Cardiopulmonary Exercise Testing

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Conflicts of Interest

- Speaker & consultant, MGC Diagnostics
- Royalties for PFT textbook, Elsevier
- Consultant, ndd Medical

* This lecture sponsored by MGC DIAGNOSTICS®
Indications for exercise testing

- Unexplained dyspnea
- Pre-op assessment
- Cardiac vs. pulmonary exercise limitation
- Fitness, impairment disability
- Cardiopulmonary rehabilitation

CPET
**Treadmill or Cycle Ergometer**

**Treadmill**
- $\text{VO}_2\text{max}$ 5-10% higher
- $\text{AT}$ at lower $\text{VO}_2$
- Familiar exercise
- Work dependent on weight
- Difficult to draw blood
- Movement artifact in pressure measures and/or $\text{SpO}_2$

**Cycle Ergometer**
- $\text{Ve}$, HR, Lactate similar
- Work independent of weight
- Less movement artifact
- Easier to draw blood
- Easier access to chest
- Can be done semi-recumbent
Protocol Strategies

- Incremental
  - Workload changes by a fixed amount at fixed intervals
  - May not allow steady-state to be attained
  - Selection of appropriate intervals important
 Protocol Strategies

Ramp

- Workload increases continuously at fixed rate
- Best suited to cycle ergometer with computer control
- Rate of workload increase must be matched to patient fitness (5-50 watts)

To estimate ramp:

\[ W = \frac{(\text{Pred VO2}-300)}{100} \]
Why Measure VO$_2$?

VO$_2$ increases linearly with workload in normal subjects (at moderate increments)
How To Measure VO$_2$
(Exhaled Gas Analysis)

Then

Now
Volume transducers are lightweight. They can be held in the mouth easily or mounted in a mask.
Gas Analyzers

- $\text{O}_2$ uses zirconium cell or other rapid responding analyzer (mass spectrometer)
- $\text{CO}_2$ uses infrared analyzer
Breath by Breath (BxB) Gas Exchange

Phase delay
Physiologic Data from Exhaled Gas Measurements*

- **VO₂ max (VO₂ peak)**
  - L/min or ml/min (STPD)
  - ml/min/Kg (ideal or actual weight?)
  - METS (ml/min/Kg ÷ 3.5)
  - % of predicted VO₂ max

- **VCO₂ and RER**

- **Anaerobic (ventilatory) threshold**

- **O₂ pulse (poor man’s cardiac output)**

- **Ventilation (VₐE, Vₜ, fₜ, V₃/D/Vₜ)**

*in addition to the ECG, blood pressure, etc.*
What is VO$_2$max?
VCO$_2$ and RER

- Exhaled gas analysis includes measurement of CO$_2$ production
- RER = VCO$_2$/VO$_2$ (at the mouth)

RER > 1.15 - 1.20 consistent with maximal effort
What Is ‘Anaerobic Threshold*’?

- VO$_2$ above which anaerobic mechanisms supplement aerobic energy production
- Increase in lactate in muscle and arterial blood
- Metabolic acidosis (lactic acidosis) occurs
- Lactic acid buffered by HCO$_3^-$
  \[
  H^+ + HCO_3^- \rightarrow CO_2 + H_2O
  \]

*also sometimes called the ‘ventilatory threshold’
Anaerobic (ventilatory) Threshold

38 y/o female
cycle ergometer

V-Slope Method
**AT/Predicted Peak VO$_2$**

*(as a %)*

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Men</th>
<th>95% LLN</th>
<th>Women</th>
<th>95% LLN</th>
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</thead>
<tbody>
<tr>
<td>20</td>
<td>53</td>
<td>42</td>
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<td>63</td>
<td>52</td>
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<tr>
<td>70</td>
<td>58</td>
<td>47</td>
<td>65</td>
<td>54</td>
</tr>
</tbody>
</table>

* AT decreases with age in men and women, but at a slower rate than predicted peak VO$_2$

Heart Rate and VO$_2$

100%

Heart Rate

VO$_2$

100%

CAD

COPD

Normal
Cardiac Output and $O_2$ Pulse

$$CO = \frac{\dot{VO}_2}{C(a - \bar{v})O_2 \times 10}$$

$$SV \times HR = \frac{\dot{VO}_2}{C(a - \bar{v})O_2 \times 10}$$

$$\frac{\dot{VO}_2}{HR} = [SV \times C(a - \bar{v})O_2 \times 10]$$
Cardiac Output and $O_2$ Pulse

$O_2$ Pulse
($VO_2$/HR)

Rest | Exercise

$VO_2$

Normal

COPD

CAD
May fall because of dynamic hyperinflation (COPD)
Maximal Ventilation – Breathing Reserve

\[ V_{\text{Emax}} = 0.7 \times \text{MVV} \]  \hspace{1cm} (50-85\% \text{ of MVV})

\text{or}

\[ V_{\text{Emax}} = 0.7 \times (\text{FEV}_1 \times 40) \]

\[ \text{BR} = \text{MVV} - V_{\text{Emax}} \]  \hspace{1cm} (absolute)

\text{or}

\[ \text{BR} = 100 - (\% \text{ Pred MVV}) \]  \hspace{1cm} (per cent)

Ventilation limitation: \[ \text{MVV} - V_{\text{Emax}} \leq 11 \text{ L/min} \]
Flow Limitation During Exercise

53 y/o Male, 67 in, 150 lbs
Flow Limitation During Exercise
$V_T$ and $V_{D/V_T}$

$$V_{D/V_T} = \frac{(P_{E-T}CO_2 - P_{E}CO_2)}{P_{E-T}CO_2}$$

38 y/o female
cycle ergometer
Determining Maximal Effort

*** Heart rate $> 85-90\%$ of predicted

*** End exercise $V_E$ $50-85\%$ of MVV $or$

MVV-$V_{E_{max}} \leq 15L$

** SpO$_2$ $< 80\%$

* Metabolic work RER $> 1.10$ $or$ lactate $> 7$

* Clinical Opinion of effort $or$

early termination criteria met

* = weight of variable

Once a single criterion is met, test is graded maximal
Heart Rate Reserve (HRR)

38 y/o female cycle ergometer
Breathing Reserve (BR)

38 y/o female
cycle ergometer
Typical VO$_2$ Predicted Values

For a 40 year old male, 70 inches, 170 lbs

Wasserman  \quad \text{pred VO}_2 = 2773 \text{ ml/min}
\quad \text{treadmill} = 3078

Jones  \quad \text{pred VO}_2 = 3029 \text{ ml/min}

For a 70 year old male, 70 inches, 170 lbs

Blackie  \quad \text{pred VO}_2 = 2280 \text{ ml/min}
\quad \text{treadmill} = 2508 \text{ ml/min}
Case Example: Dyspnea on Exertion

The patient is a 39 y/o Caucasian female with a history SLE, ILD, and increased pulmonary pressures on echocardiogram. Her chief complaint is increased dyspnea on exertion.

An maximal exercise test was performed using 3-4 minute increments and increasing the workload by 25W at each increment (cycle ergometer). PFTs were performed before exercise.
Case Example: Dyspnea on Exertion

<table>
<thead>
<tr>
<th>Exercise:</th>
<th>Pulmonary function:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BP rest 152/92</td>
<td>FVC 2.19 (59%)</td>
<td></td>
</tr>
<tr>
<td>BP peak 220/96</td>
<td>FEV₁ 1.95 (64%)</td>
<td></td>
</tr>
<tr>
<td>HR rest 81</td>
<td>FEV₁/FVC 89</td>
<td></td>
</tr>
<tr>
<td>HR peak 157 (87%)</td>
<td>MVV 114</td>
<td></td>
</tr>
<tr>
<td>SpO₂ rest 96</td>
<td>TLC 3.60 (67%)</td>
<td></td>
</tr>
<tr>
<td>SpO₂ peak 89</td>
<td>DLCO 8.40 (39%)</td>
<td></td>
</tr>
<tr>
<td>Chest pain No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECG No ST changes;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Peak = 50 Watts; Reason for stopping: dyspnea)
### Case Example: Dyspnea on Exertion

**Gas Exchange:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_2$peak ml/min</td>
<td>1122 (55%)</td>
</tr>
<tr>
<td>VO$_2$peak ml/min/Kg</td>
<td>17.0 (51%)</td>
</tr>
<tr>
<td>AT/VO$_2$max</td>
<td>34% pred max</td>
</tr>
<tr>
<td>METs</td>
<td>4.9</td>
</tr>
<tr>
<td>V$_E$max L/min</td>
<td>53</td>
</tr>
<tr>
<td>Breathing reserve</td>
<td>61 L/min (46% MVV)</td>
</tr>
<tr>
<td>RER</td>
<td>1.02</td>
</tr>
<tr>
<td>O$_2$ pulse</td>
<td>7.1 (62%)</td>
</tr>
<tr>
<td>V$_D$/V$_T$</td>
<td>50%</td>
</tr>
<tr>
<td>A-aDO$_2$</td>
<td>57</td>
</tr>
<tr>
<td>V$_E$/VCO$_2$</td>
<td>46</td>
</tr>
</tbody>
</table>

(Peak = 50 Watts; Reason for stopping: dyspnea)
Case Example: Dyspnea on Exertion

- Heart Rate Reserve
- Ventilatory Reserve
Case Example: Dyspnea on Exertion

Expected Vd/Vt
In Summary

- Measurement of VO$_2$ overcomes many of the issues with specific exercise protocols
- VO$_2$ avoids pitfalls associated with estimates of workload (METS)
- VO$_2$ allows measurement of important exercise variables (AT, O$_2$ pulse, aerobic impairment)
- VO$_2$ is relatively easy to measure (BxB)
- Exhaled gas analysis provides other important parameters ($V_E$, $V_D/V_T$, RER)
Questions??

Comet c2014 Q2 Lovejoy
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