Standard & Cardiopulmonary Exercise Testing

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Standard Stress Exercise Testing

Options

<table>
<thead>
<tr>
<th>Stress</th>
<th>Holter</th>
<th>Echo</th>
<th>Nuclear (Pharmacologic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bicycle & Pharmacologic Stresses...

Supine Bicycle

Dobutamine Administration
**Stress Echocardiogram...**

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

Image courtesy of Asian Heart & Vascular Center

Image courtesy of the Mayo Clinic

Image Courtesy of the Cleveland Clinic

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**Echocardiography...**

Image Courtesy of the Cleveland Clinic

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**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>
<thead>
<tr>
<th>Age Group</th>
<th>Sex</th>
<th>Typical</th>
<th>Probable Angina</th>
<th>High Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 30</td>
<td>Male</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>≤ 30</td>
<td>Female</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>40 to 49</td>
<td>Male</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>40 to 49</td>
<td>Female</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>50 to 59</td>
<td>Male</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>50 to 59</td>
<td>Female</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>≥ 60</td>
<td>Male</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>≥ 60</td>
<td>Female</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
</tbody>
</table>

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Table 1. Classified and Formsum Score for Pretest Probability of Coronary Artery Disease

Electrocardiogram

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)

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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 (LDBB, RBBB or hemiblocks).


Cardiopulmonary Exercise Testing*  
*Abbreviated CPET or CPX

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Vyntus® CPX Metabolic Cart.

Indications 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.

Table 1: Parameters measured during CPET

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T Tests Volume (VT)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>Minute Ventilation (VT)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>Maximal VT (VTmax)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>Oxygen Consumption (O2)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>CO2 Consumption (CO2)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>Ventilatory Threshold (VT)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>Respiratory Exchange Ratio</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>Inverse RER (1/RER)</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>VE/VO2</td>
<td>Respiratory Rate (RR or R)</td>
</tr>
<tr>
<td>VE/VCO2</td>
<td>Respiratory Rate (RR or R)</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.
- **Wi 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
Highest oxygen uptake obtained (cardiac capacity)
Values validated with age, sex, activity level, weight, and disease (<29 mL/min in elderly; >90 in elite athletes).
Non-specific but starting point for interpretation and stratifications
Peak VO₂ >85% of predicted is generally favorable;
≤14 mL/min carries a poor prognosis in heart failure (<10 if on beta-blockers).

FIGURE 1. Diagram of oxygen uptake with impairment from any source will lower the peak VO₂ and ventilatory threshold.


- 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).


VO₂ vs Heart Rate
Maximal Predicted HR = (220-Age) x 85%
Ventilatory threshold
Point at which anaerobic metabolism increases
VO2 at ventilatory threshold typically is 45%–60% of peak VO2
A low value is consistent with deconditioning or disease; a high value is consistent with athletic training

Recall: VE/VCO2 or VE/VO2 (ventilatory equivalent): describes the ratio of ventilation (minute volume) to oxygen intake, or to carbon dioxide output.


Ve/VCO2 slope
Ventilatory equivalent for carbon dioxide output reflects ventilatory efficiency
Normal 25-30
May be slightly elevated in isolation in otherwise healthy elderly patients
Limitation of ventilatory efficiency or ventilation perfusion mismatch
Value > 34 indicates clinically significant cardiopulmonary disease (heart failure, pulmonary hypertension, chronic obstructive pulmonary disease)
Higher values = worse prognosis

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

Cardiopulmonary exercise testing scoring system for patients with heart failure

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation/carbon dioxide (Ve/Vco2) slope</td>
<td>≥ 34</td>
<td>7</td>
</tr>
<tr>
<td>Heart rate recovery *</td>
<td>≤ 6 bpm</td>
<td>9*</td>
</tr>
<tr>
<td>Oxygen uptake efficiency slope</td>
<td>≤ 1.4</td>
<td>2</td>
</tr>
<tr>
<td>Peak VO2</td>
<td>≤ 14 mls/min</td>
<td>2</td>
</tr>
</tbody>
</table>

*Score > 15 points: annual mortality rate ≥ 32.2%; 12% of patients die in 1 year; no transplant, left ventricular assist device, or cardiac death.
*Score < 5 points: annual mortality rate 1.2%.
*Maximum heart rate minus heart rate at 1 minute in recovery.
*2 points if on a beta blocker.
Exercise oscillatory breathing
Abnormal breathing pattern often associated with hyperventilation.


Cardiac limitations
- Oxygen pulse (O2-pulse) < 80% predicted or flattened or falling curve
- Chronotropic incompetence
- Heart 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 Vl/MV) < 15%
- Oxygen desaturation by pulse oximetry
- Abnormal results on perfusion scanning
- Abnormal exercise flow-volume loops

Muscular disease
- Submaximal cardiac and respiratory responses
- Ventilatory (aerobic) 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

Cardioperfusion Imaging – SPECT-CT

SPECT–CT Scan...

- 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 injection for a myocardial perfusion imaging (MPI) test.
    - The patient has a SPECT–CT before and after administration of Lexiscan.
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 CPET variables.

- Cardioperfusion Imaging
  - SPECT–CT/Lexiscan/Nuclear Scan and PET

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

Plots 1–3