PRE-OPERATIVE CARDIO-PULMONARY EXERCISE TESTING (CPET)

By

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ACCP (AMERICAN COLLEGE OF CHEST PHYSICIANS) and ATS (AMERICAN THORACIC SOCIETY) gave a joint statement on CPET in 2001 & 2002 respectively.

Cardio Pulmonary Exercise Testing (CPET) is increasingly being used in a wide spectrum of clinical applications for the evaluation of undiagnosed exercise intolerance, exercise-related symptoms, and, uniquely, for the objective determination of functional capacity and impairment. Cardiopulmonary exercise testing (CPET) provides a global assessment of the integrative exercise responses involving the pulmonary, cardiovascular, hematopoietic, neuro-psychological, and skeletal muscle systems, which are not adequately reflected through the measurement of individual organ system function.

The use of CPET in patient management is increasing with the understanding that resting pulmonary and cardiac function testing cannot reliably predict exercise performance and functional capacity and that, furthermore, overall health status correlates better with exercise tolerance rather than with resting measurements.

Indications for Cardiopulmonary Exercise Testing

These include the following:

1. Evaluation of exercise tolerance
2. Evaluation of undiagnosed exercise intolerance
3. Evaluation of patients with cardiovascular disease
4. Evaluation of patients with respiratory diseases/symptoms
5. Preoperative evaluation
6. Exercise evaluation and prescription for pulmonary rehabilitation
7. Evaluation of impairment/disability
8. Evaluation for lung, heart, and heart–lung transplantation

In practice, CPET should be considered when specific questions remain un-answered after consideration of basic clinical data including history, physical examination, chest radiographs, resting pulmonary function tests, and resting electrocardiogram (ECG).
**CPET** involves the measurement of respiratory gas exchange: oxygen uptake ($V'_o2$), carbon dioxide output ($V'co2$) and minute ventilation ($V'E$), in addition to monitoring Electrocardiography, blood pressure, and pulse oximetry typically during symptom-limited maximal progressive exercise tolerance test; When appropriate, arterial sampling is also performed and provides more detailed, important information about pulmonary gas exchange.

**Equipment & Methodology**
Two modes of exercise are commonly employed in Cardiopulmonary Exercise Tests: 1) **Treadmill** and 2) **Cycle Ergometer**. In most clinical circumstances, Cycle ergometry is the preferable mode of exercise. However, depending on the reasons for which CPET is requested and equipment availability, a Treadmill may be an acceptable alternative.

Cycle ergometry is comparatively cheaper and requires less space than Treadmill. The motor-driven treadmill imposes progressively increasing exercise stress through a combination of speed and grade (elevation) increases.

There are two types of cycle ergometers: Mechanically braked & Electrically braked. Mechanically braked cycles regulate external work by adjustable frictional bands. Electrically braked cycles increase resistance to pedaling electro-magnetically. Electrically braked cycle ergometer allows direct quantification of the work rate performed and can be computer controlled.

**EXERCISE EQUIPMENT: CYCLE ERGOMETRY VERSUS TREADMILL**

<table>
<thead>
<tr>
<th></th>
<th>Cycle</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max</td>
<td>lower</td>
<td>higher</td>
</tr>
<tr>
<td>Work rate measurement</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Noise and artifacts</td>
<td>less</td>
<td>more</td>
</tr>
<tr>
<td>Safety</td>
<td>safer</td>
<td>less safe?</td>
</tr>
<tr>
<td>Weight bearing in obese</td>
<td>less</td>
<td>more</td>
</tr>
<tr>
<td>Degree of leg muscle training</td>
<td>less</td>
<td>more</td>
</tr>
<tr>
<td>More appropriate for</td>
<td>patients</td>
<td>active normal</td>
</tr>
</tbody>
</table>

The goal of cardiopulmonary exercise testing is to evaluate organs and systems involved in the exercise response under conditions of progressively intense physical stress. Therefore exercise testing involves large muscle groups, usually the lower extremity muscles as in running on the treadmill or pedaling on a cycle ergometer. It is usually most efficient to employ a progressively increasing work rate protocol so that a range of exercise intensities can be studied in a short period of time. Some patients may be unable to perform lower...
extremity exercise. For such patients, arm crank ergometers can be adapted for incremental exercise testing.

**OVERVIEW OF CARDIOPULMONARY EXERCISE TESTING**

**Clinical Status Evaluation**

Clinical diagnosis and reason(s) for CPET

Health questionnaire (cardiopulmonary); physical activity profile

Medical and occupational history and physical examination

PFTs, CXR, ECG, and other appropriate laboratory tests

Determination of indications and contraindications for CPET

**Pretest Procedures**

Abstain from smoking for at least 8 h before the test

Refrain from exercise on the day of the test

Medications as instructed

Consent form

**CONDUCT of CPET**

Laboratory procedures

Quality control

Equipment calibration

Protocol Selection

Incremental versus constant work rate; invasive versus noninvasive

Patient preparation

Familiarization
12-lead ECG, pulse oximetry, blood pressure

Arterial line (if warranted)

Cardiopulmonary exercise testing

↓

Interpretation of CPET Results

Data processing

Quality and consistency of results

Comparison of results with appropriate reference values

Integrative approach to interpretation of CPET results

Preparation of CPET report

INDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING (in detail)

Evaluation of exercise tolerance
• Determination of functional impairment or capacity (peak V’O2)
• Determination of exercise-limiting factors and pathophysiologic mechanisms

Evaluation of undiagnosed exercise intolerance
• Assessing contribution of cardiac and pulmonary etiology in coexisting disease
• Symptoms disproportionate to resting pulmonary and cardiac tests
• Unexplained dyspnea when initial cardiopulmonary testing is non-diagnostic

Evaluation of patients with cardiovascular disease
• Functional evaluation and prognosis in patients with heart failure
• Selection for cardiac transplantation
• Exercise prescription and monitoring response to exercise training for cardiac rehabilitation (special circumstances; i.e., pacemakers)

Evaluation of patients with respiratory disease
• Functional impairment assessment (see specific clinical applications)
• Chronic obstructive pulmonary disease
Establishing exercise limitation(s) and assessing other potential contributing factors, especially occult heart disease (ischemia)

Determination of magnitude of hypoxemia and for O2 prescription
When objective determination of therapeutic intervention is necessary and not adequately addressed by standard pulmonary function testing
• Interstitial lung diseases
Detection of early (occult) gas exchange abnormalities
Overall assessment/monitoring of pulmonary gas exchange
Determination of magnitude of hypoxemia and for O2 prescription
Determination of potential exercise-limiting factors
Documentation of therapeutic response to potentially toxic therapy
• Pulmonary vascular disease (careful risk–benefit analysis required)
• Cystic fibrosis
• Exercise-induced bronchospasm

Specific clinical applications
• Preoperative evaluation
Lung resectional surgery
Elderly patients undergoing major abdominal surgery
Lung volume resectional surgery for emphysema (currently investigational)
• Exercise evaluation and prescription for pulmonary rehabilitation
• Evaluation for impairment–disability
• Evaluation for lung, heart–lung transplantation

Preoperative Evaluation in detail

Preoperative evaluation for lung cancer resectional surgery.\textsuperscript{12,13,14}

Whereas routine pulmonary function tests (FEV₁, diffusing capacity of the lung for CO [DLCO]) have the greatest utility in documenting physiologic operability in low-risk patients, other diagnostic modalities, including CPET and/or split function assessment by quantitative lung scintigraphy, is/are often necessary to more accurately assess moderate- to high-risk patients. Although there are proponents for both approaches, work suggests that CPET and the measurement of \( V' \text{O}_2 \text{peak} \) (especially when expressed as a percentage of the predicted value) appear to be particularly useful in predicting postoperative pulmonary complications\textsuperscript{12,13,14}. A \( \text{V' O}_2 \text{peak} \) less than 50–60% predicted is associated with higher morbidity and mortality after lung resection\textsuperscript{12,13,14}.

Preoperative CPET and split function study results may be used in tandem to predict the risk of postoperative pulmonary complications and functional capacity; this may be most beneficial to “borderline” patients who might otherwise be precluded from surgery.

Lung volume reduction surgery (LVRS). The potential utility of CPET is highlighted by its emergence as an important tool in evaluation of emphysema patients being considered for LVRS. The range of application of CPET in this patient group includes the determination of cardiopulmonary functional status and assessment of potential operative risk before surgery, the determination of exercise training prescription before and after LVRS, the quantification and monitoring of the clinical response to surgery, and also the definition of underlying pathophysiologic mechanisms responsible for improvements in exercise performance resulting from LVRS.

National Emphysema Treatment Trial, evaluating the efficacy of LVRS, has chosen the maximal work rate derived from CPET as its primary physiologic outcome parameter, because it was considered to be the best objective measure of functional status.

Evaluation for lung or heart–lung transplantation. With the emergence of lung and heart–lung transplantation for patients with end-stage pulmonary vascular and parenchymal lung...
disease as a viable therapeutic option, comprehensive CPET is increasingly being used to evaluate these complex patients before and after transplantation. As such, CPET is useful in assessing disease progression before transplantation and in assessing functional capacity.

Preoperative evaluation for other procedures. Work has shown that CPET is helpful in objectively assessing the adequacy of cardiovascular reserve and in predicting cardiovascular risk in an elderly population.

Parameters Measured or Derived From CPET

- **Peak oxygen uptake (PkVO2):** The highest VO2 achieved during the CPET and generally occurs at or near peak exercise. Reported as a weight-adjusted parameter in mL/kg per minute.
- **Maximal oxygen uptake (VO2max):** The value achieved when VO2 remains stable despite a progressive increase in the intensity of exercise. This is synonymous with peak aerobic capacity. It is defined by the Fick equation as the product of cardiac output and arteriovenous oxygen difference \([C(a-v)O2]\) at peak exercise: \(VO2max=(HR \times SV)\times[C(a-v)O2]\)
  
The measurement of VO2max implies that an individual's physiological limit has been reached (also termed maximal aerobic capacity).
- **Breathing reserve (BR):** The reserve capacity of the ventilatory system, calculated as 1 minus the ratio of peak exercise minute ventilation (VE) to maximal voluntary ventilation. A normal value would be > 30%.
- **Anaerobic threshold (AT) or Ventilatory Threshold:** The highest oxygen uptake attained without a sustained increase in blood lactate concentration and lactate/pyruvate ratio. Reported as a weight-adjusted parameter in mL/kg per minute.
- **Respiratory exchange ratio (RER):** Related but not equivalent to its cellular counterpart, the respiratory quotient, and is defined as the ratio of VO2 to VCO2.
- **Oxygen saturation (SpO2):** The percentage of hemoglobin that is saturated with oxygen. Typically measured by pulse oximetry.
- **O2 pulse:** The amount of O2 consumed from the volume of blood delivered to tissues by each heartbeat; is calculated as: \(O2\) pulse = \(V^\prime\) O2/heart rate.
- **Ventilation/carbon dioxide production ratio (VE/\(V^\prime\)CO2):** Also known as the ventilatory equivalent for CO2, this represents a respiratory control function that reflects chemoreceptor sensitivity, acid-base balance, and ventilatory efficiency.
- **Peak \(V^\prime\)O2 lean:** The peak oxygen uptake adjusted for lean body mass. Reported as a lean body weight–adjusted parameter in mL/kg per minute.

**MET** is defined as the equivalent of the resting metabolic oxygen requirement. One metabolic equivalent equals 3.5 mL/kg per minute.

**Physiologic Basis of Cardiopulmonary Exercise Testing Measurements**

\(\dot{V}O2–\)Work Rate Relationship:

Normally, VO2 increases linearly as external work (power output) increases. The external work rate is accurately measured by cycle ergometry but can only be estimated by treadmill exercise. The slope determined from the rate of change in VO2 divided by the rate of change in external work during incremental exercise testing on a cycle ergometer (\(_\dot{V}O2/_\dot{W}R\)) is normally about 8.5–11 mL/minute per watt (3, 195) and is independent of sex, age, or height.
**VO2max–V’O2peak**

VO2max is the best index of aerobic capacity and the gold standard for cardio respiratory fitness. It represents the maximal achievable level of oxidative metabolism involving large muscle groups. VO2peak is often used as an estimate for VO2max. For practical purposes, VO2max and VO2peak are used interchangeably. VO2 can increase from a resting value of about 3.5 ml/minute per kilogram (about 250 ml/minute in an average individual) to VO2max values about 15 times the resting value (30–50 ml/minute per kilogram).

**CO2 OUTPUT**

CO2 output (VO2) during exercise is determined by factors similar to those that govern O2 uptake: cardiac output, CO2-carrying capacity of the blood, and tissue exchange are major determinants. However, because CO2 is much more soluble in tissues and blood, CO2 output measured at the mouth is more strongly dependent on ventilation than is VO2. During short-duration exercise, glycogen is used primarily by the muscles for energy, and the relation between O2 consumption and CO2 production is almost equimolar. As such, during progressive exercise VO2 co2 increases nearly as much as does VO2 over the lower work rate range, with an average VO2 co2–VO2 relationship of slightly less than 1.0 (3).

With anaerobic metabolism, VO2 co2 increases as a result of the chemical reaction between hydrogen ion (from lactate) and dissolved CO2. Because VE has been demonstrated to be closely proportionally coupled to VO2 co2 during exercise, it is useful to analyze VE in relation to VO2 co2.

**3. Respiratory Exchange Ratio**

The ratio of VO2 co2/VO2 is called the gas exchange ratio or respiratory exchange ratio (RER). Under steady state conditions, the RER equals the respiratory quotient (RQ), whose value is determined by the fuels used for metabolic processes. An RQ of 1.0 indicates metabolism of primarily carbohydrates, whereas an RQ of less than 1.0 indicates a mixture of carbohydrates with fat (RQ, about 0.7) or protein (RQ, about 0.8).

**ABSOLUTE AND RELATIVE CONTRAINDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING**

<table>
<thead>
<tr>
<th>Absolute</th>
<th>Relative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute myocardial infarction (3–5 days)</td>
<td>Left main coronary stenosis or equivalent</td>
</tr>
<tr>
<td>Unstable angina</td>
<td>Moderate stenotic valvular heart disease</td>
</tr>
<tr>
<td>Uncontrolled arrhythmias causing symptoms</td>
<td>Severe untreated arterial hypertension at rest or hemodynamic compromise (200 mmHg systolic &amp; 120 mmHg diastolic)</td>
</tr>
<tr>
<td>Syncope</td>
<td>Tachyarrhythmias or bradyarrhythmias</td>
</tr>
<tr>
<td>Active endocarditis</td>
<td>High-degree atrioventricular block</td>
</tr>
<tr>
<td>Acute myocarditis or pericarditis</td>
<td>Hypertrophic cardiomyopathy</td>
</tr>
<tr>
<td>Symptomatic severe aortic stenosis</td>
<td>Significant pulmonary hypertension</td>
</tr>
<tr>
<td>Uncontrolled heart failure</td>
<td>Advanced or complicated pregnancy</td>
</tr>
</tbody>
</table>
Acute pulm embolus/pulm infarction
Thrombosis of lower extremities
Electrolyte Abnormalities
Orthopedic impairment that compromises exercise performance

Suspected dissecting aneurysm
Uncontrolled asthma
Pulmonary edema
Room air desaturation at rest < 85%
Respiratory failure
Acute noncardiopulmonary disorder that may affect exercise performance or be aggravated by exercise (i.e. infection, renal failure, thyrotoxicosis)
Mental impairment leading to inability to cooperate

**INDICATIONS FOR EXERCISE TERMINATION**\textsuperscript{15,16}

Chest pain suggestive of ischemia
Ischemic ECG changes
Complex ectopy
Second or third degree heart block
Fall in systolic pressure > 20 mm Hg from the highest value during the test
Hypertension (> 250 mm Hg systolic; >120 mm Hg diastolic)
Severe desaturation: SpO\textsubscript{2} < 80% when accompanied by symptoms and signs of severe hypoxemia
Sudden pallor
Loss of coordination
Mental confusion
Dizziness or faintness
Signs of respiratory failure

**Conducting the test:**

The patient will fill up a short questionnaire related to cardiopulmonary and major systemic diseases and current therapy, with special attention to medications that alter heart rate (HR) and blood pressure. Furthermore, risk factors for coronary artery disease, smoking history, chest pain, cholesterol, hypertension, over-weight, and family history should be assessed.

The taking of a brief medical history and physical examination are recommended.

**Preliminary requirements for exercise testing:**

The following are required: (1) spirometry and maximal voluntary ventilation (MVV) should be measured, and lung volumes and DlCo can be included if clinically warranted; (2) if hypoxemia is clinically suspected, resting arterial blood gases should be obtained; (3) a recent hemogram and electrolytes should be determined; (4) patients who smoke should be asked to abstain from smoking for at least 8 hours; (5) consultation with a cardiologist is recommended with a
history of coronary artery disease; (6) for functional evaluation and disability, patients should be tested with their optimal medication regimen; (7) the morning of the test, patients should not exercise and should have a light breakfast no less than 2 hours before the test.

**Day of the test:** A consent form must be signed. With patient properly dressed, place the ECG electrodes and indwelling arterial catheter, if necessary. A supine resting 12-lead ECG should be obtained and used as the “standard” ECG tracing for determination of resting abnormalities before exercise testing.

**MEASUREMENTS DURING CARDIOPULMONARY EXERCISE TESTING**

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Noninvasive</th>
<th>Invasive (ABGs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External work</td>
<td>WR</td>
<td>Lactate</td>
</tr>
<tr>
<td>Metabolic gas exchange</td>
<td>V'O₂, V'CO₂, RER, AT</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>HR, ECG, BP, O₂ pulse</td>
<td></td>
</tr>
<tr>
<td>Ventilatory</td>
<td>V' E, VT, fr</td>
<td></td>
</tr>
<tr>
<td>Pulmonary gas exchange</td>
<td>SpO₂, V'E/V'CO₂, V'E/V'O₂, PEO₂, PETCO₂</td>
<td></td>
</tr>
<tr>
<td>PaO₂, SaO₂, P(A-a)O₂, VD/VT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid–base</td>
<td>pH, PaCO₂, standard</td>
<td></td>
</tr>
<tr>
<td>HCO₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptoms</td>
<td>Dyspnea, fatigue, chest pain</td>
<td></td>
</tr>
</tbody>
</table>

**INTEGRATIVELY APPROACH TO THE INTERPRETATION OF CARDIOPULMONARY EXERCISE TESTING RESULTS**

1. Determine reason(s) for CPET
2. Review pertinent clinical and laboratory information (clinical status)
3. Note overall quality of test, assessment of subject effort, and reasons for exercise cessation
4. Identify key variables: initially V'O₂, and then HR, V'E, SaO₂, and other measurements subsequently
5. Use tabular and graphic presentation of the data
6. Pay attention to trending phenomena: submaximal through maximal responses
7. Compare exercise responses with appropriate reference values
8. Evaluate exercise limitation: physiologic versus nonphysiologic
9. Establish patterns of exercise responses
10. Consider what conditions/clinical entities may be associated with these patterns
11. Correlate CPET results with clinical status
12. Generate CPET report
SUGGESTED NORMAL GUIDELINES FOR INTERPRETATION OF CARDIOPULMONARY EXERCISE TESTING RESULTS

Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Criteria of Normality</th>
</tr>
</thead>
<tbody>
<tr>
<td>V˙O2max or V˙O2peak</td>
<td>&gt; 84% predicted</td>
</tr>
<tr>
<td>Anaerobic threshold</td>
<td>&gt; 40% V˙O2max predicted; wide range of normal (40–80%)</td>
</tr>
<tr>
<td>Heart rate (HR)</td>
<td>HRmax &gt; 90% age predicted</td>
</tr>
<tr>
<td>Heart rate reserve (HRR)</td>
<td>HRR &lt; 15 beats/min</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>&lt; 220/90</td>
</tr>
<tr>
<td>O2 pulse (V˙O2/HR)</td>
<td>&gt; 80%</td>
</tr>
<tr>
<td>Ventilatory reserve (VR)</td>
<td>MVV -V˙Emax: &gt; 11 L or V˙Emax/MVVX100:&lt; 85%.</td>
</tr>
<tr>
<td>(Wide normal range: 72 +/- 15%)</td>
<td></td>
</tr>
<tr>
<td>Respiratory frequency (fR)</td>
<td>&lt; 60 breaths/min</td>
</tr>
<tr>
<td>V˙E/V˙CO2 (at AT)</td>
<td>&lt; 34</td>
</tr>
<tr>
<td>VD/VT</td>
<td>&lt; 0.28; &lt; 0.30 for age &gt; 40 years</td>
</tr>
<tr>
<td>PaO2</td>
<td>&gt; 80 mm Hg</td>
</tr>
<tr>
<td>P(A–a)O2</td>
<td>&lt; 35 mm Hg</td>
</tr>
</tbody>
</table>

Functional Impairment during Incremental Treadmill Testing in Heart Failure: (Weber-Janicki Classification)

Severity   Class  
Peak V˙O2 ml/kg per minute  Anaerobic Threshold Maximal cardiac index

L/min per m²

<table>
<thead>
<tr>
<th>Severity</th>
<th>Class</th>
<th>Peak V˙O2 ml/kg per minute</th>
<th>Anaerobic Threshold</th>
<th>Maximal cardiac index</th>
</tr>
</thead>
<tbody>
<tr>
<td>None to mild</td>
<td>A</td>
<td>&gt;20</td>
<td>&gt;14</td>
<td>&gt;8</td>
</tr>
<tr>
<td>Mild to moderate</td>
<td>B</td>
<td>16–20</td>
<td>11–14</td>
<td>6–8</td>
</tr>
<tr>
<td>Moderate to severe</td>
<td>C</td>
<td>10–16</td>
<td>8–11</td>
<td>4–6</td>
</tr>
<tr>
<td>Severe</td>
<td>D</td>
<td>6–10</td>
<td>5–8</td>
<td>2–4</td>
</tr>
<tr>
<td>Very severe</td>
<td>E</td>
<td>&lt;6</td>
<td>&lt;4</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

Findings From CPET Characteristic of Typical Cardiovascular (Chronic Heart Failure) and Pulmonary (Obstructive Airways Disease) Causes of Exercise Impairment

Cardiovascular   Pulmonary

<table>
<thead>
<tr>
<th>Peak V˙O2</th>
<th>Reduced</th>
<th>Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilatory threshold</td>
<td>Reduced</td>
<td>Normal or reduced</td>
</tr>
</tbody>
</table>
Exercise & E.C.G Data

Heart Rate
The immediate response of the cardiovascular system to exercise is an increased heart rate due to decreased vagal tone and increased sympathetic outflow. During dynamic exercise, heart rate increases linearly with work rate and $V\dot{O}_2$, but the slope and magnitude of heart rate acceleration are influenced by age, deconditioning, body position, type of exercise, and various states of health and therapy, including heart transplant. *Chronotropic incompetence*, defined as either failure to achieve 85% of the age-predicted maximal heart rate or a low chronotropic index (heart rate adjusted to the MET level), is associated with increased mortality risk in patients with known cardiovascular disease, although this assessment is confounded by the use of Beta-blockers and other heart rate–limiting medications.

Heart Rate Recovery
Heart rate recovery refers to the deceleration of the heart rate in early exercise recovery in association with vagal tone reactivation. In contrast to chronotropic assessment, heart rate recovery remains prognostically important even among patients using Beta-blockers.

Arrhythmia
Assessment for arrhythmia is important and particularly helpful in assessing the heart failure population that is frequently referred for CPET.

Ischemic Electrocardiography Changes
ST-segment depression is the most common manifestation of exercise-induced myocardial ischemia. The standard criterion for this abnormal response is horizontal or downsloping ST-segment depression of 0.10 mV (1 mm) or > 0.10 Mv for 80 ms; however, downsloping ST-segment depressions are more specific than horizontal or upsloping depressions. Other factors related to the probability and severity of CAD include the degree, time of appearance, duration, and number of leads with ST-segment depression. Severity of CAD is also related to the time of appearance of ischemic ST-segment shifts. The lower the work rate and rate-pressure product at which it occurs, the worse the prognosis and the more likely the presence of multivessel disease. The duration of ST depression in the recovery phase is also related to the severity of CAD.

Blood Pressure
Hemodynamic responses to exercise also vary depending on cardiac output and peripheral resistance. Systolic blood pressure usually rises with increasing work rates, particularly due to a rise in cardiac output. In contrast, diastolic blood pressure usually remains the same or decreases moderately with exercise. An inadequate rise (<20 to 30 mm Hg) or fall in systolic blood pressure from resting levels may result from aortic outflow obstruction, severe left ventricular dysfunction, myocardial ischemia, and certain types of medications (eg, Beta-blockers). As a general standard, exercise-induced hypotension is associated with a poor prognosis and should raise emergent consideration of significant cardiac disease, including left-main or 3-vessel CAD; however, subjects without clinically significant heart disease can also exhibit exercise-induced hypotension due to dehydration, antihypertensive therapy, or even the direct effects of prolonged high-intensity exercise.

**USUAL CARDIOPULMONARY EXERCISE RESPONSE PATTERNS**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Heart Failure</th>
<th>COPD</th>
<th>ILD</th>
<th>Vascular Disease</th>
<th>Obesity</th>
<th>Deconditioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V' \text{O}<em>{2})max or ( V' \text{O}</em>{2})peak</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased for actual</td>
<td>Decreased</td>
</tr>
<tr>
<td>A.T</td>
<td>Decreased</td>
<td>Normal/decreased</td>
<td>Normal or decreased</td>
<td>Decreased</td>
<td>Normal</td>
<td>Normal or decreased</td>
</tr>
<tr>
<td>Peak HR</td>
<td>Variable usually normal in mild</td>
<td>Decreased, normal in mild</td>
<td>Decreased</td>
<td>Normal/slightly decreased</td>
<td>Normal/slightly decreased</td>
<td>Normal/slightly decreased</td>
</tr>
<tr>
<td>O2 pulse</td>
<td>Decreased</td>
<td>Normal or decreased</td>
<td>Normal or decreased</td>
<td>Decreased</td>
<td>Normal</td>
<td>Decreased</td>
</tr>
<tr>
<td>((V' \text{E}/MVV) \times 100)</td>
<td>Normal or decreased</td>
<td>Increased</td>
<td>Normal or increased</td>
<td>Normal</td>
<td>Normal or increased</td>
<td>Normal</td>
</tr>
<tr>
<td>(V' \text{E}/V' \text{CO}_2) (at AT)</td>
<td>Increased</td>
<td>Increased</td>
<td>Increased</td>
<td>Increased</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>(V'D/V'T)</td>
<td>Increased</td>
<td>Increased</td>
<td>Increased</td>
<td>Increased</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>(P(a-a)\text{O}_2)</td>
<td>Usually normal</td>
<td>Variable, usually increased</td>
<td>Increased</td>
<td>Increased</td>
<td>Increased</td>
<td>May decrease</td>
</tr>
</tbody>
</table>

**SELECTED REFERENCE VALUES FOR MAXIMAL INCREMENTAL EXERCISE TEST**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Equations*</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work rate, kpm/min</td>
<td>20.4 (ht) 8.74(age) 288(sex) 1909</td>
<td>216</td>
</tr>
<tr>
<td>( V' \text{O}_{2}), L/min</td>
<td>0.046(ht) 0.021(age) 0.62(sex) 4.31</td>
<td>0.458</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>202 0.72(age)</td>
<td>10.3</td>
</tr>
<tr>
<td>O2 pulse, ml/beat</td>
<td>0.28(ht) 3.3(sex) 26.7</td>
<td>2.8</td>
</tr>
<tr>
<td>(V' \text{E}), L/min</td>
<td>26.3(VC) 34</td>
<td>23.1</td>
</tr>
<tr>
<td>AT, L/min ((V' \text{O}_2))</td>
<td>0.024(ht) 0.0074(age) 2.43</td>
<td>0.316</td>
</tr>
</tbody>
</table>

Definition of abbreviations: HR Heart rate; SEE standard error of estimate; \(V' \text{E}\) minute ventilation; \(V' \text{O}_2\) oxygen uptake.

* Sex, male, 0; female, 1; age, years; height (ht), centimeters.
Expanded CPET(CPX) Sample Report

Aerobic Capacity
Peak V’O2 (mL O2 _ kg⁻¹ _ min⁻¹) ____ (%predicted____)
Peak measured METs ____
V’
O2 @ ventilatory threshold ____ ( ____% of peak V’O2)
Peak RER ____
Ventilatory efficiency
Pulmonary function
FVC: Pre ____ Post ____
E/V’ CO2 slope ____
V’
E/V’ CO2 nadir ____
(%predicted____)
V’
E/V’ CO2 @ VT ____
FEV1: Pre ____ Post ____
FEV1/FVC: Pre ____ Post ____
V’
Oscillatory ventilation: Yes____ No ____
FEF25–75: Pre ____ Post ____
OUES (L/min) ____
PEF: Pre ____ Post ____
V’ E/MVV____
(Note: Document maximal post-exercise change)
PETCO2
Resting PETCO2 (mm Hg) ____
Highest PETCO2 during exercise (mm Hg) ____ (change from rest____)
PETCO2 at peak exercise (mm Hg) ____
Oxygen pulse
Resting O2 pulse (mL/beat) ____
O2 pulse at peak exercise (mL/beat) ____

A final report should describe the reason for the test and what type of test was completed (eg, modality,protocol); summarize the patient’s demographics and clinical and physiological responses to exercise (eg, duration, symptoms, reason for stopping); and avoid the use of terms positive or negative. The report should conclude with a list of final impressions or recommendations that concisely and specifically respond to the reason the test was ordered.

- Future studies are needed to rigorously evaluate whether CPET provides additional discriminatory diagnostic and prognostic value over and above that provided by standard exercise tests and other clinical variables. More studies are needed to assess the increasing number of variables that can be derived from CPET, as well as their utility in many conditions that affect the cardiovascular and pulmonary systems.

Bibliography
4) Fletcher GF, Blair SN, Blumenthal J, Caspersen C, Chaitman B, Epstein, Falls H, Froelicher ES, Froelicher VF, Pina IL. Statement on exercise: benefits and recommendations for physical activity programs for all Americans: a statement for health professionals by the Committee on Exercise and