CARDIOVASCULAR HEALTH CLINIC
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Cardiac Stress Testing

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Who is appropriate for stress testing?

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

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

Post-Revascularization or known CAD
-Rarely appropriate within 2 years of PCI or 5 years of CABG

Asymptomatic patients generally not indicated
-Coronary artery calcium score >400
-Asymptomatic with diabetes, peripheral vascular disease or strong family history of CAD

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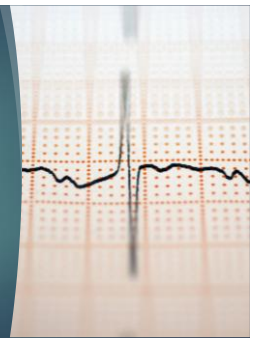
Who is not appropriate for stress testing?

- 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



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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%**

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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 -Paced rhythm

-LVH with repolarization ->0.5 mm ST depressions

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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

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Exercise Treadmill Test/ETT

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

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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)

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Exercise Treadmill Test/ETT

- Exercise protocols: Bruce and modified Bruce

Bruce Protocol for Treadmill Testing

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

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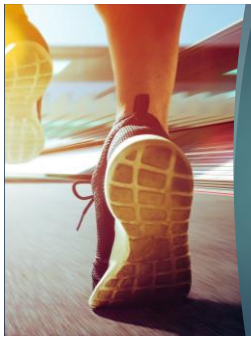

Exercise Treadmill Test/ETT

- 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

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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

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

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

DUKE TREADMILL TEST (DTS)

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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

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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

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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)

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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)

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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%

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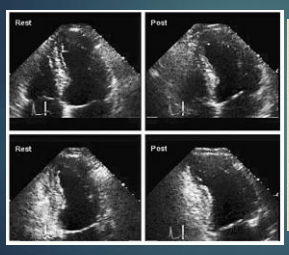
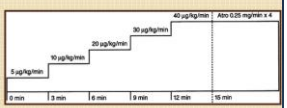
Stress Echocardiogram



Protocol for Dobutamine Stress Echo.



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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

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Cardiac SPECT

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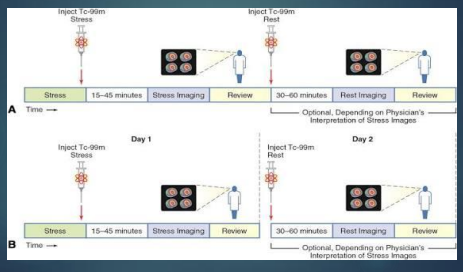
Cardiac SPECT



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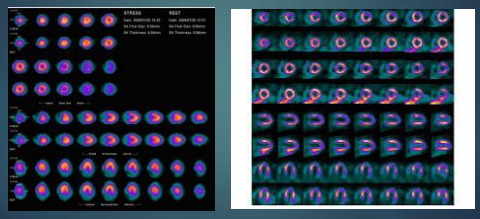
Cardiac SPECT



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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

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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)

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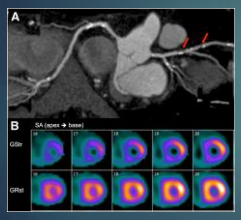
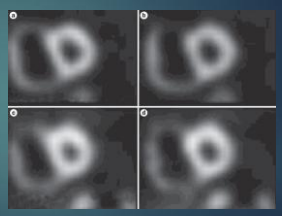
Cardiac SPECT





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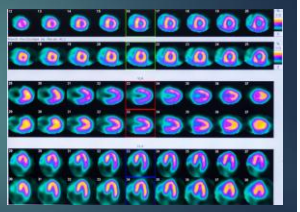
Cardiac PET



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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

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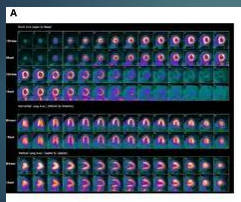
Cardiac PET

A



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	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

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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

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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

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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

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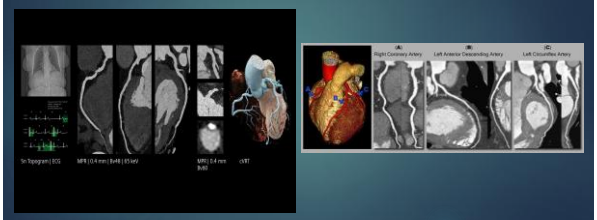
Coronary CTA (CCTA)



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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)

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Cleerly AI

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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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