Standard & Cardiopulmonary Exercise Testing

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Prof. Paul Iaizzo’s Physiology Lab, PHSL 3701

Standard Stress Exercise Testing

Options

<table>
<thead>
<tr>
<th>Test</th>
<th>HRS</th>
<th>ECG</th>
<th>Nuclear (SPECT/Planar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treadmill</td>
<td>High</td>
<td>Low</td>
<td>Treadmill Stress</td>
</tr>
<tr>
<td>Chemical</td>
<td>Low</td>
<td>High</td>
<td>Chemical Stress</td>
</tr>
</tbody>
</table>

Bricker, E. Compass. 5 Types of Cardiac Stress Tests—They are Not All the Same. https://www.compassphs.com

Bicycle & Pharmacologic Stresses...

Supine Bicycle
Dobutamine Administration

University of Minnesota ECG Lab
**Stress Echocardiogram...**

Combination of 2D echocardiography with a physical or pharmacological stress.

**Echocardiography...**

Image courtesy of the Mayo Clinic

**Who Can Be Stress Exercise Tested?**

- Low to intermediate pretest probability of CAD (Diamond & Forrester Scale).
- Known CAD with change in clinical status.
- Low to intermediate risk stable angina, free of active ischemia or heart failure for 12–24 hr after presentation.
- Risk stratification prior to discharge or surgery.

Pretest Probability...

| Table 1: Discreased and Forneter Score for Proxect Probability of Coronary Artery Disease |
|-----------------|-----------------|-----------------|-----------------|
| Age | Gender | Typical | Ischemic | Angiographic | Nonangiographic |
| ≤ 39 | Male | Intermediate | Intermediate | Intermediate | Lower |
| 40 to 50 | Male | High | Intermediate | Intermediate | Lower |
| 50 to 60 | Male | High | Intermediate | Intermediate | Lower |
| ≥ 60 | Male | High | Intermediate | Intermediate | Lower |

Electrocardiogram

Interpretation...

- ST segment deviations:
  - Normally the action potential duration is longer in the endocardium than the epicardium, and repolarization proceeds from the endocardium to the epicardium.
  - The endocardium is more susceptible to ischemia, and with ischemia the action potential shortens, and electrical gradients change causing ST depression.
  - Abnormal: 1mm or more of J point depression measured from the PQ junction, with a relatively flat ST-segment at 60ms after the J point (ST60), in three consecutive beats with a stable baseline. (With heart rate greater than 130/min – if lower use ST80)

ST Segment Abnormality...

- The sooner ST-segment depression develops and the longer it lasts during recovery suggests more severe CAD.
- Some patients with CAD (10%) develop abnormal ECG changes only during recovery.
- Other Findings
  - Inability to increase systolic BP during exercise suggests LV dysfunction or ischemia. (Stop the test if there is a fall in BP by more than 10 mm Hg).
  - Associated symptoms: angina, heart rate and workload at time of changes.
  - Ventricular tachycardia, onset of LBBB (if chronic, ST changes during exercise are not diagnostic), transient intraventricular conduction delay (LDDBB, RBBB or hemiblocks).

Duke Treadmill Score...

\[
\text{Duke Treadmill Score} = \text{Exercise Duration (min)} - \frac{\text{ST Depression (mm)}}{5} - 4 \left( \text{Angina Index} \right)
\]

**Angina Index**

- 0 = none, 1 = typical angina, 2 = angina causing test cessation

<table>
<thead>
<tr>
<th>Score</th>
<th>Risk Group</th>
<th>Stenosis</th>
<th>Multivessel Disease</th>
<th>1-Year Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 5</td>
<td>Low</td>
<td>40.1%</td>
<td>23.7%</td>
<td>0.05%</td>
</tr>
<tr>
<td>3 to 4</td>
<td>Intermediate</td>
<td>67.3%</td>
<td>55.0%</td>
<td>1.25%</td>
</tr>
<tr>
<td>&lt;3</td>
<td>High</td>
<td>98.8%</td>
<td>93.7%</td>
<td>5.25%</td>
</tr>
</tbody>
</table>


Cardiopulmonary Exercise Testing*  
*Abbreviated CPET or CPX

Evaluation of dyspnea of unclear etiology after routine cardiopulmonary testing.  
Determination of functional impairment in exercise intolerance.  
Heart failure.  
Evaluation for exercise–induced bronchospasm, and response to therapy.  
Preoperative evaluation prior to lung and/or heart surgery.  
Muscle–metabolic disorders.  
Athlete monitoring.

Indications for CPET...
Prof. Steven S. Saliterman, Also referred to as VT, Ventilatory Threshold - gases or lactate

Table 1: Parameters measured during CPET

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume (VT)</td>
<td>Inspiratory Reserve (IR) or IR/VT</td>
</tr>
<tr>
<td>Minute Ventilation (V̇e)</td>
<td>VT x RR x HR</td>
</tr>
<tr>
<td>Maximal VT (V̇emax)</td>
<td>Maximal Inspiratory Reserve (MIR)</td>
</tr>
<tr>
<td>Rate of O2 consumption (V̇O2 uptake)</td>
<td>Maximal VT (V̇emax) / Maximal Inspiratory Reserve (MIR)</td>
</tr>
<tr>
<td>Rate of CO2 excretion (V̇CO2)</td>
<td>Maximal VT (V̇emax) / Maximal Inspiratory Reserve (MIR)</td>
</tr>
</tbody>
</table>

- **MET (metabolic equivalent)**: The ratio of the work metabolic rate to the resting metabolic rate. One MET is defined as 1 kcal/kg/hour and is roughly equivalent to the energy cost of sitting quietly.
- **MMV (maximum voluntary ventilation)**: a measure of the maximum amount of air that can be inhaled and exhaled within one minute.
- **RER (respiratory exchange ratio)**: The respiratory exchange ratio is the ratio between the amount of carbon dioxide produced in metabolism and oxygen used. The ratio is determined by comparing exhaled gases to room air.
- **Vi (minute ventilation)**: the volume of gas inhaled (inhaled minute volume) or exhaled (exhaled minute volume) from a person’s lungs per minute.
- **Ventilatory Equivalents for O2 and CO2 (VE/VO2 and VE/VCO2)**: describes the ratio of ventilation (minute volume) to oxygen intake, or to carbon dioxide output.
  - Measure of instantaneous ventilatory and gas exchange efficiency.
  - How many liters does the patient have to breath in order to uptake 1 liter of oxygen or to produce 1 liter of carbon dioxide?
AT (Anaerobic Threshold) or Vt (Ventilatory Threshold): refers to the point during exercise at which ventilation starts to increase at a faster rate than VO₂ (volume of oxygen). Two thresholds;
  - VT1
    - It is a marker of intensity that can be observed in a person’s breathing at a point where lactate begins to accumulate in the blood.
    - As the intensity of the exercise begins to increase, VT1 can be identified at the point where the breathing rate begins to increase.
  - VT2
    - At VT2, lactate has quickly accumulated in the blood and the person needs to breathe heavily.
    - At this rapid rate of breathing, the exerciser can no longer speak.

Tidal volume (symbol VT, TV) is the lung volume representing the normal volume of air displaced between normal inhalation and exhalation when extra effort is not applied. In a healthy, young human adult, tidal volume is approximately 500 mL per inspiration or 7 mL/kg of body mass.
Peak VO₂ is generally considered a global marker of cardiorespiratory fitness. It represents the combination of ventricular systolic and diastolic function (cardiac output), vascular function (O₂ delivery), and peripheral skeletal muscle metabolic capacity (O₂ utilization). According to the Fick principle, VO₂ is determined by heart rate, stroke volume, the concentration of hemoglobin and its capacity to transport oxygen, as well as the difference between arterial oxygen saturation (reflecting lung problems and other right-to-left shunts) and mixed venous oxygen saturation (reflecting peripheral blood flow distribution and oxygen extraction in the muscle).
Recall: VE/VCO₂ or VE/VO₂ (ventilatory equivalent): describes the ratio of ventilation (minute volume) to oxygen intake, or to carbon dioxide output.

Recall: VE/VCO₂ (ventilatory equivalent): describes the ratio of ventilation (minute volume) to carbon dioxide output.

Recall: VE/VCO₂ (ventilatory equivalent): describes the ratio of ventilation (minute volume) to carbon dioxide output.
Exercise oscillatory breathing
Abnormal breathing pattern often seen in heat stroke
Not a universal definition
Sustained visible fluctuations in ventilations support a poorer prognosis.


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Cardiac limitations
Oxygen pulse (Dp/dt) < 80% predicted or flattened or falling curve
Chronotropic incompetence
Rise rate recovery < 12 beats per minute after 1 minute of recovery
Standard electrocardiographic criteria for ischemia

Pulmonary limitations
Peak exercise respiratory rate > 50 per minute
Ventilatory reserve (peak V̇E/V̇O2) < 15%
Oxygen desaturation by pulse oximetry
Abnormal results on perfusion scanning
Abnormal exercise flow-volume loops

Muscular disease
Submaximal cardiac and respiratory responses
Ventilatory (anaerobic) threshold < 40% of peak VO2
Elevated lactate at any given level of submaximal work


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University of Minnesota Single Photon Emission Tomography (SPECT) - CT

Table IX

<table>
<thead>
<tr>
<th>Gas Exchange Variables</th>
<th>Recommendation</th>
<th>Level of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET VO2</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>VO2, VO2 slope</td>
<td>2</td>
<td>B</td>
</tr>
<tr>
<td>NVE</td>
<td>2a</td>
<td>B</td>
</tr>
<tr>
<td>FIO2</td>
<td>2b</td>
<td>B</td>
</tr>
</tbody>
</table>

Table IX - Gas exchange variables for primary and secondary HFrEF generating in Heart Failure and reduced Ejection Fraction.

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Single photon emission tomography (SPECT) - CT

• Requires injection of a radiopharmaceutical.
• 3D nuclear scans are obtained by rotating the gamma ray camera around the patient (360 degrees).
• Image data from the nuclear scan and subsequent CT scan (also rotating 360 degrees) are fused (merged) together.
• This allows for digital compensation of interfering bone and tissue structures to the emitted gamma rays, giving a much cleaner picture.
• Lexiscan is a prescription medication used in a cardiac nuclear stress test (myocardial perfusion imaging.)
• Lexiscan works by increasing blood flow in the coronary arteries, and is given by IV in preparation for a myocardial perfusion imaging (MPI) test.
• The patient has a SPECT-CT before and after administration of Lexiscan.

Stress CMR (Cardiovascular MRI)

- Imaging stress test based on MRI (magnetic resonance imaging).
  - Only done in about 20 centers presently.
- Based on the assessment of myocardial perfusion during pharmacological stress testing with coronary vasodilators.

Types of stress CMR:
- Exercise stress CMR.
- Dobutamine stress CMR (inducible wall motion abnormalities).
- Vasodilator stress CMR.
  - Regadenoson (Lexiscan):
    - Selective A2A adenosine receptor agonist and a vasodilator.
    - Single dose of 0.4 mg for all (5cc over 10s).
    - Increases coronary artery vasodilatation to normal coronary, but it does not increase blood flow downstream to stenotic arteries as the arteriolar bed is already maximally dilated.
    - This allows the identification of areas of hypoperfused myocardium distal to a significant stenosis, which appear as a low signal intensity (dark) area on stress perfusion images.


Cardiovascular MRI...

Late gadolinium enhancement.

Rest
Peak adenosine infusion, short axis - base, mid and apex slices.

Summary

- Traditional Exercise Testing
  - Treadmill & ECG.
  - Treadmill & Echocardiography.
  - Pharmacological stressing.
  - Treadmill or chemical nuclear (SPECT-CT).
- Echocardiography
- Stress ECG interpretation
- Cardiopulmonary Stress Exercise Testing
  - Metabolic cart plus bicycle or treadmill stress.
  - Most useful CPT variables.
- Cardioperfusion Imaging
  - SPECT-CT/Lexiscan/Nuclear Scan and PET
- Stress CMR – the new standard for CAD evaluation
Indication for CPET:
- Evaluation of dyspnea of unclear etiology after routine cardiopulmonary testing.
- Determination of functional impairment in exercise intolerance.
- Heart failure.
- Evaluation for exercise-induced bronchospasm, and response to therapy.
- Preoperative evaluation prior to lung and/or heart surgery.
- Muscle–metabolic disorders.
- Athlete monitoring.

Addendum:
- Sample 9 Panel display of CPET, normal vs lung & heart disease.

