Cardiopulmonary Exercise Testing: its principles, interpretation & application

DM Seminar
Harshith
Outline

• Physiology of exercise
• Introduction
• Equipment and working
• Principles
• Interpretation and variables
• Indications and contraindications
• Clinical application
• Recent advances
References

• ATS/ACCP statement on CPET.
  Am J Respir Crit Care Med. 2003; 167:211-277

• AHA Clinician’s guide to CPET in adults
  Circulation. 2010;122:191-225

• Fishman’s pulmonary diseases and disorders
• Braunwald’s heart disease
Exercise

• 2 types
  – Endurance
  – Resistance
Physiologic response to exercise
Introduction

• Non invasive
• Dynamic testing, evaluation of submaximal and peak exercise response
• Integrated analysis of multiple systems
  – Respiratory
  – Cardiac
  – Metabolic
  – Hematological
  – Musculoskeletal
Equipment

- Cycle ergometer/ treadmill
- Airflow or volume transducers
- Gas analysers
- Electrocardiograph
- NIBP
- Pulse oximetry
- Intra arterial BP monitoring and ABG (if invasive, optional)
Options available for both models, **Clinical** and **Professional**:

- Exercise flow-volume loop with flow-limited evaluation.
- Interface and control of most Bike Ergometers and Treadmills.
- Heart rate chest belt.
- Advanced integrated 12 leads ECG module, for resting and exercise applications, one-touch operation with complete ECG analysis, arrhythmia detection and analysis, real-time printing.
- SpO2.
- Automated Blood pressure external Tango™ option, with exercise artifact rejection.

**Can be combined with the following devices:**

ECG, FeNO+, FOT Rasmus Pro, BodyBox, HypAir, Micro 5000, Micro 6000, SpiroAir.
Parameters monitored

- **Baseline lung function**
  - Tidal volume (VT); Respiratory rate (RF)
  - Minute ventilation (VE = VT \* RER)
  - Vital capacity (FVC, LVC)
  - Ventilatory reserve (RV)
  - VMM: maximal minute voluntary ventilation
  - Dyspnea scale...

- **Ventilatory function**

- **Heart Function**
  - Electrocardiography (ECG)
  - Heart rate (HR)
  - Blood pressures (BP)

- **Metabolic function**
  - Oxygen uptake (VO2)
  - CO2 output (VCO2)
  - Blood gas index (PaO2, PaCO2, pH, lactate...)

- **Work rate (Watt)**
Comparing the test modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Spirometry</th>
<th>VO2, VCO2</th>
<th>ECG</th>
<th>Heart rate</th>
<th>Blood pressure</th>
<th>Blood gas</th>
<th>Pulse oxymetry</th>
<th>+Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>✓</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>b</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>c</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>d</td>
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<td>✓</td>
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<td>e</td>
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<td>✓</td>
<td>✓</td>
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<td>f</td>
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<td>✓</td>
<td>✓</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Exercise testing stages
How do we do it? Protocols

• Based on work rate applied
  – Continuous ramp
  – Multistage (modified Bruce)
  – Constant work rate (modified Balke)
  – Discontinuous
## Cycle ergometry vs treadmill

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cycle</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak oxygen content (PVO₂)</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Work rate measurement</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Blood gas collection</td>
<td>Easier</td>
<td>More difficult</td>
</tr>
<tr>
<td>Noise and artefacts</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 subjects</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 subjects</td>
</tr>
</tbody>
</table>

Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.¹
Ficks principle

- Vo2 = cardiac output x (CaO2 - CvO2)

- Pulmonary – ventilation, gas exchange
- O2 carrying capacity of blood – Hb, Hb-O2 dissociation
- Cardiac function – Heart rate, Stroke volume
- Tissue extraction – Capillary, mitochondrial density, tissue perfusion
CENTRAL ILLUSTRATION  Determinants of the O₂ Transport and Utilization Chain Framed on the Fick Principle

Heart Failure

- Signs and Symptoms
- HFrEF
- Exercise Intolerance
  - Dypnea and Fatigue
- HFrEF

Organ Systems and Pathways in O₂ Uptake Process
[Convection (Delivery), Release, Diffusion, and Use]

\[ VO_2 = CO \times (CaO2 - CvO2) \]

<table>
<thead>
<tr>
<th>Pulmonary</th>
<th>Cardiac</th>
<th>Hematologic</th>
<th>Vascular</th>
<th>Mitochondrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation/Gas Exchange</td>
<td>Stroke Volume</td>
<td>Hb Concentration</td>
<td>Vasoregulation</td>
<td>Krebs Cycle-ATP Generation</td>
</tr>
<tr>
<td>O₂ Diffusion (Alveolar)</td>
<td>Heart Rate</td>
<td>Mediators of Release</td>
<td>Capillary Network</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O₂ Delivery</td>
<td>O₂ Delivery and Release</td>
<td>O₂ Diffusion</td>
<td>O₂ Use (Extraction)</td>
</tr>
</tbody>
</table>

### Variables for interpretation

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Noninvasive</th>
<th>Invasive</th>
</tr>
</thead>
<tbody>
<tr>
<td>External work</td>
<td>WR</td>
<td></td>
</tr>
<tr>
<td>Metabolic gas exchange</td>
<td>VO2, VCO2, RER, AT</td>
<td>Lactate/ bicarbonate</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>HR, ECG, BP, Oxygen pulse</td>
<td></td>
</tr>
<tr>
<td>Ventilatory</td>
<td>Ve, Vt, fR</td>
<td></td>
</tr>
<tr>
<td>Symptoms</td>
<td>Dyspnea, fatigue, chest pain</td>
<td></td>
</tr>
</tbody>
</table>
Oxygen uptake (Vo2)

- Key measurement in exercise testing
- 250ml/min or 30-50ml/kg/min (MET)
- Age, sex, body wt, conditioning of muscles
- Indicators of exercise capacity
- 2 types
  - Maximum Vo2
  - Peak Vo2
Oxygen uptake (Vo2)
Vo2 max vs Vo2 peak

- Maximal achievable level of oxidative metabolism
- Gold std for assessing cardio-respiratory fitness
- Best index of aerobic capacity
- Plateau achieved with max exercise

- In Patients: clear plateau not reached
- Practical purposes
- Rough estimate of max o2 uptake
Recommendation

- Vo2max/Vo2 peak should be obtained from the maximal Vo2 value measured during an incremental exercise protocol taken to symptom limitation even if a plateau in Vo2 is not seen. Noteworthy symptoms should be appropriately recorded.
VCO2 : CO2 production
Respiratory exchange ratio

• Ratio of VCO2/VO2
• Measure of respiratory quotient at tissue level
• In steady state, RER=RQ
• RER >1 indicates lactic acidosis, hyperventilation
Ventilatory/AAnaerobic threshold

• Estimator of onset of metabolic acidosis due to rise in arterial lactate during exercise

• Expressed as % of VO2max

• Normally, 50-60% of predicted VO2max
AT clinical significance

- Signifies the upper limit of exercise intensities which can be done aerobically

- Exercise prescription

- Limited discriminatory ability in distinguishing clinical conditions
How to determine AT?

• Invasive
  – Lactate
  – bicarbonate

• Noninvasive
  – Ventilatory equivalents
    • VE/VO2
    • VE/VCO2
  – V slope method
V slope method
Cardiac Output

• Best index of cardiac function
• Linear function of Vo2
• Early exercise by increase in HR and Stroke volume
• Mod to severe exercise by increase in HR only
• Routinely not measured in clinical exercise testing
Heart Rate

• Linear relationship with VO2
• Initially by decreased parasympathetic activity and later almost exclusively by increased sympathetic tone
• Compared with age predicted maximal HR (220-age)
• Heart rate reserve
Significance

• Peak heart rate = maximal patient effort
• HR VO2 slope indicates stroke volume
Oxygen pulse

• Ratio of VO2/HR
• Reflects amount of O2 extracted per heart beat
• Estimates stroke volume during exercise
Blood pressure

• Normally systolic BP increases and diastolic BP may remain constant or decline slightly with increasing Vo2

• Excessive rise: abnormal BP control
• Declining BP/ fails to rise: cardiac limitation, abnormal sympathetic control
ECG-Ischemia

ST SEGMENT DEPRESSION DURING EXERCISE

No ST Depression
J-point only Depression
Upsloping ST Depression
Horizontal ST Depression
Downsloping ST Depression

60-80 ms after j-point
<1.0 mm (0.1 mV)
≥1.0 mm
≥1.0 mm
≥1.0 mm

Negative standard ECG responses
Equivocal standard ECG response
Positive standard ECG responses
Ventilation

• Assessment
  – Minute ventilation (VE)
  – Breathing pattern
    • Tidal volume (VT)
    • Respiratory rate (f)
Breathing pattern

• Mild exercise: VT
• Moderate exercise: both VT and f
• Severe exercise: mostly f

• Decrease in TE and TI both (TE>TI)
Ventilatory reserve

- Percentage of MVV achieved at peak exercise
- Or difference between MVV and VE at peak exercise
- MVV = FEV1 x (35-40)

- Decreased in pulmonary diseases, old age and low fitness
VE VCO2 relationship

• Represents ventilatory response in relation to rise in CO2

• Increased in cardiac and pulmonary disorders

• Discriminates cardiopulmonary disorders from obesity and deconditioning
Respiratory muscle evaluation

- Inspiratory pressures at FRC or at RV
- Expiratory pressures at TLC
- Indices for assessment of respiratory muscle weakness
Hypoxemia

- SpO2 < 88%
- PaO2 < 55mmHg
- ΔSpO2 > 4%
- Decreased in ILD, PVD
- Differentiates between cardiac and pulmonary disease
P(A-a)O2

- Normally less than 10 mmHg at rest
- May increase to >20mmHg during exercise
- >35mmHg indicates possible gas exchange abnormalities
- >50mmHg likely indicates pulmonary abnormality
VD/VT

- Ratio of physiological dead space to tidal volume
- Indicates the fraction of breath that is wasted and inefficiency of ventilation
- Dependent on the breathing pattern
- \[ \text{VD/VT} = \frac{(\text{PaCO}_2 - \text{PECO}_2)}{\text{PaCO}_2} \]
- PECO2 is mixed expired value of alveolar and dead space gas
VD/VT and exercise

- Normally 0.3
- Generally falls with increasing intensity of exercise
- Higher values are seen in pulmonary disease & Requires increased minute ventilation
Symptom assessment

• Perceptual response
• Report dyspnea, leg discomfort, chest pain

• Quantification
  – Visual analogue scale (VAS)
  – Category ratio (CR) 10 Scale
Normal exercise limitation

• No single exercise limiting factor

• Predominant factors limiting exercise in health
  – Cardiac output (gas transport abnormality)
  – Tissue oxygen extraction (metabolic)
Exercise limitation in disease

• Predominantly by *symptom perception*
• Cardiovascular
  – Reduced oxygen delivery
• Respiratory
  – Decreased ventilation
  – Decreased gas exchange
  – Respiratory muscle dysfuntion
• Peripheral
  – Muscular
  – metabolic
Indications

• Evaluation of exercise tolerance
  – Functional impairment or capacity
  – Exercise limiting factors

• Evaluation of undiagnosed exercise tolerance
  – Contribution of cardiac and pulmonary etiology in coexisting disease
  – Unexplained dyspnea
• Cardiovascular disease
  – Functional assessment and prognosis of heart failure
  – Cardiac transplantation
  – Exercise prescription and cardiac rehabilitation
• Respiratory diseases
  – COPD
    • Exercise limitation
    • Magnitude of hypoxemia, O2 prescription
  – ILD
    • Early detection of gas exchange abnormalities
    • Magnitude of hypoxemia, O2 prescription
    • Assessing therapeutic response
  – PVD
  – Cystic fibrosis
  – Exercise induced bronchospasm
• Specific clinical application
  – Preoperative evaluation
    • Lung resection surgery
    • Major abdominal surgeries
  – Pulmonary rehabilitation
  – Lung, lung heart transplantation
Contraindications

**Cardiac**
- Acute MI <5days
- Unstable angina
- Uncontrolled arrhythmias
- Syncope
- Active endocarditis
- Acute myocarditis
- Severe aortic stenosis
- Uncontrolled heart failure
- Dissecting aneurysm

**Pulmonary**
- Respiratory failure
- Acute PTE
- Uncontrolled asthma
- Pulmonary edema
- RA desaturation <85%
- Any disorder aggravated by exercise or which affects exercise performance
Risks to the patient

- Relatively safe procedure
- 2-5 deaths per 1,00,000 clinical exercise tests
- Risk is related to the underlying disease
Exercise termination

• Ischemic chest pain/ECG changes
• Complex ectopy/ 2\textsuperscript{nd} 3\textsuperscript{rd} degree heart block
• Fall in SBP > 20mmHg
• BP >220/120mmHg
• Severe desaturation <80% with symptoms
• Respiratory failure
• Pallor/ syncope
• Confusion/incordination
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Heart Failure</th>
<th>COPD</th>
<th>ILD</th>
<th>Pulmonary Vascular Disease</th>
<th>Obesity</th>
<th>Deconditioned</th>
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</thead>
<tbody>
<tr>
<td>$V_{02\text{max}}$ or $V_{02\text{peak}}$</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased for actual, normal for ideal weight</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td>Anaerobic threshold</td>
<td>Decreased</td>
<td>Normal/decreased/indeterminate</td>
<td>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>$O_2$ 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>$(V_{E}/MVV) \times 100$</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>$V_{E}/VCO_2$ (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>$P_{aO_2}$</td>
<td>Normal</td>
<td>Variable</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Normal/may increase</td>
<td>Normal</td>
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<tr>
<td>$P(a-a)O_2$</td>
<td>Usually normal</td>
<td>Variable, usually increased</td>
<td>Increased</td>
<td>Increased</td>
<td>May decrease</td>
<td>Normal</td>
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</table>
CLINICAL APPLICATION AND RECENT ADVANCES OF CPET
Peak VO2 & survival

<table>
<thead>
<tr>
<th>Disease</th>
<th>Measurement/modality</th>
<th>Subjects (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal men</td>
<td>Estimated aerobic exercise capacity in METs (1 MET = 3.5 ml/kg/min)/treadmill</td>
<td>2534</td>
</tr>
<tr>
<td>Normal women</td>
<td>Estimated aerobic exercise capacity in METs (1 MET = 3.5 ml/kg/min)/treadmill</td>
<td>2994</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>Estimated aerobic exercise capacity/treadmill</td>
<td>3679</td>
</tr>
<tr>
<td></td>
<td>Measured VO₂/treadmill</td>
<td>2812</td>
</tr>
<tr>
<td>Heart failure and cardiac</td>
<td>Measured VO₂/both treadmill and cycle</td>
<td>114</td>
</tr>
<tr>
<td>transplantation</td>
<td></td>
<td>284</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary</td>
<td>Measured VO₂/cycle ergometer</td>
<td>150</td>
</tr>
<tr>
<td>disease</td>
<td>Measured VO₂/cycle ergometer</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>Measured VO₂/treadmill</td>
<td>195</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
<td>Measured VO₂/53 treadmill/17 cycle ergometer</td>
<td>70</td>
</tr>
<tr>
<td>Surgery – thoracic</td>
<td>Measured VO₂/cycle ergometer</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>204</td>
</tr>
<tr>
<td>Surgery – abdominal</td>
<td>Measured VO₂/cycle ergometer</td>
<td>187</td>
</tr>
</tbody>
</table>

Severity of heart failure

Table 3. Use of the physiologic variables peak VO$_2$ and gas exchange lactic acid threshold to quantify the severity of heart failure.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Class</th>
<th>Peak VO$_2$ (ml/kg/min)</th>
<th>Gas exchange anaerobic threshold (ml/kg/min)</th>
<th>Maximum cardiac index (l/min per m$^2$)</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>

Data from [2,11].

Systolic vs diastolic Heart failure

• Farr et al. comparing CPET responses in SHF and DHF patients with similar NYHA symptom classes did not show any systematic clinical or statistical differences

• 185 patients with SHF (mean EF: 30%),
• 43 patients with DHF (mean EF: 56%)

• found that peak VO2 and VE/VCO2 ratios were very similar in the two groups

VE/VCO₂ slope and prognosis

- Increasing VE/VCO₂ slope resulted in decreasing event-free survival


<table>
<thead>
<tr>
<th>Ventilatory classification</th>
<th>$V_E/VCO_2$ slope</th>
<th>Event-free survival over 2 years (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC I</td>
<td>$\leq 29$</td>
<td>97.2</td>
</tr>
<tr>
<td>VC II</td>
<td>30–35.9</td>
<td>85.2</td>
</tr>
<tr>
<td>VC III</td>
<td>36.0–44.9</td>
<td>72.3</td>
</tr>
<tr>
<td>VC IV</td>
<td>$\geq 45$</td>
<td>44.2</td>
</tr>
</tbody>
</table>
Perioperative mortality

• Brunelli et al. assessed preoperative CPET in 204 consecutive patients who were to undergo pulmonary lobectomy or pneumonectomy, the peak VO2 was the best predictor of postoperative complications and mortality. Patients with a peak VO2 of greater than 20 ml/kg/min had dramatically fewer complications than those with a peak VO2 less than 12 ml/kg/min.

• For those with a VO2 of less than 12 ml/kg/min, pulmonary complications increased by eightfold, cardiac complications by fivefold and mortality by 13-fold

Role in lung resection

• VO2 peak less than 50% of predicted is associated with higher morbidity and mortality after lung resection
• Beneficial in evaluation of borderline patients on spirometry

CPET in exercise tolerance

• Subjective measures of a patient’s quality of life shows a stronger correlation with exercise tolerance than with either spirometry or oxygenation

Regenerative medicine

- Wisloff et al. demonstrated the use of CPET as an outcome variable in regenerative research in a study in rats
- Rats were selected across generations for either low or high aerobic capacity
- Over 11 generations, there was a dramatic difference in VO2max (43 vs 68 ml/kg/min);

Heart transplantation: AHA guidelines

- Peak VO2
  - $<14\text{ml/kg/min}$: relative indication
  - $<10\text{ml/kg/min}$: absolute indication

Costanzo MR et al. Selection and treatment of candidates for heart transplantation; A statement for health professionals from committee on heart failure and cardiac transplantation of the council on clinical cardiology, American heart association. Circulation 1995;92:3593-3612
Role in lung transplantation

• Useful in assessment of
  – Disease progression before Tx
  – Functional capacity
  – Causes of exercise limitation
  – Rehabilitation after lung Tx

• Presently, no consensus on how indices of exercise performance may impact the clinical decision for lung transplantation selection

CPET in ILD

• Exercise tolerance correlates strongly with the prognosis of IPF patients

Veinshelboim B et al. Physical activity and exertional desaturation are associated with Mortality in IPF. J Clin Med 2016;5:E73
• Impairement in exercise capacity and abnormal ventilatory responses during CPET were confirmed to be associated with poorer survival in a study performed in 34 IPF patients who were followed for 40 months.

Vainshelboim B et al. The prognostic role of ventilatory efficiency and exercise capacity in IPF. Respir Care 2016;61:1100-1109
Currently, no data suggest a clinically significant minimal important difference (MID) identified on CPET in monitoring ILD patients.

Recent data suggest a role of 6MWD.

CPET and PVD

- VO2 max correlates with severity and functional capacity
- CPET and 6MWT provide complimentary information in evaluation of PVD

CPET and cystic fibrosis

• VO2 peak predicts prognosis
• CPET results and estimates of muscle size cross sectional area may provide an optimized exercise prescription for CF patients

Role in asthma?

• May be used for increasing physical activity and for optimizing exercise prescription in asthmatic patients

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of exercise-induced bronchoconstriction</td>
<td>A</td>
</tr>
<tr>
<td>Detection of exercise-induced arterial oxygen desaturation</td>
<td>B</td>
</tr>
<tr>
<td>Functional evaluation of subjects with unexplained exertional dyspnea and/or exercise intolerance and normal resting lung and heart function</td>
<td>D</td>
</tr>
<tr>
<td>To recognize specific disease exercise response patterns that may help in the differential diagnosis of ventilatory versus circulatory causes of exercise limitation</td>
<td>C</td>
</tr>
<tr>
<td>Functional and prognostic evaluation of patients with COPD</td>
<td>B, C</td>
</tr>
<tr>
<td>Functional and prognostic evaluation of patients with ILD</td>
<td>B, B</td>
</tr>
<tr>
<td>Functional and prognostic evaluation of patients with CF</td>
<td>C, C</td>
</tr>
<tr>
<td>Functional and prognostic evaluation of patients with PPH</td>
<td>B, B</td>
</tr>
<tr>
<td>Functional and prognostic evaluation of patients with CHF</td>
<td>B, B</td>
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<tr>
<td>Evaluation of interventions</td>
<td></td>
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<tr>
<td>- Maximal incremental test</td>
<td>C</td>
</tr>
<tr>
<td>- High-intensity constant work-rate ‘endurance’ tests</td>
<td>B</td>
</tr>
<tr>
<td>Prescription of exercise training</td>
<td>B</td>
</tr>
</tbody>
</table>

The grade of recommendation is from A to D, with A = highest and D = lowest. Of note, grade A is relatively rare and grade B is usually considered the best achievable.

CF: Cystic fibrosis; CHF: Chronic heart failure; COPD: Chronic obstructive pulmonary disease; ILD: Interstitial lung disease; PPH: Primary pulmonary hypertension.

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Take home message

• CPET is definitely an important armamentarium of practicing clinicians for evaluation of cardio respiratory disorders

• Provides thorough assessment of integrative multiorgan physiological response to exercise

• Huge scope for research in its clinical application
Future research

• Evidence based approach for CPET
• Sensitivity, specificity, PPV, NPV of individual variables in diagnosing and differentiating different diseases
• Classification of level of fitness based on CPET variables
• Relationship between perceptual and physiologic response during exercise
• Role of CPET in lung transplantation
THANK YOU