Stress Echocardiography

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DISCLOSURE

Relevant Financial Relationship(s)
None

Off Label Usage
None
Growth in Services Provided by Cardiologists


Appropriate Use Criteria

ACCF/AHA/ASE/ASNC/HFSA/HRS/SCAI/SCCT/SCMR/STS
2013 Multimodality Appropriate Use Criteria for the Detection and Risk Assessment of Stable Ischemic Heart Disease


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Journal of Cardiac Failure Vol. 20 No. 2 2014
Stress Echo
Appropriate Use

Symptomatic

- ECG uninterpretable
- Unable to exercise
- Intermediate (10-90%) to high (>90%) pretest likelihood**

Asymptomatic

Diamond and Forrester Pre-Test Probability of CAD by Age, Sex and Symptoms

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Sex</th>
<th>Typical/Definite Angina Pectoris</th>
<th>Atypical/Probable Angina Pectoris</th>
<th>Nonanginal Chest Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤39</td>
<td>Men</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>≤39</td>
<td>Women</td>
<td>Intermediate</td>
<td>Very low</td>
<td>Very low</td>
</tr>
<tr>
<td>40-49</td>
<td>Men</td>
<td>High</td>
<td>Intermediate</td>
<td>Intermediate</td>
</tr>
<tr>
<td>40-49</td>
<td>Women</td>
<td>Intermediate</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>50-59</td>
<td>Men</td>
<td>High</td>
<td>Intermediate</td>
<td>Intermediate</td>
</tr>
<tr>
<td>50-59</td>
<td>Women</td>
<td>Intermediate</td>
<td>Low</td>
<td>Intermediate</td>
</tr>
<tr>
<td>≥60</td>
<td>Men</td>
<td>High</td>
<td>Intermediate</td>
<td>Intermediate</td>
</tr>
<tr>
<td>≥60</td>
<td>Women</td>
<td>High</td>
<td>Intermediate</td>
<td>Intermediate</td>
</tr>
</tbody>
</table>

Typical (Definite): 1. Substernal chest pain or discomfort; 2. provoked by exertion or emotional stress; 3. relieved by rest and/or nitroglycerin

Atypical (Probable): Chest pain or discomfort that lacks one of the Characteristics for definite or typical angina.

Nonanginal Chest Pain: Chest pain or discomfort that meets one or none of the Typical angina characteristics.
**Stress Echo**

**Appropriate Use**

- **Symptomatic**
  - ECG uninterpretable
  - Unable to exercise
  - Intermediate (10-90%) to high (>90%) pretest likelihood**

- **Asymptomatic**
  - High risk of CAD event or Intermediate risk (unable to exercise or ECG uninterpretable^)
  - High Coronary Calcium Score (≥100-400 AU)

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**Ischemic Cascade**

- Reduced Perfusion
- Decline in function
- Abnormal ECG
- Symptoms

Occlusion

Sensitivity Specificity
• 16.7% of patients who did not develop chest pain or ischemic ECG changes developed new or worsening regional wall motion abnormalities (+ Exercise Echo)
• Significant prognostic implications for predicting Mortality and MACE.
Abnormal Stress Echo Outcome

Dobutamine

Exercise

It is **Not Always** about the **Anatomy**.
But it is **Always** about the **Physiology**.
Case

- 73 year old male
- No antecedent CV disease history. Asymptomatic
- Reduced functional capacity due to orthopedic limitations
- Hypertension, diabetes
- Pre-operative cardiac risk stratification prior to an orthopedic procedure
2014 ACC/AHA Guideline on Perioperative Cardiovascular Evaluation and Management of Patients Undergoing Noncardiac Surgery

Resting ECG
Objectives

1. Stress Modalities
2. Interpretation
3. Test Characteristics: Diagnosis
4. Prognostic Value
5. Safety
6. Other Uses
7. Appropriate Use
Stress Echocardiography Modalities

**Exercise**
- Treadmill
- Bicycle
  - Supine
  - Upright

**Pharmacologic**
- Dobutamine / Atropine
- Vasodilator
  - Dipyridamole
  - Adenosine

**Other**
- Handgrip
- Pacing

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Stress Echocardiography Treadmill

- Most common is multistage Bruce protocol
- Modified Bruce and Naughton protocols are lower intensity exercise protocols used in those with limited exercise capacity
- Cornell protocol provides a more gradual increase in speed and incline compared to the Bruce protocol
Stress Echocardiography Bicycle

- The cycles are calibrated in kiloponds or Watts which can then be converted to metabolic equivalents (METs).
- It may allow image acquisition during exercise... Doppler information.

Treadmill Versus Supine Bicycle

<table>
<thead>
<tr>
<th>Hemodynamic Effects</th>
<th>Upright</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration and Maximum Workload</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>Heart Rate</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>End-diastolic Volume</td>
<td></td>
<td>&gt;</td>
</tr>
<tr>
<td>Mean Arterial Pressure</td>
<td></td>
<td>&gt;</td>
</tr>
<tr>
<td>Wall Stress</td>
<td></td>
<td>&gt;</td>
</tr>
<tr>
<td>Myocardial Oxygen Demand</td>
<td></td>
<td>&gt;</td>
</tr>
<tr>
<td>Filling Pressures</td>
<td></td>
<td>&gt;</td>
</tr>
</tbody>
</table>
Exercise Stress Echocardiography

Indications To Stop

**Absolute**
- ST elevation ≥ 1 mm in leads without Q waves
- Ventricular tachycardia
- Decrease in systolic blood pressure > 10 mm Hg from baseline with other signs of ischemia
- Moderate to severe angina
- Nervous system symptoms
- Signs of poor perfusion (cyanosis, pallor)
- Technical difficulties with ECG or blood pressure monitoring
- Patient’s desire to stop

**Relative**
- Arrhythmias other than ventricular tachycardia
- ST or QRS changes including horizontal or downsloping ST depression > 2 mm
- Development of bundle branch block or intraventricular conduction delay that cannot be distinguished from ventricular tachycardia
- Increasing chest pain
- Decrease in systolic blood pressure > 10 mm Hg from baseline without other signs of ischemia
- Fatigue, shortness of breath, wheezing, leg cramps, claudication
- Hypertensive response (> 250 mm Hg systolic and/or > 115 mm Hg diastolic)

Stress Echocardiography

Pharmacologic

Inotropic / Dobutamine

- Dobutamine acts directly on β-1 adrenergic receptors → Increase in HR and Contractility (4x in normal subjects and < 2x in those with DCM)
- As dobutamine dose increases there is a greater β-2 response resulting in peripheral vasodilation which may lead to a drop in BP
- Compared with exercise LV volumes and wall stress increase less with dobutamine.
Pharmacologic Vasodilators

- Dipyridamole, adenosine, regadenoson
- Small decrease in BP and increase in HR
- If obstructive epicardial disease or microcirculatory dysfunction

Heterogeneity of coronary blood flow between areas subtended by stenosis Vs. normal coronary arteries.

Segmental Analysis of Left Ventricular Walls

Interpretation

Change in LV Ejection Fraction
- **Increase EF: Normal** (global contractile reserve in patients with no resting dysfunction is defined by \( \geq 5\% \) increase in LVEF)
- **No change or decrease**: Abnormal

Change in LV end-systolic size / volume
- **Decrease: Normal** (Flow reserve is defined by \( \geq 20\% \) increase in forward stroke volume)
- **No change or increase**: Abnormal (**supine bike**)

Regional LV Function Evaluation
- **Wall thickening, Wall motion Score Index**
Segmental Wall Motion Scoring

1 = Normal or hyperdynamic: (systolic increase in thickness >50%)

2 = Hypokinetic: delay in the velocity or onset of contraction (<30-40% systolic increase in thickness)

3 = Akinesis or minimal thickening: <10%

4 = Dyskinetic: Systolic outward motion of the segment

Wall Motion Score Index

Wall Motion

Wall Motion Score Index = 1.0

Stress

Wall Motion Score Index = 38/16 = 2.38
### Interpretation Of Wall Motion

<table>
<thead>
<tr>
<th>Rest</th>
<th>Stress</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normokinetic</td>
<td>Normal-hyperkinetic</td>
<td>Normal</td>
</tr>
<tr>
<td>Hypokinetic</td>
<td>Akinetic / Dyskinetic</td>
<td>Ischemic Response</td>
</tr>
<tr>
<td>Wall Motion abnormality</td>
<td>(segment worsens function)</td>
<td></td>
</tr>
<tr>
<td>Resting Dysfunction</td>
<td>Fixed / No Change in Function</td>
<td>Infarct / Necrotic</td>
</tr>
<tr>
<td>Resting Dysfunction</td>
<td>Slow Sustained Improvement</td>
<td>Stunning or Cardiomyopathy</td>
</tr>
<tr>
<td>Resting Dysfunction</td>
<td>Biphasic Response</td>
<td>Hibernating</td>
</tr>
<tr>
<td>Akinetic</td>
<td>Dyskinetic</td>
<td>Passive / Mechanical</td>
</tr>
</tbody>
</table>

### Cause of Wall Motion Abnormalities

**Wall Motion Abnormalities at Rest**

- **Ischemic heart disease**
  - Infarction
  - Stunned / Hibernating
- **Conduction**
  - Pacing
  - LBBB
- **Cardiomyopathy**
- **Myocarditis**
- **Right ventricular volume / pressure overload**
### Cause of Wall Motion Abnormalities

<table>
<thead>
<tr>
<th>Wall Motion Abnormalities at Rest</th>
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<tbody>
<tr>
<td>• Ischemic heart disease</td>
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<tr>
<td>- Infarction</td>
</tr>
<tr>
<td>- Stunned / Hibernating</td>
</tr>
<tr>
<td>• Conduction</td>
</tr>
<tr>
<td>- Pacing</td>
</tr>
<tr>
<td>- LBBB</td>
</tr>
<tr>
<td>• Cardiomyopathy</td>
</tr>
<tr>
<td>• Myocarditis</td>
</tr>
<tr>
<td>• Right ventricular volume / pressure overload</td>
</tr>
</tbody>
</table>

### Wall Motion Abnormality Conduction
Arterial Distribution

Wall Motion Abnormality
Conduction

### Cause of Wall Motion Abnormalities

<table>
<thead>
<tr>
<th>Wall Motion Abnormalities at Rest</th>
<th>Wall Motion Abnormalities during Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ischemic heart disease</td>
<td>Ischemia with obstructive CAD</td>
</tr>
<tr>
<td>- Infarction</td>
<td></td>
</tr>
<tr>
<td>- Stunned / Hibernating</td>
<td></td>
</tr>
<tr>
<td>• Conduction</td>
<td>Ischemia in the absence of epicardial obstruction</td>
</tr>
<tr>
<td>- Pacing</td>
<td>- Hypertensive response</td>
</tr>
<tr>
<td>- LBBB</td>
<td>- Microvascular disease</td>
</tr>
<tr>
<td>• Cardiomyopathy</td>
<td>Cardiomyopathy</td>
</tr>
<tr>
<td>• Myocarditis</td>
<td>Rate-related LBBB</td>
</tr>
<tr>
<td>• Right ventricular volume /</td>
<td>Pulmonary</td>
</tr>
<tr>
<td>pressure overload</td>
<td></td>
</tr>
</tbody>
</table>

### Wall Motion Abnormality

**Diameter Stenosis**

- **< 85% narrow rest**
  - Collaterals
  - Level of exertion/stress
  - Wall thickness

- **> 50% narrowing stress**
  - Collaterals
  - Level of exertion/stress
  - Wall thickness
Transmural Extent of Infarct Thickness and Systolic Thickening

Systolic Thickening (%)

Infarct Thickness (%)

-20 0 1-20 21-40 41-60 61-80 81-100

p<0.001

p = 0.27

Lieberman et al. Circulation 1981;63;739-46

Quantitative Evaluation of Left Ventricular Function
Chordal Center Line Analysis (Centroids)
Translation and Rotation

Floating Epicardial Center of Mass
Centroid

Test Characteristics:
Diagnosis - CAD

Schuijf Eur J Nucl Med Mol Imaging 2006;33:93
Impact of Pretest Probability

100 Patients
Pre test Likelihood 10%

CAD + 10 pts
Sensitivity = 90%
Specificity = 80%

CAD - 90 pts

false - 1 pts
True + 9 pts
false + 18 pts
True - 72 pts

27 + tests:
33% positive predictive value

Impact of Pretest Probability

100 Patients
Pre test Likelihood 40%

CAD + 40 pts
Sensitivity = 90%
Specificity = 80%

CAD - 60 pts

false - 4 pts
True + 36 pts
false + 12 pts
True - 48 pts

48 + tests:
75% positive predictive value
**Test Characteristic: Diagnostic Criteria**

- **Sensitivity**
  - 1 Segment, > 1 Segment, LV dilation

- **Specificity**

**Test Characteristics**

Exercise Echo vs SPECT TI

- **Sensitivity**
  - 1 vessel: Ex Echo 58%, SPECT TI 61%
  - 2 vessels: Ex Echo 86%, SPECT TI 86%
  - 3 vessels: Ex Echo 94%, SPECT TI 94%

- **Specificity**
  - 1 vessel: Ex Echo 88%, SPECT TI 81%
  - 2 vessels: Ex Echo 81%, SPECT TI 81%
  - 3 vessels: Ex Echo 94%, SPECT TI 94%

*Quinones et al: Circ, 1992*
Detection/Exclusion CAD

Risk of adverse event

Prognosis

Diagnosis

Stress Echocardiography

Normal SECHO

Physical or Pharmacologic

Very Low Risk

• < 1% per year risk of MI, cardiac death or late revascularization

Low Risk

• 1-3% per year risk of MI, cardiac death or late revascularization
  -submaximal stress (men <7 METS, women < 5 METS)
  -LVEF <40%

Safety of Stress Echocardiography Supervised by Registered Nurses: Results of a 2-Year Audit of 15,404 Patients

Garvan C. Kane, MD, PhD, Mary J. Hepinstall, RN, Glenda M. Kidd, RN

<table>
<thead>
<tr>
<th></th>
<th>ExEcho n=8592</th>
<th>DSE n= 6755</th>
<th>P value</th>
<th>Total n = 5349</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Complication Rate</td>
<td>8 (0.09%)</td>
<td>47 (0.7%)</td>
<td>&lt;0.001</td>
<td>55 (0.36%)</td>
</tr>
<tr>
<td>Arrhythmia Requiring Rx</td>
<td>4 (0.05%)</td>
<td>39 (0.58%)</td>
<td>&lt;0.001</td>
<td>43 (0.28%)</td>
</tr>
<tr>
<td>SVT / AF</td>
<td>4 (0.05%)</td>
<td>33 (0.49%)</td>
<td>&lt;0.001</td>
<td>37 (0.24%)</td>
</tr>
<tr>
<td>VT / VF</td>
<td>0</td>
<td>6 (0.09%)</td>
<td>&lt;0.005</td>
<td>6 (0.04%)</td>
</tr>
<tr>
<td>Markedly + / Prolonged CP requiring hospitalization</td>
<td>3 (0.03%)</td>
<td>5 (0.07)</td>
<td>0.56</td>
<td>8 (0.05%)</td>
</tr>
<tr>
<td>Symptomatic Hypotension requiring hospitalization</td>
<td>1 (0.01%)</td>
<td>3 (0.04%)</td>
<td>0.44</td>
<td>4 (0.03%)</td>
</tr>
<tr>
<td>Transfer to Hospital</td>
<td>5 (0.06%)</td>
<td>21 (0.31%)</td>
<td>0.0005</td>
<td>26 (0.17%)</td>
</tr>
<tr>
<td>Cardiac Rupture or Death</td>
<td>0</td>
<td>0</td>
<td>----</td>
<td>0</td>
</tr>
</tbody>
</table>

*Compared with previous reports and not substantial increase in safety of stress echocardiography supervised by physicians.

Stress Echocardiography
Diastolic Stress Test
What do we expect?

E vel

e’ vel
Case

- 55 year old male
- No known CAD
- Hypertension & exertional dyspnea

Stress Echo
Diastolic Stress Test

Pre

E=0.6  E/e’=8

e’=0.8

Post

E=0.9  E/e’=8

e’=0.12

Case

• 67 year old male
• No known CAD
• Diabetes and hypertension
• Complains of dyspnea on exertion (NYHA II)
Important Observations From the Initial Studies

- Those with increased filling pressure at baseline will further increase filling pressure with exercise.
- Therefore, those who benefit most from diastolic stress testing are those with normal resting LVFP but abnormal relaxation (grade I).

Exercise-limiting Dyspnea

- Ischemia: 10%
- Pulmonary HTN: 6%
- Elevated LVFP: 14%

None: 46%

Ischemia: 27%
Pulmonary HTN: 22%
Elevated LVFP: 34%
Any abnormality: 54%

n=630

Elevated LVFP: ex. E/e’ >13
Pulm HTN: ex. RVSP >50 mm Hg

Reduced Exercise Capacity

Women <5 METs, Men <7 METS

- Ischemia: 12.5%
- Pulmonary HTN: 11.7%
- Elevated LVFP: 19.5%

None: 25%

Ischemia: 32%
Pulmonary HTN: 36%
Elevated LVFP: 45%
Any abnormality: 75%

n=128

Elevated LVFP: ex. E/e’ >13
Pulm HTN: ex. RVSP >50 mm Hg
Treadmill Exercise Echo (2010→)
Mayo Clinic, Rochester, MN

Baseline
- EF, RWMA's, valves
- Color flow

Post-exercise
- Quads for EF, LVESV resp, RWMA's
- RV systolic pressure
- LV filling pressure
- TR Vmax
- Then TR Vmax
- Then E, e', E/e'

Depressed EF / Myocardial Disease and Normal EF
When Is Diastolic Stress Testing Indicated?

Grading LV Filling Pressures
Depressed EF / Myocardial Disease and Normal EF

- E/A ≤ 0.8 + E ≤ 50cm/s
- E/A > 0.8 + E > 50 cm/ OR E/A > 0.8 - < 2
- E/A ≥ 2

Rule of 2's
1. AV E/e' > 14
2. TR > 2.8 m/s

Normal LAP
Grade I DD
Grade II DD
Grade III DD

If symptomatic
- Consider CAD
- Proceed to Diastolic Stress Test

If negative
- Rule Out CAD
- Proceed to Diastolic Stress Test

Rule of 2's

If negative
- Rule Out CAD
- Proceed to Diastolic Stress Test

If negative
- Rule Out CAD
- Proceed to Diastolic Stress Test

If positive
- Consider CAD
- Diastolic Stress Test
**Diastolic Stress Test Interpretation**

**Definitely Abnormal**
1. Average E/e’ > 14 or Septal >15
2. Septal e’ < 7 cm/sec or
   Lateral e’ < 10 cm/sec
3. Peak TR velocity > 2.8 m/sec

**Normal**
1. Average (or septal) E/e’ < 10
2. Peak TR velocity < 2.8 m/sec

---

**Normal RV Systolic Pressure**

<table>
<thead>
<tr>
<th>Post-TM Exercise</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age group (yr)</strong></td>
<td><strong>RVSP (mm Hg)</strong></td>
</tr>
<tr>
<td>&lt;40</td>
<td>33</td>
</tr>
<tr>
<td>40-49</td>
<td>50</td>
</tr>
<tr>
<td>50-59</td>
<td>53</td>
</tr>
<tr>
<td>60-69</td>
<td>54</td>
</tr>
<tr>
<td>≥70</td>
<td>56</td>
</tr>
</tbody>
</table>

95% limit

**R 5 mm Hg**

Kane et al. 2010 (n=469), Slide courtesy Rob McCully
Summary

1. Exertional dyspnea portends a poor prognosis (> angina).
2. An exercise induced increase in E/e’ relates to changes in filling pressure and its finding has adverse prognostic significance.
3. The post exercise E/e’ can be measured minutes into recovery, ideally as soon as the discrete waves are appreciated.
4. The ideal patient is one with exertional dyspnea and baseline grade I diastolic dysfunction.
Class IIa
Exercise testing is reasonable in selected patients with asymptomatic severe VHD to
1) confirm the absence of symptoms, or
2) assess the hemodynamic response to exercise, or
3) determine prognosis.

(Level of Evidence: B)
Severe Valve Disease
Asymptomatic (Stage C)

Positive Stress Test

Valve Intervention

LVEF > 50%
LVESE < 50mm
LVDD < 65mm

LVEF > 50%
Vmax < 5m/s
ΔPmean < 60mmHg
Normal ETT
ΔVmax < 0.3m/s/yr

LVEF > 60%
LVESE < 40mm
Sinus Rhythm
PASP < 50mmHg
Successful Repair > 95%
Or Mortality ≥ 1%

Very Severe MVA ≥ 1cm² T₁/₂ ≥ 220
- Unfavorable morphology,
LA clot, > mild MR
Severe MVA ≥ 1.5cm² T₁/₂ ≥ 150
- Sinus rhythm
- Afib with unfavorable morphology,
LA clot, > mild MR

Valve Regurgitation*
Aortic Stenosis
Mitrail Regurgitation
Mitrail Stenosis (rheumatic)

* ACC/AHA not ESC guidelines

Stress Echo in Valvular Heart Disease

VHD (MR, MS, AR, AS) severity not matching with symptoms

Asymptomatic moderate-severe VHD (MR, MS, AR, AS)

Symptoms, Δ blood pressure, exercise tolerance

Valve

Δ 18-20mmHg MPG in AS
MPG > 15-18mmHg in MS
> 10-13mm² EROA in MR

Δ < 4-5% LVEF (lack of CR)
Δ < 2% GLS (lack of CR)
Δ SV < 20% (lack or FR)
Δ WMSI (ischemia)
LV dyssynchrony
RV dysfunction (TAPSE < 19mm)

Match symptoms with the cardiac involvement

Risk stratification

Guide decision making and guide optimal timing for valve intervention

Baseline Doppler hemodynamics

Class IIa
AVR is reasonable in symptomatic patients with low-flow/low-gradient severe AS with reduced LVEF (stage D2) with a low-dose dobutamine stress study that shows an aortic velocity ≥ 4.0 m/s (or mean pressure gradient ≥ 40 mm Hg) with a valve area < 1.0 cm² at any dobutamine dose.

True Severe AS (D2) IIa

Pseudo Severe AS

Conclusion

1. Understand the differences and indications for the various stress modalities.
2. Know the walls and their coronary supply.
3. Understand the methods and interpretation of wall motion.
5. Understand the test characteristics.
6. Emerging uses: Valve Disease and SOB.
7. Appropriate use.