REVIEW ARTICLE

Cardiopulmonary Exercise Test: Applications and Interpretation

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Abstract:

Cardiopulmonary exercise test (CPET) is often an overlooked and underutilized modality but offers an ocean of information about a patient's functional status. The following parameters are measured: ventilation; oxygen consumption (VO2); carbon dioxide production (VCO2); and the other variables of conventional exercise testing. The CPET allows defining mechanisms related to low functional capacity that can cause symptoms, such as dyspnoea, and correlate them with changes in the cardiovascular, pulmonary and skeletal muscle systems. Indications include evaluation of dyspnea, distinguishing cardiac vs pulmonary vs peripheral limitation vs others and detection of exercise-induced bronchoconstriction.

Exercise modalities are cycle ergometer and treadmill. In heart disease breathing reserve is >30%, and heart rate reserve is <15%, in pulmonary disease breathing reserve is <30% but heart rate reserve is >15%.

Key words: *Exercise Test; Oxygen Consumption; Carbon dioxide production; Anaerobic threshold, Breathing resrve; Heart rate reserve.*

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Introduction:

Cardiopulmonary exercise test (CPET) is often an overlooked and underutilized modality but offers an ocean of information about a patient's functional status. In its most frequent applications, CPET consists in applying a gradually increasing intensity exercise until exhaustion or until the appearance of limiting symptoms and/or signs. The following parameters are measured: ventilation; oxygen consumption (VO2); carbon dioxide production (VCO2); and the other variables of conventional exercise testing. The CPET provides joint data analysis that allows complete assessment of the cardiovascular, respiratory, muscular and metabolic systems during exertion, being considered gold standard for cardiorespiratory functional assessment.[1-6]

The CPET allows defining mechanisms related to low functional capacity that can cause symptoms, such as dyspnoea, and correlate them with changes in the cardiovascular, pulmonary and skeletal muscle systems. Furthermore, it can be used to provide the prognostic assessment of patients with heart or lung diseases, and in the preoperative period, in addition to aiding in a more careful exercise prescription to healthy subjects, athletes and patients with heart or lung diseases.

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Indications[7]:

1. Evaluation of dyspnea	6. Preoperative evaluation and risk stratification
2. Distinguish cardiac vs pulmonary vs peripheral limitation vs others	7. Prognostication of life expectancy
3. Detection of exercise-induced bronchoconstriction.	8. Disability determination
4. Detection of exertional desaturation.	9. Fitness evaluation
5. Chest physiotherapy: Exercise intensity/ prescription, response to participation	10. Confirms diagnosis 11. Assess response to therapy

Contraindication[7]

Absolute Contraindica	Relative Contraindication
Acute myocardial infarction	Left main or 3-V CAD
Unstable angina	Severe arterial HTN (>200/120)
Unstable arrhythmia	Significant pulmonary HTN
Acute endocarditis, myocarditis, pericarditis	Tachyarrhythmia, bradyarrhythmia
Syncope.	High degree AV block
Severe, symptomatic atrial stenosis	Hypertrophic cardiomyopathy
Uncontrolled CHF	Electrolyte abnormality
	Moderate stenotic valvular heart disease
	Advanced or complicated pregnancy
	Orthopedic impairment

Procedure:

Initial assessment

- **History:** Regarding 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
- **ECG**
- **Pulmonary Function Tests:** spirometry, lung volumes, diffusing capacity, arterial blood gases

Prior To Test

Should wear loose fitting clothes, low-heeled or athletic shoes ,should be abstain from coffee and cigarettes at least 2 hours before the test, maintenance of medications, may eat a light meal at least 2 hours before the test.

Exercise modalities: cycle ergometer and treadmill

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, requires less space, less noise

Advantages of treadmill:

Attains higher VO2, more functional

Indication of test termination[7]

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, systolic BP >0-250, diastolic BP>110-120,fall in BP sys>20 mmHg, SpO2<81-

85%, dizziness, faintness, onset of confusion, onset of pallor

General Mechanisms of Exercise Limitation:

1) Pulmonary

Ventilatory impairment, respiratory muscle dysfunction, impaired gas exchange

2)Cardiovascular

Reduced stroke volume, abnormal HR response, circulatory abnormality, blood abnormality

3)Peripheral

Inactivity, atrophy, neuromuscular dysfunction,

reduced oxidative capacity of skeletal muscle, malnutrition, perceptual, motivational, environmental

CPET Measurements:

- Work, VO2, VCO2, AT, HR, ECG, BP,RR, SpO2,ABG,Lactate,dyspnea, leg fatigue

Pulmonary Parameters

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 propioceptors and chemoreceptors.
2. Breathing Rate
   - Normal = 12 –16 / min, At Exercise = 40 –50 / min, responsible for the increase in minute ventilation. In Anaerobic Threshold (AT) the minute ventilation increases more than the workload
3. Tidal Volume
   - Normal = 500 ml, During Exercise = 2.3 –3 liters.
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
8. Pulmonary ventilation (VE): expressed as liters per minute, is the volume of air moved in and out of the lungs. It is determined as the product of respiratory rate by the volume of air exhaled at every cycle (tidal volume). At rest, 7 to 9 L/min are ventilated, but in athletes that value can reach 200 L/min at maximal exertion.6It reflects disease severity and relates to worse prognosis in patients with HF.3-5
9. Breathing Reserve (VE/MVV): represents the ratio between maximal ventilation during exercise (VE) and maximum voluntary ventilation (MVV) at rest, both variables in L/min. It is useful in the differential diagnosis of dyspnea related to pulmonary mechanism.6

Cardiovascular Parameters

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. In 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.
2. Stroke Volume
   - Normal = 50 –80 ml. At Exercise : double

     increase is linear with increase in workload but 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 or HR max = 210 –(0.65 x age)

Heart Rate Reserve

Comparison of actual peak HR and predicted peak HR

= (1 –Actual/Predicted) x100%

Normally <15%

4. 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) .

Metabolic Parameters

1) Oxygen Consumption:

$Vo_2 = (SV \times HR) \times (Cao_2 " Cvo_2)$

Normally 250 ml / min. 3.5 –4 ml / min / kg increases directly with the level of muscular work and increases until exhaustion occurs .

VO2max = maximum level of oxygen consumption anddefinite indicator of muscular work capacity.

Normal Range is 1,700 –5,800 ml / min

The term 'peak VO2' is used as a synonym for VO2 max throughout this text. Peak VO2 is considered abnormal when below 85% of the predicted value.[6] It has been used as a universal marker1-3,5

2). Carbon Dioxide Production

- Normally 200 ml / min. 2.8ml / min / kg. At Exercise,

  In initial phase, increases at same rate as VO2, Once Anaerobic Threshold (AT) is reached, increases at a faster rate than VO2

3) Lactate threshold (θL)[8]
Lactic Acid is Buffered by Bicarbonate
Lactic acid + HCO3→H2CO3+ Lactate

$$\downarrow$$
$$H2O + CO2$$

θL is the highest $v´O_2$ at which arterial lactate is not systematically increased, and is estimated using an incremental test. It is considered an important demarcator of exercise intensity. Noninvasive estimation of θL requires the demonstration of an augmented $v´cO_2$ in excess of that produced by aerobic metabolism , and its associated ventilator sequel.

4) Anaerobic Thershold (At)

- Normal: occurs at about 60% of VO2 max followed by breathlessness, burning sensation begins in working muscles increase is due to increased acid production

The normal mean AT values expected for adults are around 40% to 65% of peak VO2.6 The AT values are important for the individualized prescription of exercise, as well as for the diagnosis of anemia, physical unfitness, myopathies and cardiopathies in the presence of values lower than the predicted ones.[2-6]

5) Respiratory Quotient (RQ)
RER = CO_2produced / O_2consumed
= VCO2/ VO2

- Resting Level = 0.8

Values above 1.0 can reflect intense exercise, but those ee 1.10 are those searched on CPET, and have been accepted as a parameter of exhaustion or quasi-exhaustion.3,7

6) Blood PH
relatively unchanged until AT is reached, the body becomes less able to buffer the excessive acid produced by anaerobic metabolism

7) Arterial –Venous Oxygen Content Difference $(Cao_2 " Cvo_2)$

- mLof O2 / 100 ml of blood. Normal = 5 vol%. At Exercise = 2.5 –3 times higher

8) Ventilatory Equivalents

Ventilatory equivalent for carbon dioxide = Minute ventilation / VCO2

Efficiency of ventilation, Liters of ventilation to eliminate 1 L of CO2

Ventilatory equivalent for oxygen = Minute ventilation / VO2

- Liters of ventilation per L of oxygen uptake

  Relationship of AT to RER and Ventilatory Equiv for O2
- Below the anaerobic threshold, with carbohydrate metabolism, RER=1 (CO2production = O2consumption).
- 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 (CO2production > O2consumption).
- Carbon dioxide regulates ventilation.
- Ventilation will disproportionately increase at lactate threshold to eliminate excess CO2.

Increase in ventilator equivalent for oxygen demarcates the anaerobic threshold.

Patients with inadequate ratio between pulmonary ventilation and pulmonary perfusion (increased physiological dead space) ventilate inefficiently and have high VE/VO2 values (pulmonary disease and HF).6 Peak values above 50 have been useful to diagnose patients suspected of having mitochondrial myopathy.10 On the other hand, VE/VCO2 represents the ventilatory need to eliminate a certain amount of CO2 produced by active tissues, being influenced by partial pressure of carbon dioxide (PaCO2). The VE/VCO2 slope reflects the severity and prognosis of patients with HF, pulmonary hypertension, HCM, COPD and restrictive pulmonary disease.1,3-5,8,11,12

8)End-tidal CO2 partial pressure (PETCO2): reflects ventilation–perfusion within the pulmonary system, and, indirectly, cardiac function.6 Its value ranges from 36 to 42 mmHg, with 3- to 8-mmHg elevations during moderate intensity exercise, reaching a maximal value with subsequent drop, due to VE increase, characterizing RCP.1

9)△VO2/△WR Relationship: relationship between VO2 (Y axis in mL.min-1) and workload (X axis in Watts), measured only during exercise on a cycle ergometer with ramp protocol, whose value is progressively and linearly incremented until maximal effort. It is useful in the diagnosis of patients suspected of having myocardial ischemia with left ventricular dysfunction on exertion. Its normal value for adults is 9 mL.min-1.W-1 (the lowest limit being 8.6 mL.min-1.W-1).

Interpretation of CPET[7]

- Peak oxygen consumption
- Peak HR
- Peak work
- Peak ventilation

Estimation of Predicted Peak HR

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

Or 210 –(age x0.65)
- For age 40: 210 -(40 x0.65) = 184
- For age 70: 210 -(70 x0.65) = 164

Heart Rate Reserve

Comparison of actual peak HR and predicted peak HR

= (1 –Actual/Predicted) x100%

Normally <15%

Oxygen Pulse

O2 PULSE = VO2/ HR

Normally 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

Under certain circumstances, the morphological analysis of its curve aids in the diagnosis of ventricular dysfunction and important effort-induced myocardial ischemia.1,3-6

Increases During Exercise[7]

Heart rate, Oxygen extraction, cardiac output, oxygen uptake, carbon dioxide out, minute ventilation, alveolar ventilation, oxygen pulse, RQ and RER,METS , arterial blood pressure

DECREASES DURING EXERCISE[7]

During exercise, there are decreases in: VD/ VT

Comparison CPET results[7]

	Normal	CHF	COPD
Predicted Peak HR	150	150	150
Peak HR	150	140	120
MVV	100	100	50
Peak VO_2	2.oo	1.2	1.2
AT	1.oo	0.6	1.0
Peak VE	60	40	49
Breathing Reserve	40%	60%	2%
HR Reserve	0%	7%	20%
Borg Breathlessness	5	4	8
Borg leg discomfort	8	8	5

CPET Interpretation[7]

	Peak VO_2	HRR	BR	$AT/VO_{2\,max}$	A-a
Normal	>80%	<15%	>30%	>40%	normal
Heart Disease	<80%	<15%	>30%	<40%	normal
Pulmonary vascular disease	<80%	<15%	>30%	<40%	increased
Pulmonary mechanical disease	<80%	>15%	<30%	>40%	increased
Deconditioning	<80%	>15%	>30%	>40%	normal

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