CARDIOPULMONARY EXERCISE TESTING AND CLINICAL APPLICATION

Erlang samoedro Sp.P
SOURCES OF ENERGY FOR ATP

Aerobic Glycolysis

Glycogen

Glucose

ADP + PI

ATP

Pyruvic acid

Sufficient Oxygen

CO₂ + H₂O

Anaerobic Glycolysis

Glycogen

Glucose

ADP + PI

ATP

Pyruvic acid

Insufficient Oxygen

Lactic acid

Fig. 1
Coupling of External Ventilation and Cellular Metabolism

- Mitochondria
- $V_{O_2}$
- $V_{CO_2}$
- $O_2$ Consum. Muscle CO$_2$ Prod.
- Inspired Ventilation Expired
- Obesity
- Airflow obstruction
- Heart disease
  - Coronary
  - Myocardial
  - Valvular
  - Anemia
- Obstruction
  - Restriction
  - Chestwall
  - Infiltrative
- Occlusion
- Hypertension
- Vasoregulatory asthenia
- Thromboemboli
- Vasculitis
- 1° Pulmonary hypertension
The goal of CARDIO-PULMONARY exercise testing is to evaluate the physiologic response of the
- heart
- lungs and
- muscles to an increase in physical stress.
50 year old, male, computer technician

retired 10 years ago because of progressive dyspnea

was a heavy cigarette smoker, but denies cough/phlegm/wheezing/chest pains

recurrent pneumothorax secondary to multiple bullous disease
<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th>Measured</th>
<th>%Pred</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>4.84</td>
<td>1.88</td>
<td>39</td>
</tr>
<tr>
<td>FEV1</td>
<td>3.73</td>
<td>1.48</td>
<td>40</td>
</tr>
</tbody>
</table>
QUESTION 1:

WOULD YOU CLEAR THIS PATIENT FOR PNEUMONECTOMY?

A. YES

B. NO
Predicted Post-Operative FEV1

PPO FEV1 = Pre-Op FEV1 \times (1-a/b)

a = number of unobstructed segments to be removed
b = total number of unobstructed segments

PPO FEV1 = 1480 ml \times (1 - 9/19)
= 778 ml
INDICATIONS FOR CPET

- Evaluation of dyspnea
  - distinguish cardiac vs pulmonary vs peripheral limitation vs others
  - detection of exercise-induced bronchoconstriction
  - detection of exertional desaturation

- Pulmonary rehabilitation
  - exercise intensity/prescription
  - response to participation

- Pre-op evaluation and risk stratification

- Prognostication of life expectancy
INDICATIONS …

- Disability determination
- Fitness evaluation
- Confirm the diagnosis
- Assess response to therapy
ABSOLUTE CONTRAINDICATIONS TO CPET

- Acute MI
- Unstable angina
- Unstable arrhythmia
- Acute endocarditis, myocarditis, pericarditis
- Syncope
- Severe, symptomatic Atrial Stenosis
- Uncontrolled CHF
- Acute PE, DVT
- Respiratory failure
- Uncontrolled asthma
- $\text{SpO}_2 < 88\%$ on RA
- Acute significant non-cardiopulmonary disorder that may affect or be adversely affected by exercise
- Significant psychiatric/cognitive impairment limiting cooperation
RELATIVE CONTRAINDICATIONS

- Left main or 3-V CAD
- Severe arterial HTN (>200/120)
- Significant pulmonary HTN
- Tachyarrhythmia, bradyarrhythmia
- High degree AV block
Hypertrophic cardiomyopathy
Electrolyte abnormality
Moderate stenotic valvular heart disease
Advanced or complicated pregnancy
Orthopedic impairment
EXERCISE MODALITIES

- Advantages of cycle ergometer
  - cheaper
  - safer
    - Less danger of fall/injury
    - Can stop anytime
  - direct power calculation
    - Independent of weight
    - Holding bars has no effect
  - little training needed
  - easier BP recording, blood draw
  - requires less space
  - less noise

- Advantages of treadmill
  - attain higher VO$_2$
  - more functional
<table>
<thead>
<tr>
<th></th>
<th><strong>CYCLE</strong></th>
<th><strong>TREADMILL</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VO2 MAX</strong></td>
<td>LOWER</td>
<td>HIGHR</td>
</tr>
<tr>
<td><strong>LEG MUSCLE FATIGUE</strong></td>
<td>OFTEN LIMITING</td>
<td>LESS LIMITING</td>
</tr>
<tr>
<td><strong>WORK RATE QUANTIFICATION</strong></td>
<td>YES</td>
<td>ESTIMATION</td>
</tr>
<tr>
<td><strong>WEIGHT BEARING IN OBESE</strong></td>
<td>LESS</td>
<td>MORE</td>
</tr>
<tr>
<td><strong>NOISE &amp; ARTIFACTS</strong></td>
<td>LESS</td>
<td>MORE</td>
</tr>
<tr>
<td><strong>SAFETY ISSUES</strong></td>
<td>LESS</td>
<td>MORE</td>
</tr>
</tbody>
</table>
INDICATIONS TO EXERCISE TERMINATION

- Patient’s request: fatigue, dyspnea, pain
- Ischemic ECG changes
  - 2 mm ST depression
- Chest pain suggestive of ischemia
- Significant ectopy
- 2nd or 3rd degree heart block
- $Bp_{sys} > 240-250$, $Bp_{dias} > 110-120$
INDICATIONS TO TERMINATION …

- Fall in $BP_{sys} > 20$ mmHg
- $SpO_2 < 81-85\%$
- Dizziness, faintness
- Onset of confusion
- Onset of pallor
General Mechanisms of Exercise Limitation

- **Pulmonary**
  - Ventilatory impairment
  - Respiratory muscle dysfunction
  - Impaired gas exchange

- **Cardiovascular**
  - Reduced stroke volume
  - Abnormal HR response
  - Circulatory abnormality
  - Blood abnormality

- **Peripheral**
  - Inactivity
  - Atrophy
  - Neuromuscular dysfunction
  - Reduced oxidative capacity of skeletal muscle
  - Malnutrition

- **Perceptual**
- **Motivational**
- **Environmental**
Interpretation of CPET

- Peak oxygen consumption
- Peak HR
- Peak work
- Peak ventilation
- Anaerobic threshold
- Heart rate reserve
- Breathing reserve
Estimation of Predicted Peak HR

- 220 – age
  - For age 40: 220 - 40 = 180
  - For age 70: 220 - 70 = 150

- 210 – (age x 0.65)
  - For age 40: 210 - (40 x 0.65) = 184
  - For age 70: 210 - (70 x 0.65) = 164
Comparison of actual peak HR and predicted peak HR

\[ = (1 - \text{Actual/Predicted}) \times 100\% \]

- Normal <15%
Flow chart for the differential diagnosis of exertional dyspnea and fatigue.

- Peak VO₂
  - Normal ≥ 85% predicted
    - Anxiety
    - Obesity
    - Mild Disease
  - Low < 85% predicted
    - Anaerobic Threshold
      - Normal ≥ 40% predicted PkVO₂
        - Breathing Reserve
          - Normal ≥ 30%
            - Poor Effort
          - Low < 30%
            - Deconditioning
            - Coronary Disease
          - Ventilatory Impairment
      - Low < 40% predicted PkVO₂
        - Breathing Reserve
          - Normal ≥ 30%
          - Circulatory Impairment
        - Low < 30%
          - Mixed Lesions

Abnormal patterns of responses from CPX characteristic of disorders that cause dyspnea

**Abnormal Responses**
- High VO$_2$/HR
- Low peak HR
- Low Peak VO$_2$ and VT
- Low ΔVO$_2$/Δ WR
- Low VO$_2$/HR
- High VE/VCO$_2$
- High VD / tidal volume
- Increased P(A-a)O$_2$
- Low breathing reserve
- Dynamic hyperinflation
- Reduced inspiratory flow
- Erratic breathing pattern
- Early or absent VT
- High C.O. / VO$_2$
- Low VO$_2$/HR
- Abnormal HR or blood pressure

**Selected associated conditions**
- Chronotropic insufficiency
- Inefficient pulmonary gas exchange
- Vocal Cord Dysfunction
- Hyperventilation syndrome
- Metabolic myopathy
- Autonomic dysfunction

**General Patterns**
- Circulatory impairment
- Pulmonary vascular disease
- COPD
- Ventilatory impairment
- O$_2$ extraction or utilization impairment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal</th>
<th>Clinical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ max (peak)</td>
<td>&gt;84%</td>
<td>Decreased in heart failure, COPD, ILD, obesity, pulmonary vascular disease, and deconditioned.</td>
</tr>
<tr>
<td>AT</td>
<td>&gt;40% VO₂ max</td>
<td>Decreased in heart failure, COPD, ILD, pulmonary vascular disease, and deconditioned. Normal in obesity.</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>&gt;90%</td>
<td>Decreased in COPD, obesity, pulmonary vascular disease, and deconditioned. Normal in heart failure.</td>
</tr>
<tr>
<td>Heart Rate Reserve</td>
<td>&lt;15 beats/min</td>
<td></td>
</tr>
<tr>
<td>Oxygen Pulse</td>
<td>&gt;80%</td>
<td>Decreased in heart failure, COPD, ILD, pulmonary vascular disease, and deconditioned. Normal in obesity.</td>
</tr>
<tr>
<td>Vₑ max Frequency</td>
<td>70 – 80%</td>
<td>Increased or normal in heart failure, COPD, ILD, obesity, pulmonary vascular disease, and deconditioned.</td>
</tr>
<tr>
<td>Ventilatory or Breathing Reserve</td>
<td>20 – 30%</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Normal</td>
<td>Clinical Significance</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>SaO₂</td>
<td>≥95%</td>
<td>Decreased in ILD and pulmonary vascular disease.</td>
</tr>
<tr>
<td></td>
<td>≤4% decrease</td>
<td>Normal in heart failure, obesity and deconditioned.</td>
</tr>
<tr>
<td>PaO₂</td>
<td>≥80 mmHg</td>
<td>Decreased in ILD and pulmonary vascular disease</td>
</tr>
<tr>
<td></td>
<td>≤10 mmHg fall</td>
<td>Normal in heart failure, obesity and deconditioned.</td>
</tr>
<tr>
<td>P(A-a)O₂</td>
<td>&lt;35 mmHg</td>
<td>Increased in COPD, ILD, and pulmonary vascular disease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal in heart failure and deconditioned.</td>
</tr>
<tr>
<td>V̄D/V̄T</td>
<td>&lt;0.28</td>
<td>Increased in heart failure, COPD, ILD, pulmonary vascular disease, and normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in obesity and deconditioned.</td>
</tr>
<tr>
<td>V̄E/V̄CO₂(at AT)</td>
<td>&lt;34</td>
<td>Increased in heart failure, COPD, ILD, and pulmonary vascular disease.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal in obesity and deconditioned.</td>
</tr>
</tbody>
</table>
Fig. 5.6 The balance approach to identifying the pattern of exercise limitation. In this example, the patient has many features that are consistent with a cardiac pattern of limitation and only one aspect of their data—the small ventilatory reserve—that is consistent with a ventilatory limitation. Because the preponderance of factors favor the left side of the balance, this patient would be best described as having a cardiac pattern or limitation.
Heart Disease
- Breathing reserve >30%
- Heart rate reserve <15%

Pulmonary Disease
- Breathing reserve <30%
- Heart rate reserve >15%
CPET to Predict Risk of Lung Resection in Lung Cancer

Lim et al; Thorax 65:iii1, 2010
Alberts et al; Chest 132:1s, 2007
Balady et al; Circulation 122:191, 2010

- **Peak VO₂ >15 ml/kg/min**
  - No significant increased risk of complications or death

- **Peak VO₂ <15 ml/kg/min**
  - Increased risk of complications and death

- **Peak VO₂ <10 ml/kg/min**
  - 40-50% mortality
  - Consider non-surgical management

In one report, inability to perform cycle ergometry was found to be an independent predictor of bad outcome after lung resection.
Cardiopulmonary measurements obtained at rest may not estimate functional capacity reliably.

CPET includes the measurement of expired oxygen and carbon dioxide.

CPET may assist in pre-op evaluation and risk stratification, prognostication of life expectancy, and disability determination.

Reduced aerobic fitness is associated with worse perioperative outcomes in morbidity and mortality.
Thank You
References

Lim et al; Thorax 65:iii1, 2010
Alberts et al; Chest 132:1s, 2007 Balady
et al; Circulation 122:191, 2010