CARDIOPULMONARY EXERCISE TESTING

JOSEPHINE B. BLANCO-RAMOS, M.D., FPCP, FPCCP, FACCP
MEDICAL HEAD
PULMONARY DIAGNOSTIC & THERAPEUTIC CENTER
THE MEDICAL CITY
OUTLINE

- Description of CPET
- Who should and who should not get CPET
- When to terminate CPET
- Exercise physiology
- Define terms: respiratory exchange ratio, ventilatory equivalent, heart rate reserve, breathing reserve, oxygen pulse
- Patterns of CPET results
SOURCES OF ENERGY FOR ATP

Aerobic Glycolysis:
- Glycogen → Glucose
- Glucose → Pyruvic acid
- Pyruvic acid → ATP
- CO₂ + H₂O

Anaerobic Glycolysis:
- Glycogen → Glucose
- Glucose → Pyruvic acid
- Pyruvic acid → ATP
- Lactic acid

Fig. 1
Derangements of gas exchange in disease.

- Obesity
- Airflow obstruction

- Heart disease
  - Coronary
  - Myocardial
  - Valvular
  - Anemia

- Obstruction
  - Restriction
  - Chestwall
  - Infiltrative

- Occlusion
- Hypertension
- Vasoregulatory asthenia

- Thromboemboli
- Vasculitis
- 1º Pulmonary hypertension

Coupling of External Ventilation and Cellular Metabolism

- Mitochondria
  - $V_O^2$
  - $V_CO^2$

- Muscles
  - $O_2$ Consum.
  - $CO_2$ Prod.

- Pulmonary Arteries
  - Circulation
  - Syst. Art.

- 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
Cardiac assessment: low risk or treated patient

FEV1, DLCO

Both >80%

Either one <80%

Exercise testing
Peak VO2 or climbing 7 flights (>22m)
If the patient does not climb >22m, VO2 peak measurement is required

<35% η <10 ml/kg/min

>75% η >20 ml/kg/min

35-75% η 10-20 ml/kg/min

3poFEV1, 3poDLCO

Both >30%

At least one <30%

<35% η <10-20 ml/kg/min

Ppo-peakVO2

>35% η >10 ml/kg/min

Lobectomy or pneumonectomy are usually not recommended

Resection up to calculated extent

Resection up to pneumonectomy

Figure 2. Algorithm for assessment of cardiopulmonary reserve before lung resection in patients with lung cancer
Predicted Post-Operative FEV1

\[
PPO \text{ FEV1} = \text{Pre-Op FEV1} \times (1-a/b)
\]

- \(a\) = number of unobstructed segments to be removed
- \(b\) = total number of unobstructed segments

\[
PPO \text{ FEV1} = 1480 \text{ ml} \ (1 - 9/19)
= 778 \text{ ml}
\]
QUESTION 2:

WHAT IS THE NEXT MOST APPROPRIATE DIAGNOSTIC PROCEDURE TO CONFIRM WHETHER THIS PATIENT CAN UNDERGO PNEUMONECTOMY?

A. STAIR CLIMBING
B. DIFFUSION CAPACITY
C. VENTILATION-PERFUSION SCANNING
D. CARDIOPULMONARY EXERCISE TESTING
Use of CPX in the clinical evaluation of chronic dyspnea.

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
ABSOLUTE CONTRA ...

- 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
HISTORY: tobacco use, medications, tolerance to normal physical activities, any distress symptoms, contraindicated illnesses

PHYSICAL EXAM: height, weight, assessment of heart, lungs, peripheral pulses, blood pressure

EKG

PULMONARY FUNCTION TESTS: spirometry, lung volumes, diffusing capacity, arterial blood gases
PRIOR TO THE TEST

- Wear loose fitting clothes, low-heeled or athletic shoes
- Abstain from coffee and cigarettes at least 2 hours before the test
- Continue maintenance medications
- May eat a light meal at least 2 hours before the test
CARDIOPULMONARY EXERCISE TEST (CPET)

- symptom-limited exercise test
- measures airflow, \(\text{SpO}_2\), and expired oxygen and carbon dioxide
- allows calculation of peak oxygen consumption, anaerobic threshold
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 VO₂
  - more functional
<table>
<thead>
<tr>
<th></th>
<th>Cycle</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2 Max</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Leg Muscle Fatigue</td>
<td>Often Limiting</td>
<td>Less Limiting</td>
</tr>
<tr>
<td>Work Rate Quantification</td>
<td>Yes</td>
<td>Estimation</td>
</tr>
<tr>
<td>Weight Bearing in Obese</td>
<td>Less</td>
<td>More</td>
</tr>
<tr>
<td>Noise &amp; Artifacts</td>
<td>Less</td>
<td>More</td>
</tr>
<tr>
<td>Safety Issues</td>
<td>Less</td>
<td>More</td>
</tr>
</tbody>
</table>
EXERCISE TEST PROTOCOLS

INCREMENTAL

WORK

TIME

RAMP

WORK

TIME
INDICATIONS TO EXERCISE TERMINATION

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

- Fall in $B_{\text{sys}} > 20$ mmHg
- $\text{SpO}_2 < 81-85$
- Dizziness, faintness
- Onset of confusion
- Onset of pallor
<table>
<thead>
<tr>
<th>Pulmonary</th>
<th>Peripheral</th>
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<tbody>
<tr>
<td>Ventilatory impairment</td>
<td>Inactivity</td>
</tr>
<tr>
<td>Respiratory muscle dysfunction</td>
<td>Atrophy</td>
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<tr>
<td>Impaired gas exchange</td>
<td>Neuromuscular dysfunction</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Reduced oxidative capacity of skeletal muscle</td>
</tr>
<tr>
<td>Reduced stroke volume</td>
<td>Malnutrition</td>
</tr>
<tr>
<td>Abnormal HR response</td>
<td>Perceptual</td>
</tr>
<tr>
<td>Circulatory abnormality</td>
<td>Motivational</td>
</tr>
<tr>
<td>Blood abnormality</td>
<td>Environmental</td>
</tr>
<tr>
<td>CPET Measurements</td>
<td></td>
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<tr>
<td>--------------------</td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td></td>
</tr>
<tr>
<td>VO&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>VCO&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>AT</td>
<td></td>
</tr>
<tr>
<td>HR</td>
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</tr>
<tr>
<td>ECG</td>
<td></td>
</tr>
<tr>
<td>BP</td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td></td>
</tr>
<tr>
<td>SpO&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>ABG</td>
<td></td>
</tr>
<tr>
<td>Lactate</td>
<td></td>
</tr>
<tr>
<td>Dyspnea</td>
<td></td>
</tr>
<tr>
<td>Leg fatigue</td>
<td></td>
</tr>
</tbody>
</table>
Metabolic endpoint to evaluate results of therapeutic interventions.

Appropriate Endpoint:

- \( PkVO_2 \)
- \( PkVO_2 \) Lean*
- AT
- \( VE/VCO_2 \) change

1. MINUTE VENTILATION
   - NORMAL = 5 – 6 liters/ min
   - AT EXERCISE = 100 liters/min
   - increase is due to stimulation of the respiratory centers by brain motor cortex, joint proprioceptors and chemoreceptors
   - ANAEROBIC THRESHOLD (AT) the minute ventilation increases more than the workload
2. TIDAL VOLUME

- NORMAL = 500 ml
- DURING EXERCISE = 2.3 – 3 liters
- increases early in the exercise
- increases ventilation
3. BREATHING RATE

- NORMAL = 12 – 16 / min
- AT EXERCISE = 40 – 50 / min
- responsible for the increase in minute ventilation
4. DEAD SPACE / TIDAL VOLUME ratio

- NORMAL = 0.20 – 0.40
- AT EXERCISE = 0.04 – 0.20
- decrease is due to increased tidal volume with constant dead space
5. PULMONARY CAPILLARY BLOOD TRANSIT TIME
   - NORMAL = 0.75 second
   - AT EXERCISE = 0.38 second
   - The decrease is due to increased cardiac output

6. ALVEOLAR-ARTERIAL OXYGEN DIFFERENCE
   - NORMAL = 10 mm Hg
   - AT EXERCISE = 20 – 30 mm Hg
   - Changes very little until a heavy workload is achieved
7. OXYGEN TRANSPORT
   - increase in temperature, PCO2 and relative acidosis in the muscles -> increase in release of Oxygen by blood for use by the tissues for metabolism
1. CARDIAC OUTPUT

- NORMAL = 4 – 6 liters / min
- AT EXERCISE = 20 liters / min

- increase is linear with increase in workload during exercise until the point of exhaustion
- first half of exercise capacity, the increase is due to increase in Heart Rate and Stroke Volume
- later, due to increase in Heart Rate alone
CARDIOVASCULAR...

2. STROKE VOLUME
   - NORMAL = 50 – 80 ml
   - AT EXERCISE = double
   - increase is linear with increase in workload
   - after a Heart Rate of > 120/ min, there is little increase in Stroke Volume
3. HEART RATE
   - NORMAL = 60 – 100 /min
   - AT EXERCISE =  2.5 – 4 times the resting HR
   - HR max is achieved just prior to total exhaustion, physiologic endpoint of an individual

   - HR max =  220 – age
   - HR max =  210 – (0.65 x age)
4. **OXYGEN PULSE**
   - **NORMAL** = 2.5 – 4 ml O2 / heartbeat
   - **AT EXERCISE** = 10 – 15 ml
   - With increasing muscle work during exercise, each heart contraction must deliver a greater quantity of oxygen out to the body

   - **O2 PULSE** = VO2/ HR
5. BLOOD PRESSURE

DURING EXERCISE:

- Systolic BP increases (to 200 mm Hg)
- Diastolic BP is relatively stable (up to 90 mmHg)
- Increase in Pulse Pressure (difference between Systolic and Diastolic pressures)
5. ARTERIAL – VENOUS OXYGEN CONTENT DIFFERENCE

- mL of O2 / 100 ml of blood
- NORMAL = 5 vol %
- AT EXERCISE = 2.5 – 3 times higher
- the increase is due to the greater amounts of Oxygen that are extracted by the working muscle tissue
1. OXYGEN CONSUMPTION

- NORMAL = 250 ml / min
  
  \[ 3.5 \text{ – } 4 \text{ ml / min / kg} \]

- increases directly with the level of muscular work
- increases until exhaustion occurs and until individual reaches ....

- VO2max = maximum level of oxygen consumption
  
  definite indicator of muscular work capacity

  NORMAL RANGE = 1,700 – 5,800 ml / min
2. CARBON DIOXIDE PRODUCTION
   - NORMAL = 200 ml / min
     2.8 ml / min / kg
   - AT EXERCISE
     - initial phase, increases at same rate as VO2
     - once Anaerobic Threshold (AT) is reached, increases at a faster rate than VO2
     - increase is due to increased acid production
Lactic acid + HCO₃⁻ → H₂CO₃ + Lactate

↓

H₂O + CO₂
3. ANAEROBIC THERSHOLD (AT)
  - NORMAL: occurs at about 60% of VO2 max
  - followed by breathlessness, burning sensation begins in working muscles
4. RESPIRATORY QUOTIENT (RQ)
   - RESTING LEVEL = 0.8
   - AT = 1.0 or more
   - may exercise for a short time on 1.5

\[
RER = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}} = \frac{VCO_2}{VO_2}
\]

5. BLOOD pH
   - relatively unchanged until AT is reached
   - the body becomes less able to buffer the excessive acid produced by anaerobic metabolism
INCREASES DURING EXERCISE

- Heart rate
- Oxygen extraction
- Cardiac output
- Oxygen uptake
- Carbon dioxide output
- Arterial blood pressure
- Minute ventilation
- Alveolar ventilation
- Oxygen pulse
- RQ and RER
- METS
During exercise, there are decreases in:
- VD/ VT
Ventilatory Equivalents

- Ventilatory equivalent for carbon dioxide = Minute ventilation / \( VCO_2 \)
  - Efficiency of ventilation
  - Liters of ventilation to eliminate 1 L of CO\(_2\)

- Ventilatory equivalent for oxygen = Minute ventilation / \( VO_2 \)
  - Liters of ventilation per L of oxygen uptake
Below the anaerobic threshold, with carbohydrate metabolism, RER=1 (CO\textsubscript{2} production = O\textsubscript{2} consumption).

Above the anaerobic threshold, lactic acid is generated.

Lactic acid is buffered by bicarbonate to produce lactate, water, and carbon dioxide.

Above the anaerobic threshold, RER >1 (CO\textsubscript{2} production > O\textsubscript{2} consumption).

Carbon dioxide regulates ventilation.

Ventilation will disproportionately increase at lactate threshold to eliminate excess CO\textsubscript{2}.

Increase in ventilatory equivalent for oxygen demarcates the anaerobic threshold.
The lactate measurement shows the sudden increase in lactate.
Determination of AT from Ventilatory Equivalent Plot
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: \(210 - (40 \times 0.65) = 184\)
  - For age 70: \(210 - (70 \times 0.65) = 164\)
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 VO_2

- Normal ≥ 85% predicted
  - Anxiety
  - Obesity
  - Mild Disease
- Low < 85% predicted
  - Anaerobic Threshold

Breathing Reserve

- Normal ≥ 40% predicted PkVO_2
  - Normal ≥ 30%
    - Poor Effort
  - Low < 30%
    - Deconditioning
    - Coronary Disease
  - Ventilatory Impairment
- Low < 40% predicted PkVO_2
  - Normal ≥ 30%
  - Circulatory Impairment
  - Low < 30%
  - Mixed Lesions

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

- High VO₂/HR
- Low peak HR
- Low Peak VO₂ and VT
- Low ΔVO₂/Δ WR
- Low VO₂/HR
- High VE/VCO₂
- High VD / tidal volume
- Increased P(A-a)O₂
- Low breathing reserve
- Dynamic hyperinflation
- Reduced inspiratory flow
- Erratic breathing pattern
- Early or absent VT
- High C.O. / VO₂
- Low VO₂/HR
- Abnormal HR or blood pressure
- Chronotropic insufficiency
- Inefficient pulmonary gas exchange
- Vocal Cord Dysfunction
- Hyperventilation syndrome
- Metabolic myopathy
- Autonomic dysfunction

Selected associated conditions:
- Low stroke volume
- CHF
- Pulmonary vascular disease
- COPD

General Patterns:
- Circulatory Impairment
- Ventilatory Impairment
- O₂ extraction or utilization Impairment

# Predicted and Normal Values for Test Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Predicted Value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO(<em>2)(</em>\text{max}) (ml/min)</td>
<td>Based on gender, age, height</td>
<td>Lower limit of normal &lt; 80% predicted</td>
</tr>
<tr>
<td>Resting VO(_2) (ml/min)</td>
<td>150 + (6 X weight in kg)</td>
<td>250 - 300 (larger in obese individuals)</td>
</tr>
<tr>
<td>Peak Heart Rate (bpm)</td>
<td>220 - age or 210 - (0.65 X age)</td>
<td>90% predicted ± 15 bpm</td>
</tr>
<tr>
<td>Oxygen pulse (ml/beat)</td>
<td>(Predicted VO(<em>2)(</em>\text{max}))(^p) (predicted max HR)</td>
<td>80% predicted (~ 15 ml/beat in men; ~ 10 ml/beat in women)</td>
</tr>
<tr>
<td>Minute Ventilation (L/min)</td>
<td></td>
<td>Peak Exercise: 70-80% of MVV</td>
</tr>
<tr>
<td>Maximum Tidal Volume</td>
<td>60% of the FVC</td>
<td></td>
</tr>
<tr>
<td>V(_E)/VCO(_2) (early exercise)</td>
<td></td>
<td>25-35</td>
</tr>
<tr>
<td>V(_E)/VO(_2) (early exercise)</td>
<td></td>
<td>25-35</td>
</tr>
<tr>
<td>V(_D)/V(_T)</td>
<td></td>
<td>0.25-0.35 at rest Should decrease with exercise</td>
</tr>
<tr>
<td>P(_{ET})CO(_2) (mm Hg)</td>
<td></td>
<td>38-42 (Should decline after ventilatory threshold)</td>
</tr>
<tr>
<td>P(_{ET})O(_2) (mm Hg)</td>
<td></td>
<td>95-100 (Should rise after ventilatory threshold)</td>
</tr>
<tr>
<td>A-a O(_2) Difference (mm Hg)</td>
<td></td>
<td>Rest: 10-20 Peak Exercise: 15-30</td>
</tr>
<tr>
<td>S(_a)O(_2) (%)</td>
<td></td>
<td>&gt; 95% (Should remain constant with exercise)</td>
</tr>
<tr>
<td>Respiratory Exchange Ratio</td>
<td>Rest: 0.8 Peak Exercise: &gt; 1.15</td>
<td>Rest: 0.6-1.0 Peak Exercise: 1.1-1.3</td>
</tr>
</tbody>
</table>

Note: Normal values based on data from Gold WM. "Clinical Exercise Testing" in Murray and Nadel’s Textbook of Respiratory Medicine. Elsevier Saunders. Philadelphia
### Table 1. Basic Patterns Observed On Cardiopulmonary Exercise Testing in Normals and Patients With Various Forms of Disease

<table>
<thead>
<tr>
<th>Variable</th>
<th>Disease Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Patient</td>
</tr>
<tr>
<td>VO(<em>2),(</em>\text{max})</td>
<td>Normal *</td>
</tr>
<tr>
<td>Heart Rate Reserve</td>
<td>Absent to small reserve (&lt; 20 bpm)</td>
</tr>
<tr>
<td>VE,(_\text{max})/MVV (Ventilatory Reserve)</td>
<td>&lt; 0.8</td>
</tr>
<tr>
<td>Ventilatory Threshold</td>
<td>Present</td>
</tr>
<tr>
<td>Dead Space ((V_D/V_T))</td>
<td>Decreases</td>
</tr>
<tr>
<td>Oxygen Saturation</td>
<td>Stable</td>
</tr>
<tr>
<td>End-Tidal CO(_2) (in late exercise)</td>
<td>Decrease</td>
</tr>
<tr>
<td>Reason for Stopping</td>
<td>Leg Fatigue</td>
</tr>
</tbody>
</table>

**Note:**
* "Normal" or "decreased" refers to how the variable changes relative to age, gender and size matched individuals.

# Interstitial lung disease patients demonstrate a pattern very similar to the pulmonary vascular pattern and can only be differentiated based on their PFTs and chest imaging.
### Estimation of Predicted Peak HR

- **For age 40:** $220 - 40 = 180$
- **For age 70:** $220 - 70 = 150$

### Variable | Normal | Clinical Significance
---|---|---
VO$_2$ max (peak) | >84% | Decreased in heart failure, COPD, ILD, obesity, pulmonary vascular disease, and deconditioned.
AT | >40% VO$_2$max | Decreased in heart failure, COPD, ILD, pulmonary vascular disease, and deconditioned. Normal in obesity.
Heart Rate | >90% | Decreased in COPD, obesity, pulmonary vascular disease, and deconditioned.
Heart Rate Reserve | <15 beats/min | Normal in heart failure.
Oxygen Pulse | >80% | Decreased in heart failure, COPD, ILD, pulmonary vascular disease, and deconditioned. Normal in obesity.
$V_E$ max | 70 – 80% | Increased or normal in heart failure, COPD, ILD, obesity, pulmonary vascular disease, and deconditioned.
Frequency | <60 bpm | 
Ventilatory or Breathing Reserve | 20 – 30% |
<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal</th>
<th>Clinical Significance</th>
</tr>
</thead>
<tbody>
<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>V₅/V₇</td>
<td>&lt;0.28</td>
<td>Increased in heart failure, COPD, ILD, pulmonary vascular disease, and normal in obesity and deconditioned.</td>
</tr>
<tr>
<td>Vₑ/VCO₂ (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>
## Comparison CPET results

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>CHF</th>
<th>COPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted Peak HR</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Peak HR</td>
<td>150</td>
<td>140</td>
<td>120</td>
</tr>
<tr>
<td>MVV</td>
<td>100</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Peak VO₂</td>
<td>2.0</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>AT</td>
<td>1.0</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Peak VE</td>
<td>60</td>
<td>40</td>
<td>49</td>
</tr>
<tr>
<td>Breathing Reserve</td>
<td>40%</td>
<td>60%</td>
<td>2%</td>
</tr>
<tr>
<td>HR Reserve</td>
<td>0%</td>
<td>7%</td>
<td>20%</td>
</tr>
<tr>
<td>Borg Breathlessness</td>
<td>5</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Borg Leg Discomfort</td>
<td>8</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Condition</td>
<td>Peak VO₂</td>
<td>HRR</td>
<td>BR</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>Normal</td>
<td>&gt;80%</td>
<td>&lt;15%</td>
<td>&gt;30%</td>
</tr>
<tr>
<td>Heart disease</td>
<td>&lt;80%</td>
<td>&lt;15%</td>
<td>&gt;30%</td>
</tr>
<tr>
<td>Pulm vasc dis</td>
<td>&lt;80%</td>
<td>&lt;15%</td>
<td>&gt;30%</td>
</tr>
<tr>
<td>Pulm mech dis</td>
<td>&lt;80%</td>
<td>&gt;15%</td>
<td>&lt;30%</td>
</tr>
<tr>
<td>Deconditioning</td>
<td>&lt;80%</td>
<td>&gt;15%</td>
<td>&gt;30%</td>
</tr>
</tbody>
</table>
Cardiac vs Pulmonary Limitation

- Heart Disease
  - Breathing reserve >30%
  - Heart rate reserve <15%

- Pulmonary Disease
  - Breathing reserve <30%
  - Heart rate reserve >15%
II. CARDIAC LIMITATION TO EXERCISE

- If HRR is PRESENT
  - NOT ACHIEVED
    - AT % < 40%
      - Q R S
    - AT % > 40%
      - T U V W

- If HRR is ABSENT
  - NOT ACHIEVED
    - AT % < 40%
      - Q R S
    - AT % > 40%
      - T U V W
<table>
<thead>
<tr>
<th>Peak Cardiovascular Responses</th>
<th>Measured</th>
<th>% Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2 (ml/kg/min)</td>
<td>38.3</td>
<td>24.0</td>
</tr>
<tr>
<td>VO2 (l/min)</td>
<td>2.938</td>
<td>1.517</td>
</tr>
<tr>
<td>VCO2 (l/min)</td>
<td></td>
<td>1.677</td>
</tr>
<tr>
<td>Work (Watts)</td>
<td>205</td>
<td>250</td>
</tr>
<tr>
<td>Anaerobic Threshold (AT) (l/min)</td>
<td>&gt; 1.175</td>
<td>1.029</td>
</tr>
<tr>
<td>AT (% Predicted Max VO2)</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>Heart Rate (bpm)</td>
<td>174</td>
<td>166</td>
</tr>
<tr>
<td>O2 Pulse (ml/beat)</td>
<td>15.2</td>
<td>9.1</td>
</tr>
<tr>
<td>Systolic Blood Pressure (Max)</td>
<td>179</td>
<td></td>
</tr>
<tr>
<td>Diastolic Blood Pressure (Max) 85-105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart Rate Reserve (bpm)</td>
<td>&lt;15</td>
<td>174</td>
</tr>
</tbody>
</table>

**Peak Ventilatory Responses**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VE Max (l/min) BTPS</td>
<td>65.8</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Tidal Volume (VT) (L)</td>
<td>0.620</td>
<td>1.240</td>
<td>200</td>
</tr>
<tr>
<td>Respiratory Rate (RR)</td>
<td>&lt;50</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Breathing Reserve (%)</td>
<td>20-40</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Gas-Exchange Responses**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>End Tidal CO2 (Peak PetCO2)</td>
<td>40.7</td>
<td></td>
</tr>
<tr>
<td>End Tidal O2 (Peak PetO2)</td>
<td>111.9</td>
<td></td>
</tr>
<tr>
<td>VE/VO2 @ AT</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>VE/VCO2 @ AT</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>VD/VT (Est) @ Rest</td>
<td>0.30</td>
<td>0.12</td>
</tr>
<tr>
<td>VD/VT (Est) Peak</td>
<td>0.18</td>
<td>0.23</td>
</tr>
<tr>
<td>Respiratory Quotient (RQ)(Peak)</td>
<td>1.1-1.3</td>
<td>1.11</td>
</tr>
<tr>
<td>SpO2 (O2 Sat--Pulse Ox) @ Peak</td>
<td>97</td>
<td>95</td>
</tr>
</tbody>
</table>
QUESTION 3:

Would you clear this patient for pneumonectomy?

A. Yes
B. No
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
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.

Cycle ergometer permits direct power calculation.

Peak VO$_2$ is higher on treadmill than cycle ergometer.
Peak VO\(_2\) may be lower than VO\(_2\)\(_{\text{max}}\).

Absolute contraindications to CPET include unstable cardiac disease and SpO\(_2\) <88% on RA.

Fall in BP\(_{\text{sys}}\) >20 mmHg is an indication to terminate CPET.

1 glucose yields 36 ATP in slow twitch fiber, and 2 ATP + 2 lactic acid in fast twitch fiber.

RER= CO\(_2\) produced / O\(_2\) consumed
Above the anaerobic threshold, CO₂ production exceeds O₂ consumption.

Ventilation will disproportionately increase at lactate threshold to eliminate excess CO₂.

AT may be determined graphically from V slope method or from ventilatory equivalent for CO₂.

Derived from the Fick equation, Oxygen Pulse = VO₂ / HR, and is proportional to stroke volume.

In pure heart disease, BR is >30% and HRR <15%.

In pure pulmonary disease, BR is <30% and HRR >15%.
Principles of Exercise Testing and Interpretation, 5th edition, Dr. Karl Wasserman


Thank You