

-Moderate to severe angina

-CNS symptoms (ataxia, dizziness or near syncope)

-Signs of poor perfusion (cyanosis or pallor)

-Hemodynamically significant arrhythmia

-Patient request

Relative indications:

-Marked ST depressions ≥ 2 mm

-Exaggerate BP response (SBP ≥ 250 or DBP ≥115 mm HG)

-Arrhythmias with the potential to worsen

How accurate are these tests

-Sensitivity of 68% and specificity of 77%

Summary: Rarely the optimal stand-alone test. Best for patients with an interpretable EKG, no known CAD and the ability to exercise

Stress Echocardiography

- **Combines a standard echocardiogram with either exercise or medications that increase the heart's workload to evaluate how the heart performs under stress**
- Components:

  1. Baseline echo: LV size and function, EF, wall motion and valves

  2. Stress component: Bruce protocol vs Dobutamine

  3. Immediate post stress imaging: Within 60-90 secs of peak exercise or at peak dobutamine infusion

Stress Echocardiogram

- What does the test look for

1. Ischemia

A. Normal myocardium: Contracts normally at rest and contracts more vigorously during stress (hyperdynamic)

B. Ischemic myocardium: Contracts normally at rest but develops new hypokinesis, akinesis or dyskinesis during peak stress

2. Prior myocardial infarction: An infarcted segment is abnormal at rest. Remains abnormal during stress and usually represents scar rather than inducible ischemia

3. Viability (done with dobutamine): Low dose dobutamine can identify hibernating myocardium. Improvement in contraction at low dose dobutamine suggest viability. Worsening at higher dose (biphasic response)

Stress Echocardiogram

Other possible use:

1. Valvular heart disease: Low flow low gradient AS. Mitral stenosis/MR
2. Pulmonary HTN: PA pressure elevation, RV dysfunction, exercise intolerance
3. Diastolic dysfunction: elevated filling pressures
4. Exercise capacity, HR response, BP response, EKG changes and symptoms (Similar to ETT)

Stress Echocardiogram

- Advantages:

  -No radiation exposure

  -Provides information about heart structure and function

  -Logistical advantages: cost, weight limits, space availability and patient experience

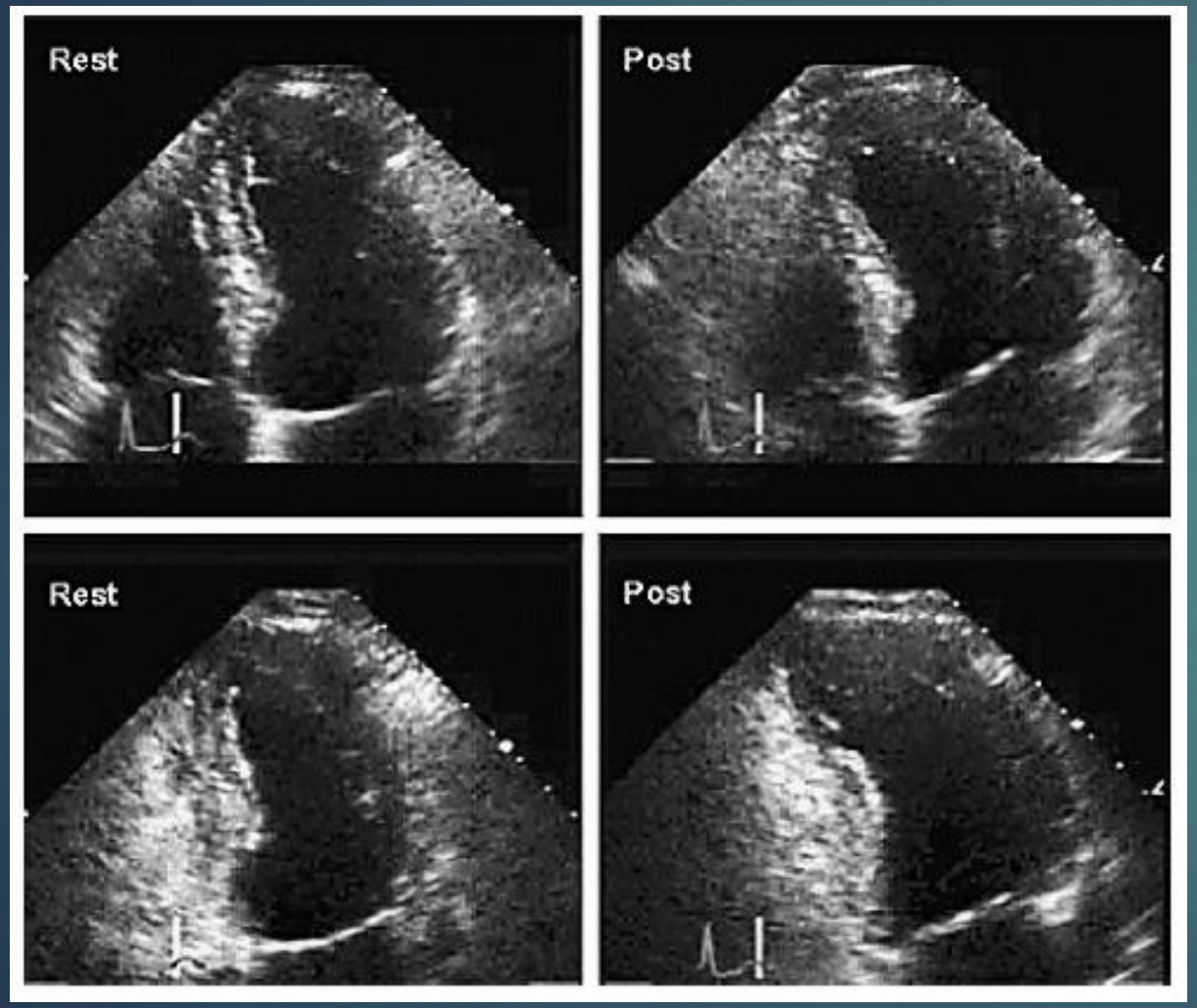
  Disadvantages:

  -Image quality can be limited in some patients (obese and lung patients)

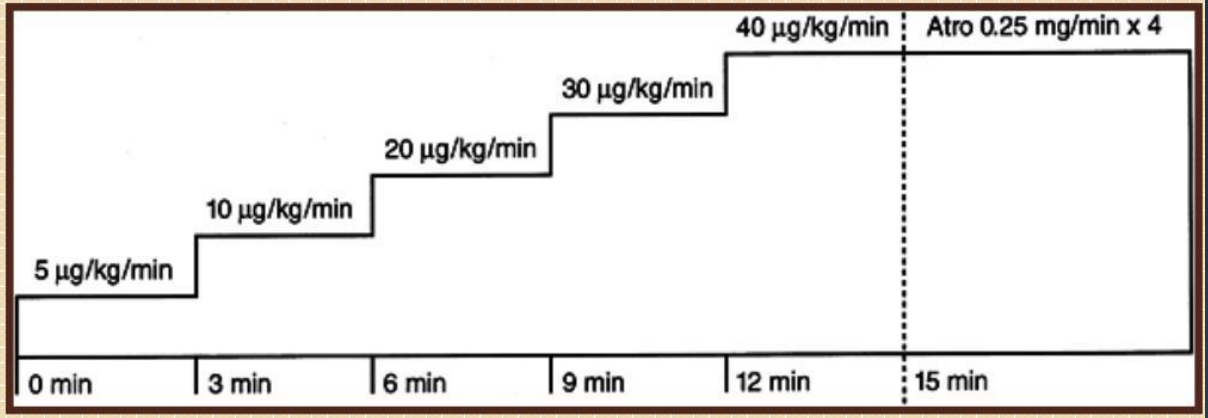
  - Sensitivity 80-85%

  - Specificity 95-90%

Stress Echocardiogram



Protocol for Dobutamine Stress Echo.

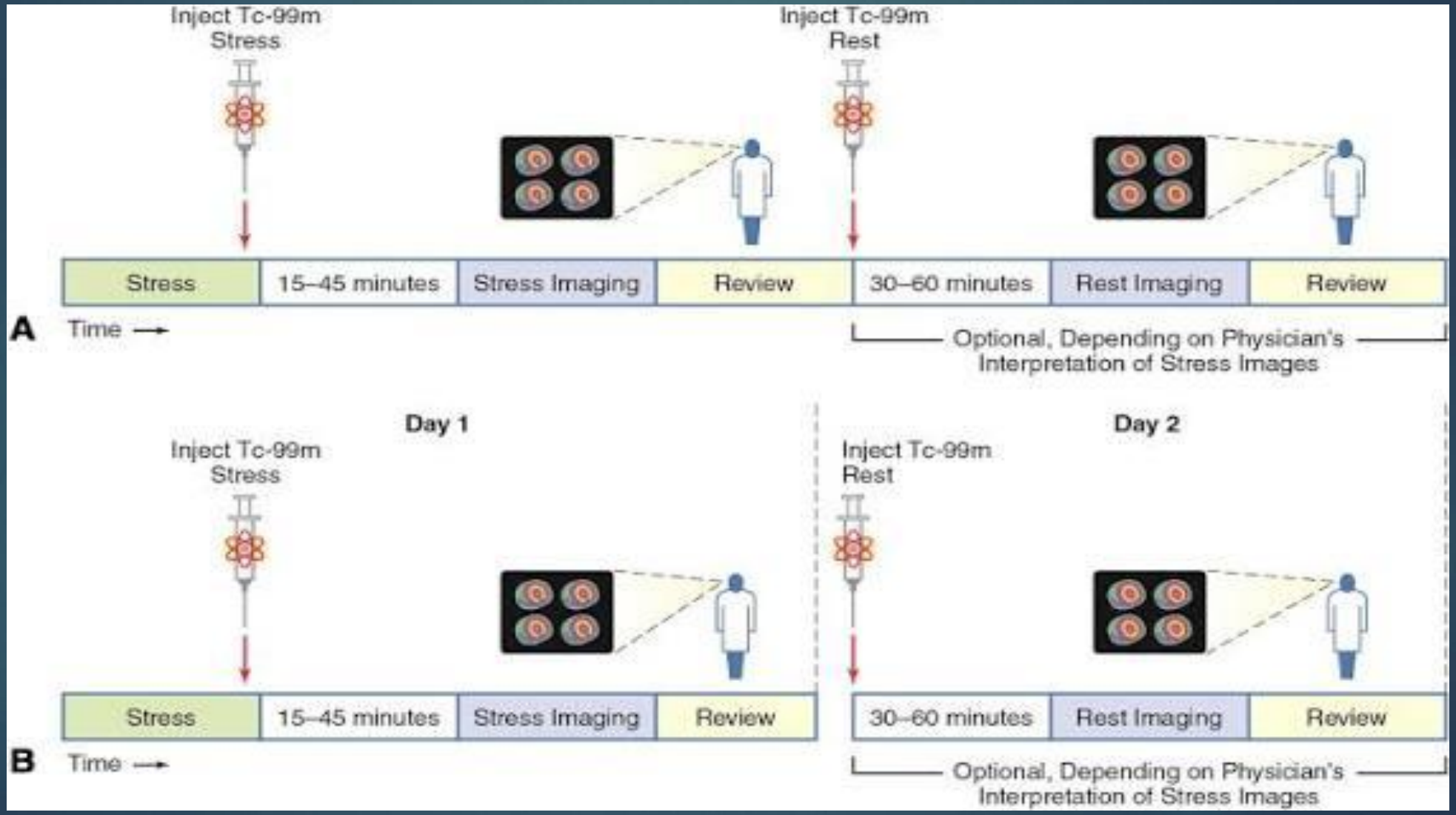


Cardiac SPECT

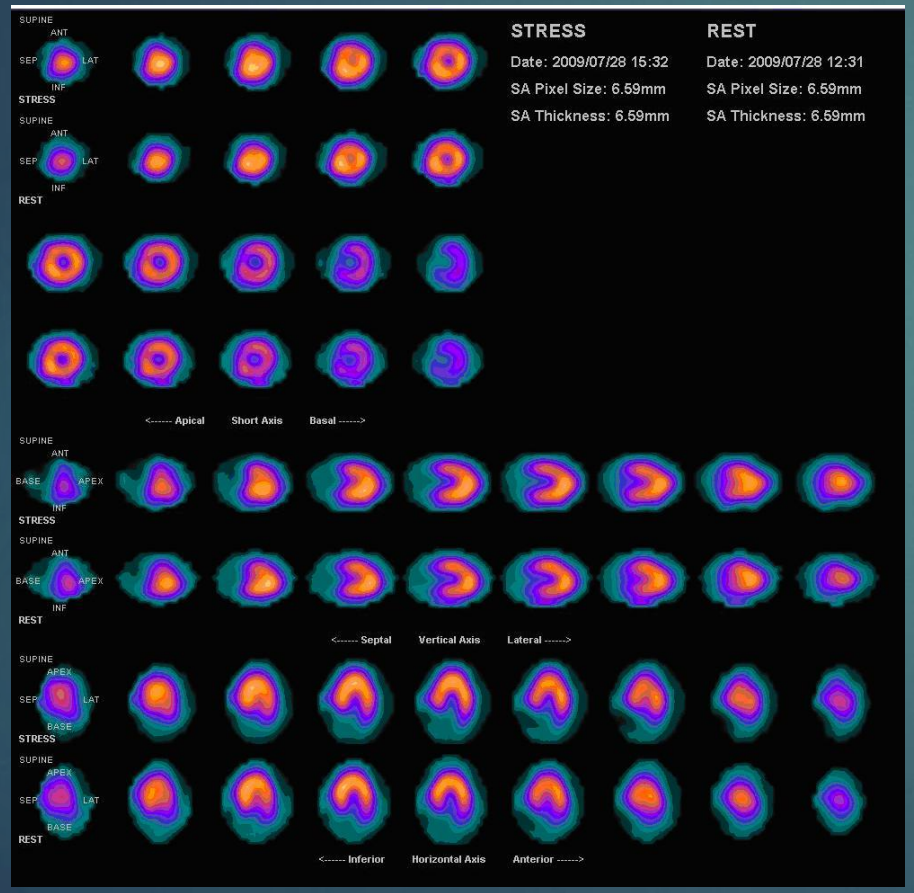
- Single Photon Emission Computed Tomography (SPECT) or Myocardial Perfusion Imaging (MPI)
- Uses 99mTc labeled isotopes (sestamibi ot tetrofomin)
- Injected at rest and during stress (exercise or pharmacological)
- The tracer is extracted by viable myocytes in proportion to regional perfusion
- Gamma Ray photons are emitted from the myocardium and detected and reconstructed in tomographic images
    - -Short axis
    - -Vertical long axis
    - -Horizontal long axis
- Gated imaging also provides LVEF and wall motion assessment

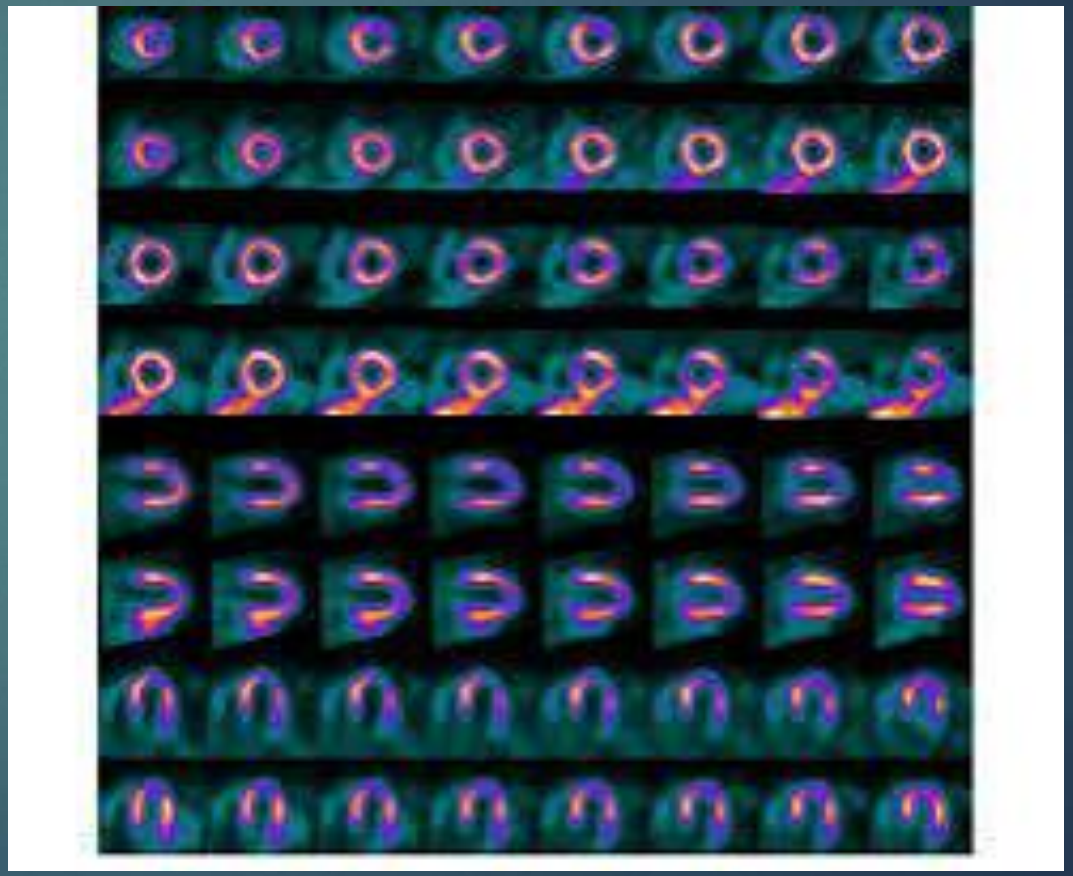
Cardiac SPECT

Cardiac SPECT



Cardiac SPECT





Cardiac SPECT

- Diagnostic Performance

  -Sensitivity: 87-89%

  -Specificity: 73-75%

- High Risk Finding

  -Transient Ischemic Dilation (TID): Marker of diffuse subendocardial hypoperfusion. Often marker of triple vessel disease. Quantified as stress to rest LV cavity volume ratio. Abnormal >1.2

  -Increased lung intake: Reflects elevated left ventricular filling pressures due to stress induced LV dysfunction. Calculated as a lung to heart ratio (LHR). >0.44 for sestamibi

  -Post stress LV dysfunction

Cardiac SPECT

Limitations:

-Biggest is that SPECT measures relative rather than absolute myocardial blood flow. This can lead to balance ischemia (only 25% of patients with 3 vessel CAD had defects in all 3 territories and 12% had completely normal SPECT findings)

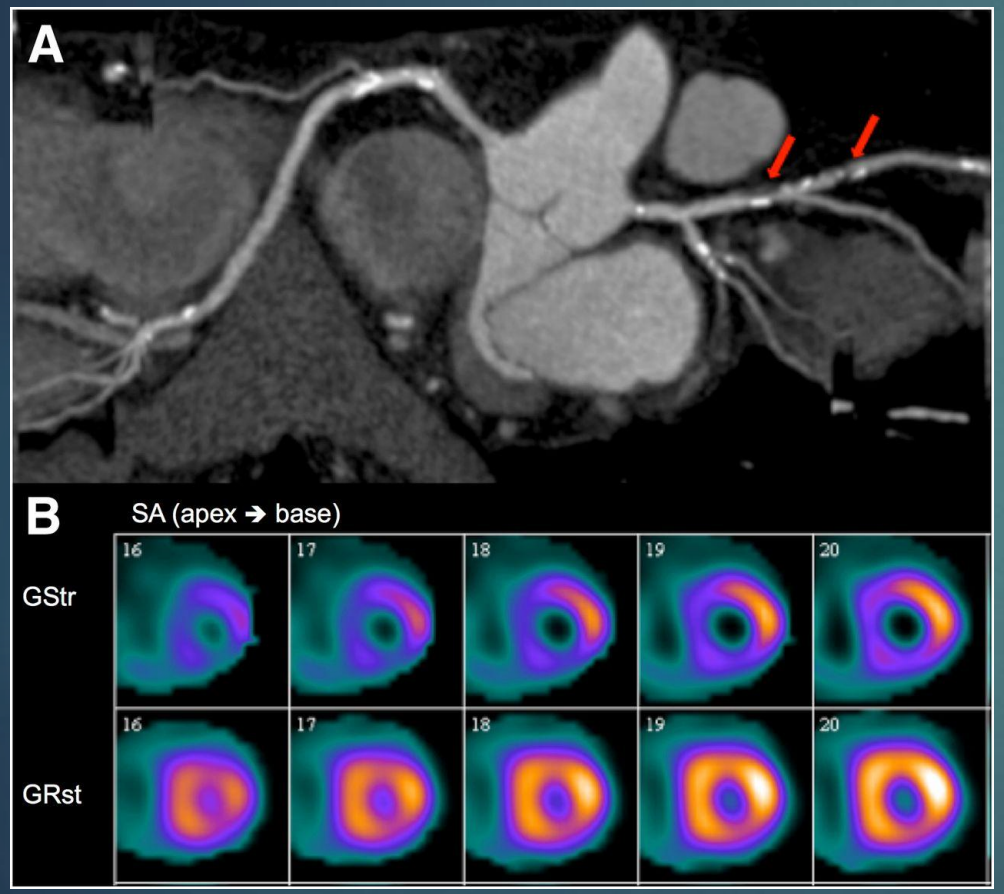
-Soft tissue attenuation: Most common cause of false positives. Breast and diaphragm

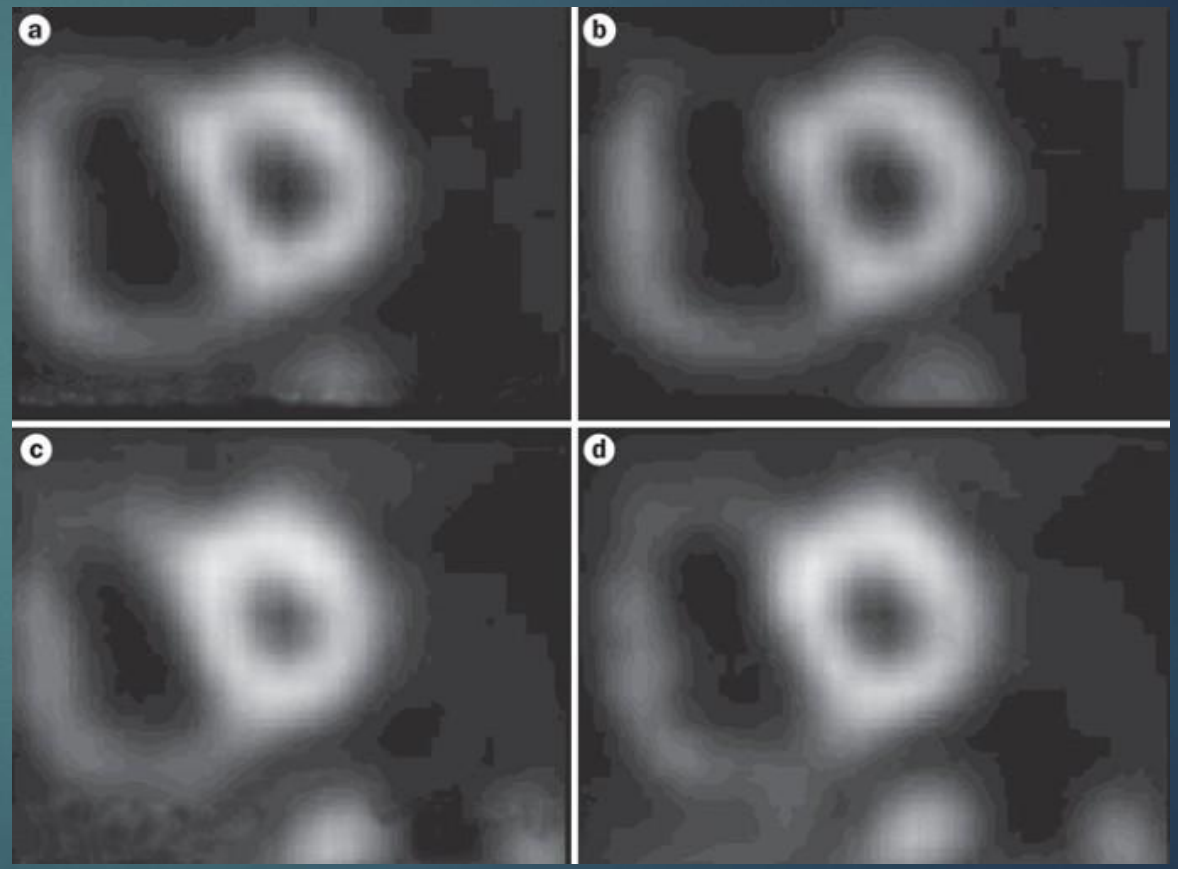
-Limited spatial resolution (10-12 mm vs PET of 4mm and cardiac MRI 1-2mm)

-Patient motion artifact. 15-20 minute acquisition

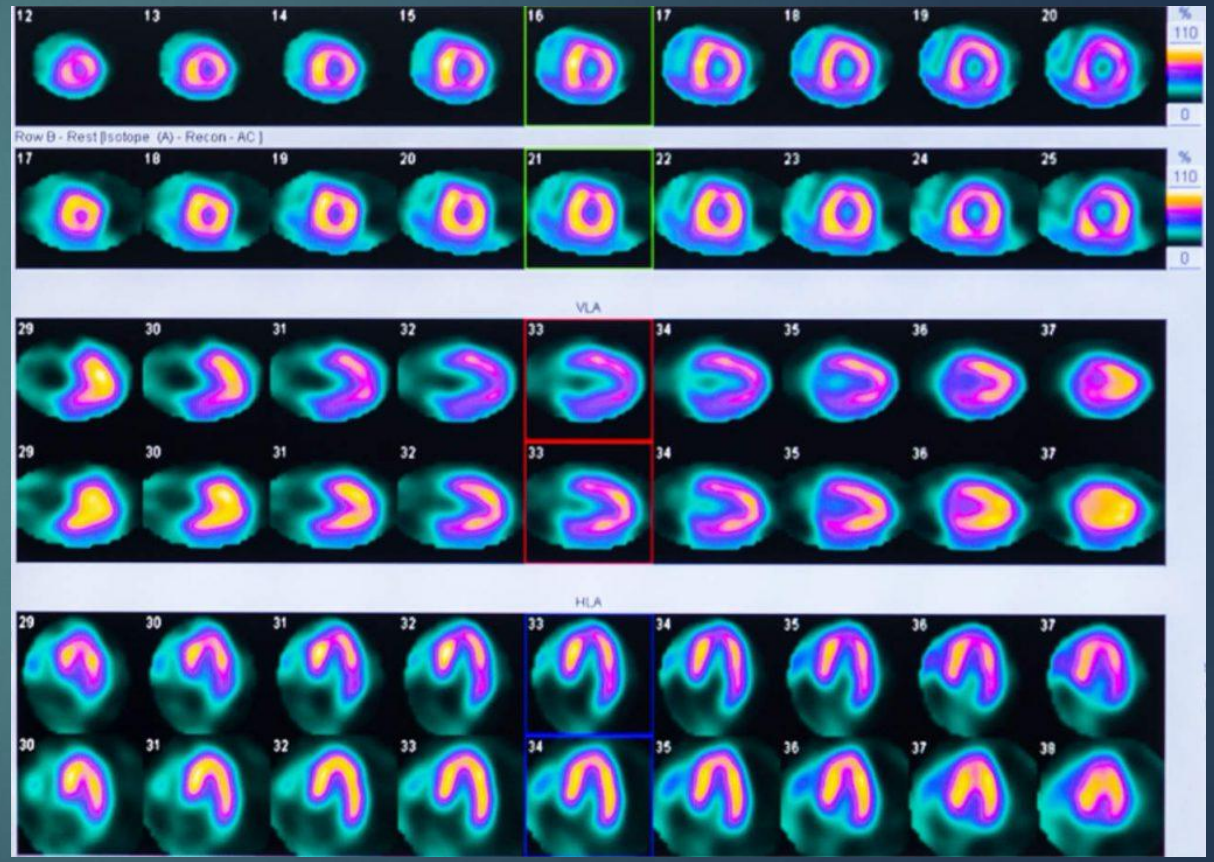
-Radiation exposure. (6-12 mSv vs PET 2 mSv)

Cardiac SPECT





Cardiac PET



Cardiac PET

- Rest/Stress images are acquired
- No exercise needed
- Radiotracers:

  1.Rubidium 82 (half life of 75 sec)
- Stress phase use vasodilators

  1.Regadenoson (Lexiscan)

  2. Adenosine

  3. Dipyridamole
- What does the test evaluate:

  1.Perfusion defects

  2. LV function

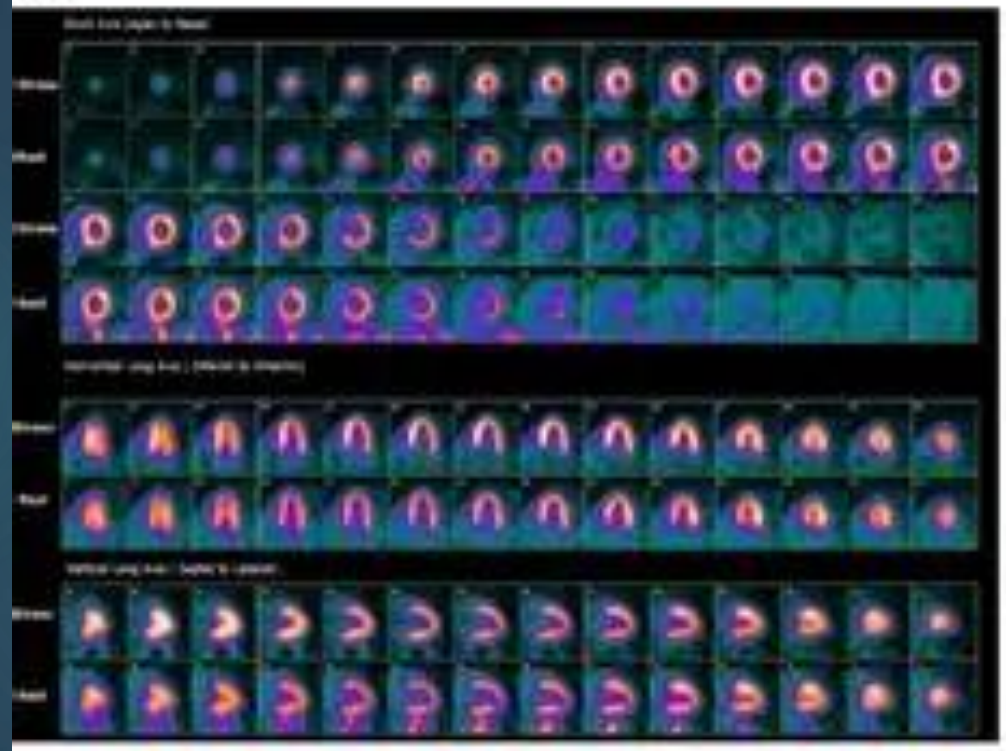
  3.Myocardial blood flow reserve (MBFR): mL/min/g

  -Stress blood flow ÷ Rest blood flow

  -≥ 2.0: Normal

Cardiac PET

A



B

	Rest (ml/g/min)	Stress (ml/g/min)	Reserve Stress/Rest
LAD	1.20	4.13	3.44
LCx	1.12	3.40	3.06
RCA	1.13	4.12	3.60
Global	1.16	3.94	3.38

C

Cardiac PET

Myocardial Blood Flow Reserve (MBFR)

-A reduced MBFR may indicate

1. Multivessel CAD
2. Coronary microvascular dysfunction
3. Endothelial dysfunction

Advantages of Cardiac PET

1. Highest diagnostic accuracy: 90% sensitivity and specificity of 76%
2. Very good in obese patients gives attenuation correction
3. Lower radiation dosage (3 mSv vs 10-13 mSv for SPECT)
4. Does not require a cyclotron like SPECT
5. Fast image acquisition (20 min)
6. Simultaneous coronary artery calcium scoring

Coronary CTA (CCTA)

- Preparation
  -IV access
  -HR is ideally <60 BPM (Beta blockers often given)
  -SL nitro also given to dilate blood vessels
- Contrast injection: 4-6 mL/sec
- CT acquisition
  -ECG-gated images are obtained during a single breath hold (5-10 sec)
- Image reconstruction
  -Coronary anatomy (anomalous coronaries)
  -Presence and severity of plaque (sensitivity of 95-99% and specificity of 80-90%)
  -Plaque composition (Calcium score obtained during test)
    CAC 1-99: Mild plaque
    CAC 100-399: Moderate plaque
    CAC ≥ 400 Extensive plaque

Coronary CTA (CCTA)

- CT derived fractional flow reserve (FFR-CT)

-When there is a stenosis that is intermediate 40%-70%, specialized software can estimate the physiologic significance of the lesion

-Apply computational fluid dynamics to estimate pressure, blood flow velocity and resistance

-FFR > 0.80: Not flow limiting

-FFR ≤ 0.80: Indicate functionally significant ischemia

Limitations:

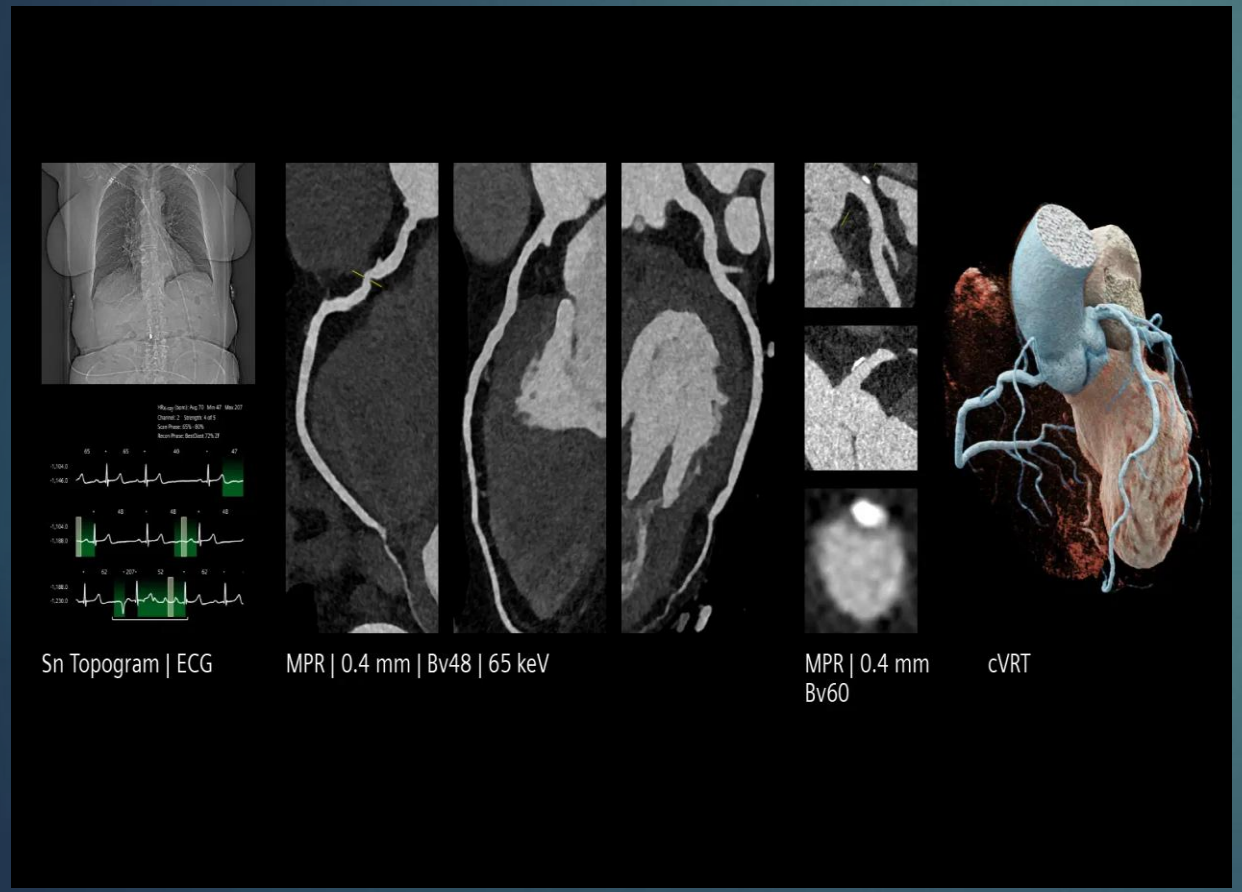
-Iodinated contrast

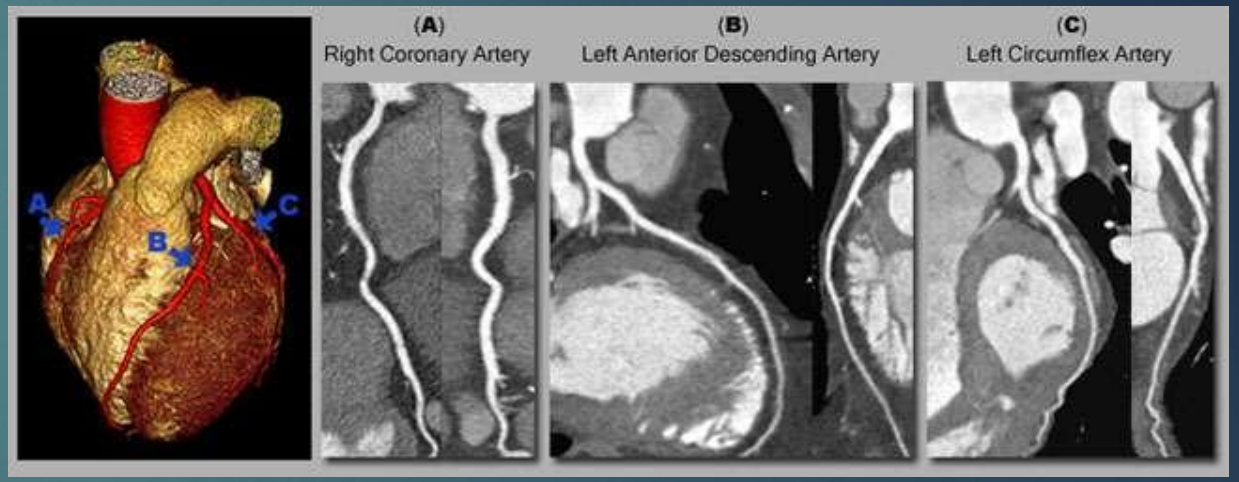
-Radiation exposure (1-5 mSv)

-Image quality decreased with high heart rates and heavy calcification

-Unless coupled with FFR-CT, it does not measure ischemia

Coronary CTA (CCTA)





The Future

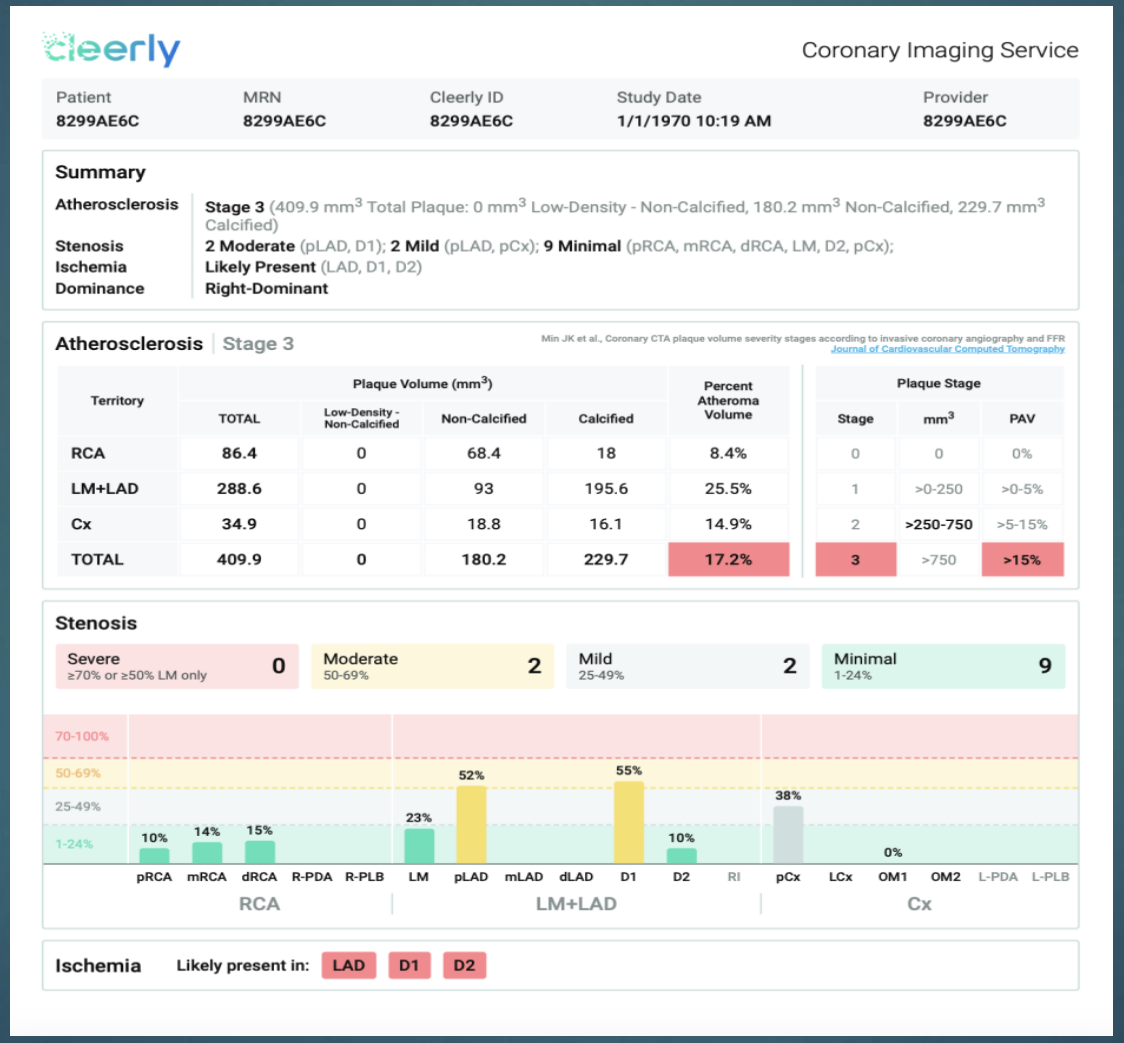
- Cleerly AI
- FDA cleared, AI based software service for quantitative coronary CT angiography (AI-QCT)
- Similar to CCTA but additional AI generated information is provided including plaque burden, plaque type, stenosis severity and future cardiovascular risk
- Not a separate scan. Patient gets CCTA
- Low attenuation plaque ("vulnerable plaque")

  -Plaque that contains lipid rich (fatty), necrotic core

  -Increased risk of plaque rupture

  What makes it low attenuation (<30 HU)

Cleerly AI



cleerly

Coronary Imaging Service

Patient	MRN	Cleerly ID	Study Date	Provider
8299AE6C	8299AE6C	8299AE6C	1/1/1970 10:19 AM	8299AE6C

Summary

Atherosclerosis	**Stage 3** (409.9 mm^3 Total Plaque: 0 mm^3 Low-Density - Non-Calcified, 180.2 mm^3 Non-Calcified, 229.7 mm^3 Calcified)
Stenosis	**2 Moderate** (pLAD, D1); **2 Mild** (pLAD, pCx); **9 Minimal** (pRCA, mRCA, dRCA, LM, D2, pCx);
Ischemia	**Likely Present** (LAD, D1, D2)
Dominance	**Right-Dominant**

Atherosclerosis | Stage 3

Min JK et al., Coronary CTA plaque volume severity stages according to invasive coronary angiography and FFR
Journal of Cardiovascular Computed Tomography

Territory	Plaque Volume (mm^3)				Percent Atheroma Volume	Plaque Stage		
	TOTAL	Low-Density - Non-Calcified	Non-Calcified	Calcified		Stage	mm^3	PAV
RCA	86.4	0	68.4	18	8.4%	0	0	0%
LM+LAD	288.6	0	93	195.6	25.5%	1	>0-250	>0-5%
Cx	34.9	0	18.8	16.1	14.9%	2	>250-750	>5-15%
TOTAL	409.9	0	180.2	229.7	17.2%	3	>750	>15%

Stenosis

Severe	Moderate	Mild	Minimal
≥70% or ≥50% LM only: 0	50-69%: 2	25-49%: 2	1-24%: 9

Ischemia

Likely present in: LAD D1 D2

Cost of stress testing

- ETT: $200-$300
- Stress echo: $250-$400
- SPECT: $1000-$2500
- PET: $3700-$5000
- CCTA: $500-$1500
- CCTA-FFR: Additional $1500-$2000 (After CCTA cost)
- Cleerly AI: Not covered by insurance. $1200-$2000

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