A Primer in Cardiopulmonary Exercise Testing

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Cardiopulmonary Exercise Testing

- Physiologic Requirements for Exercise
- Instrumentation for Exercise Testing
- Pathophysiologic Exercise Response Patterns

Physiologic Requirements to Perform Exercise

Metabolic Pathways for Energy Production
Reciprocal Changes in Arterial Bicarbonate and Lactate during Incremental Exercise

Oxygen Uptake and CO₂ Output During Incremental Exercise

Determining the anaerobic threshold (AT), S₁, S₂ and VO₂max
Concordance of invasive and noninvasive measures of the anaerobic threshold

Cardiopulmonary Exercise Testing
- Physiologic Requirements for Exercise
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Methods for Cardiopulmonary Exercise Testing
- Measuring Ventilation and Gas Exchange
- Equipment for Exercise Testing
- Exercise Testing Protocols

Calculation of Breath-by-Breath Gas Exchange
\[
VCO_2 = \sum FeCO_2 Ve \Delta t
\]
Methods for Cardiopulmonary Exercise Testing

- Measuring Ventilation and Gas Exchange
- Equipment for Exercise Testing
- Exercise Testing Protocols

Exercise Testing Instrumentation

Mobile Exercise Testing
Mobile Exercise Testing

Exercise Testing Instrumentation

Flow Sensor for Exercise Testing

Exercise Testing Instrumentation
Methods for Cardiopulmonary Exercise Testing

- Measuring Ventilation and Gas Exchange
- Equipment for Exercise Testing
- Exercise Testing Protocols

Choosing an Ergometer - comparison of advantages -

<table>
<thead>
<tr>
<th>Treadmill</th>
<th>Cycle Ergometer</th>
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<tbody>
<tr>
<td>• more familiar activity</td>
<td>• safe</td>
</tr>
<tr>
<td>• larger muscle mass used</td>
<td>• lower cost</td>
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<tr>
<td></td>
<td>• takes less space</td>
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<tr>
<td></td>
<td>• freedom from motion artifacts</td>
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<td>• precise quantitation of external work rate</td>
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Exercise Testing Protocols

- Incremental
- Ramp

Cardiopulmonary Exercise Testing

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Measures of Exercise Tolerance

- Peak Oxygen Uptake
- Anaerobic Threshold

Utility of the Anaerobic Threshold

The anaerobic threshold is an *effort independent* measure of endurance exercise capacity.

Pathophysiologic Exercise Response Patterns

- Cardiovascular Limitation
- Gas Exchange Limitation
- Ventilatory Limitation
Cardiovascular Limitation Due to Peripheral Vascular Disease

Cardiovascular Limitation Due To:
Pulmonary Vascular Disease

Primary Cardiac Dysfunction

Differential Diagnosis of Cardiovascular Limitation to Exercise

- Cardiac Disease
  - marked by ECG or blood pressure abnormalities
- Peripheral Vascular Disease
  - marked by disproportionate leg pain
- Pulmonary Vascular Disease
  - marked by abnormal gas exchange
- Poor Blood Oxygen Transport
  - marked by anemia, hypoxemia or carboxyhemoglobinemia
- Muscular Deconditioning
  - marked by history of sedentary lifestyle
Pathophysiologic Exercise Response Patterns

• Cardiovascular Limitation
• Gas Exchange Limitation
• Ventilatory Limitation

Arterial Blood Sampling for Assessment of Pulmonary Gas Exchange:

CO₂ exchange: \( V_D/V_T \)

O₂ exchange: \( P(A-a)O_2 \)
Assessing Pulmonary Oxygen Transport

Pathophysiologic Exercise Response Patterns

- Cardiovascular Limitation
- Gas Exchange Limitation
- Ventilatory Limitation
  - Obstructive
  - Restrictive

Ventilatory Limitation to Exercise in COPD

Physiologic Factors Dictating High Ventilatory Requirement

\[ V_E = \frac{k \cdot VCO_2}{PaCO_2 \cdot (1-V_D/V_T)} \]
Ventilatory Limitation to Exercise in COPD

Pathophysiologic Exercise Response Patterns

- Cardiovascular Limitation
- Gas Exchange Limitation
- Ventilatory Limitation
  - Obstructive
  - Restrictive

Assessing Breathing Pattern Responses

Cardiopulmonary Exercise Testing
- major diagnostic insights-

- Cardiovascular limitation to exercise
  - low AT, shallow VO₂ slope, flat O₂ pulse
- Gas exchange limitation to exercise
  - high P(A-a)O₂, high VD/V̇T
- Ventilatory limitation to exercise
  - low breathing reserve
Cardiopulmonary Exercise Testing

- Physiologic Requirements for Exercise
- Instrumentation for Exercise Testing
- Pathophysiologic Exercise Response Patterns

Utility of Cardiopulmonary Exercise Testing

- Calculate effort and effort-independent measures of exercise tolerance
- Assess mechanism(s) of exercise intolerance
- Define contraindications to an exercise program
- Establish an exercise prescription
- Evaluate need for supplemental oxygen
- Determine the response to an intervention