# CARDIO PULMONARY EXERCISE TEST PRACTICAL TIPS

Dr. Mahsa Mirdamadi

Respiratory Fellow

Royal Brisbane and Women's Hospital ( RBWH)

- Introduction
- Indication and Contraindication
- Patient preparation
- Exercise Equipment
- Measurements during the test and parameters
- Questions before interpreting

# INTRODUCTION

## CPET in clinical practice , Recent advances , Current challenges and future direction:

In last 3 decades CPET was stablished and was used around the world. 3541 of the 5100 (~70%) manuscripts involving CPET since 1978 have been published in the past 10 years.

We have some guidelines published in2003( from ATS ) and 2007 (from ERS).

# INDICATIONS FOR PERFORMING CARDIOPULMONARY EXERCISE TESTING:

- ▶ Investigation of unexplained dyspnoea.
- ▶ Evaluation of cardiovascular disease.
- ▶ Evaluation of respiratory disease.
- ▶ Preoperative assessment for major surgery.
- ▶ Exercise prescription.
- ▶ Evaluation of impairment/disability.
- ▶ Evaluation of exercise tolerance

Adapted from the American Thoracic Society and American College of Chest Physicians

# What are the specific scenarios in which CPET has advanced the provision of clinically relevant information in the past decade ?

INVESTIGATING EXERCISE INTOLERANCE

INVESTIGATING POTENTIAL PULMONARY VASCULAR DISEASE

INVESTIGATING OF ISCHEMIC HEART DISEASE

UNCOVER DYSFUNCTIONAL BREATHING AND/OR HYPERVENTILATION

RISK ASSESSMENT : PROGNOSIS IN CARDIOPULMONARY DISEASE

PRE-OPERATIVE ASSESSMENT

CLINICAL EXERCISE TESTING , ERS MONOGRAPH 2018, PAOLO PALANGE, P.LAVENEZIANA ET ALL.

# Why am I being asked to perform this test?

- ■ determine a cause of unexplained shortness of breath
- ■ assess exercise capacity
- ■ assess your risk for a planned surgical procedure In people who have known heart or lung disease
- ■ check the severity of respiratory disease (such as chronic obstructive lung disease, pulmonary vascular disease, cystic fibrosis, and others)
- ■ determine how much of a limit in exercise is due to the heart or the lungs in people who have both heart and lung disease
- ■ help define how much impairment or disability a person has to help guide what he or she can do in a rehabilitation programs or to get an exercise prescription
- ■ define the response to treatments
- ■ see if advanced treatments like heart transplantation should be considered to help with congestive heart failure (CHF) Sometimes CPET is done as a part of a research study.

# THINGS TO DO BEFORE DO THE TEST:

- Pretest assessment( indication and contraindication)
- The day of the test
- Pretest resting parameters and ECG
- Supervision of the test

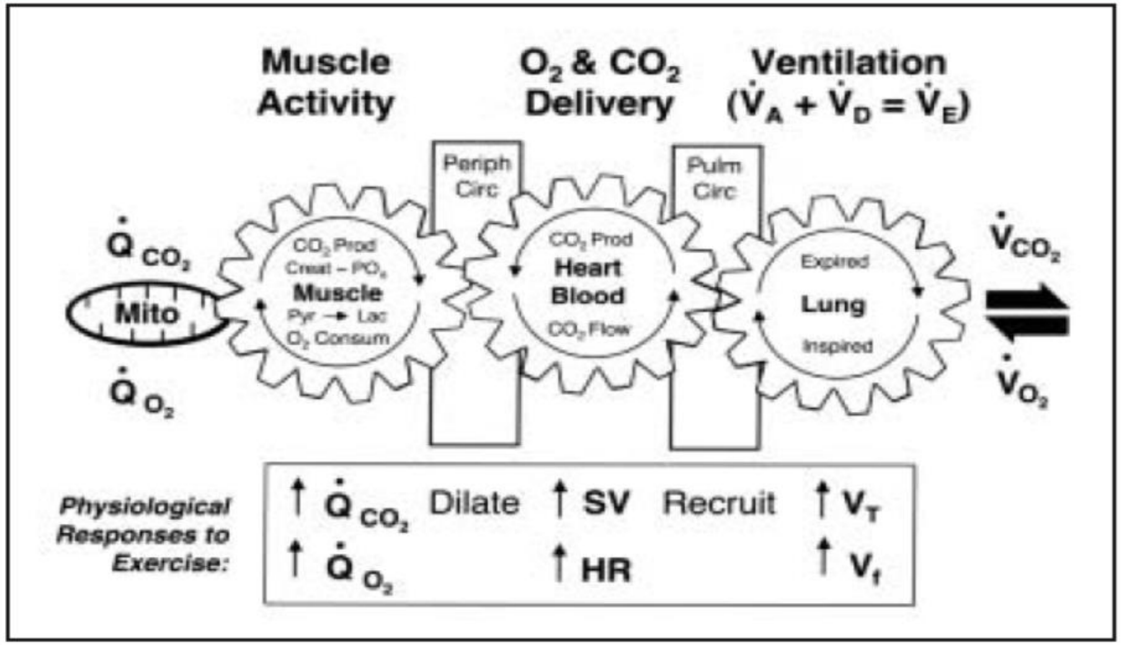
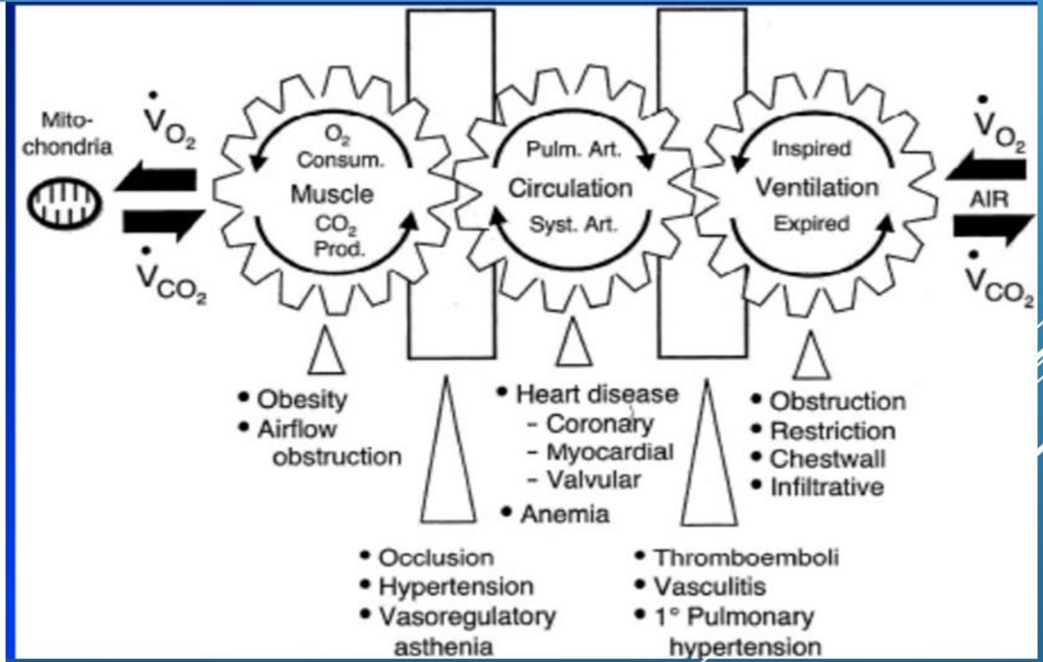



FIGURE 1. Gas transport mechanisms coupling cellular (internal) respiration to pulmonary (external) respiration. Circ = circulation; $CO_2$ = carbon dioxide; Consum = consumption; Creat = creatine; Lac = lactate; HR = heart rate; Mito = mitochondria; $PO_4$ = phosphate; $O_2$ = oxygen; Periph = peripheral; Prod = production; Pulm = pulmonary; Pyr = pyruvate; $\dot{Q}CO_2$ = carbon dioxide production; $\dot{Q}O_2$ = oxygen utilization; SV = stroke volume; $\dot{V}_A$ = minute alveolar ventilation; $\dot{V}_D$ = minute dead space ventilation; $\dot{V}_E$ = minute ventilation; $V_f$ = breathing frequency; $V_T$ = tidal volume; $\dot{V}CO_2$ = carbon dioxide output; $\dot{V}O_2$ = oxygen uptake. From *Principles of Exercise Testing and Interpretation*, 3rd ed,[7] with permission from Lippincott Williams & Wilkins.




Classical description by Wasserman and Whipp of the linked processes involved in exercise. Reproduced from Wasserman K, Hansen JE, Sue DY, et al., Principles of Exercise Testing and Interpretation: Including Pathophysiology and Clinical Applications, 4th edition, Copyright (2004), with permission from Wolters Kluwer Health.

**TABLE 1. INDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING**

**Evaluation of exercise tolerance**
- Determination of functional impairment or capacity (peak $\dot{V}O_2$)
- Determination of exercise-limiting factors and pathophysiologic mechanisms

**Evaluation of undiagnosed exercise intolerance**
- Assessing contribution of cardiac and pulmonary etiology in coexisting disease
- Symptoms disproportionate to resting pulmonary and cardiac tests
- Unexplained dyspnea when initial cardiopulmonary testing is nondiagnostic

**Evaluation of patients with cardiovascular disease**
- Functional evaluation and prognosis in patients with heart failure
- Selection for cardiac transplantation
- Exercise prescription and monitoring response to exercise training for cardiac rehabilitation (special circumstances; i.e., pacemakers)

**Evaluation of patients with respiratory disease**
- Functional impairment assessment (see specific clinical applications)
- Chronic obstructive pulmonary disease
  - Establishing exercise limitation(s) and assessing other potential contributing factors, especially occult heart disease (ischemia)
  - Determination of magnitude of hypoxemia and for $O_2$ prescription
  - When objective determination of therapeutic intervention is necessary and not adequately addressed by standard pulmonary function testing
- Interstitial lung diseases
  - Detection of early (occult) gas exchange abnormalities
  - Overall assessment/monitoring of pulmonary gas exchange
  - Determination of magnitude of hypoxemia and for $O_2$ prescription
  - Determination of potential exercise-limiting factors
  - Documentation of therapeutic response to potentially toxic therapy
- Pulmonary vascular disease (careful risk–benefit analysis required)
- Cystic fibrosis
- Exercise-induced bronchospasm

**Specific clinical applications**
- Preoperative evaluation
  - Lung resectional surgery
  - Elderly patients undergoing major abdominal surgery
  - Lung volume resectional surgery for emphysema (currently investigational)
- Exercise evaluation and prescription for pulmonary rehabilitation
- Evaluation for impairment–disability
- Evaluation for lung, heart–lung transplantation

*Definition of abbreviation*: $\dot{V}O_2$ = oxygen consumption.
Adapted by permission from Reference 27.

ATS/ACCP Statement on Cardiopulmonary Exercise Testing was adopted by the ATS Board of Directors, March 1, 2002 and by the ACCP Health Science Policy Committee, November 1, 2001

**Table 3** American College of Cardiology/American Heart Association guidelines for cardiopulmonary exercise testing

| Class | Indication |
|---|---|
| I (indicated) | 1 Evaluation of exercise capacity and response to treatment in patients with heart failure who are being considered for heart transplantation<br>2 Assistance in the differentiation of cardiac versus pulmonary limitations as a cause of exercise-induced dyspnoea or impaired exercise capacity when the cause is uncertain |
| IIa (good supportive evidence) | Evaluation of exercise capacity when indicated for medical reasons in patients for whom the estimates of exercise capacity from exercise test time or work rate are unreliable |
| IIb (weak supportive evidence) | 1 Evaluation of the patient's response to specific therapeutic interventions in which improvement of exercise tolerance is an important goal or end point<br>2 Determination of the intensity for exercise training as part of comprehensive cardiac rehabilitation |
| III (not indicated) | Routine use to evaluate exercise capacity |

Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.[1]

**TABLE 8. ABSOLUTE AND RELATIVE CONTRAINDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING**

| Absolute | Relative |
|---|---|
| Acute myocardial infarction (3–5 days) | Left main coronary stenosis or its equivalent |
| Unstable angina | Moderate stenotic valvular heart disease |
| Uncontrolled arrhythmias causing symptoms or hemodynamic compromise | Severe untreated arterial hypertension at rest (> 200 mm Hg systolic, > 120 mm Hg diastolic) |
| Syncope | Tachyarrhythmias or bradyarrhythmias |
| Active endocarditis | High-degree atrioventricular block |
| Acute myocarditis or pericarditis | Hypertrophic cardiomyopathy |
| Symptomatic severe aortic stenosis | Significant pulmonary hypertension |
| Uncontrolled heart failure | Advanced or complicated pregnancy |
| Acute pulmonary embolus or pulmonary infarction | Electrolyte abnormalities |
| Thrombosis of lower extremities | Orthopedic impairment that compromises exercise performance |
| Suspected dissecting aneurysm | |
| Uncontrolled asthma | |
| Pulmonary edema | |
| Room air desaturation at rest ≤ 85%* | |
| Respiratory failure | |
| Acute noncardiopulmonary disorder that may affect exercise performance or be aggravated by exercise (i.e. infection, renal failure, thyrotoxicosis) | |
| Mental impairment leading to inability to cooperate | |

Adapted by permission from References 10, 43, and 295.
* Exercise patient with supplemental $O_2$.

ATS/ACCP Statement on Cardiopulmonary Exercise Testing was adopted by the ATS Board of Directors, March 1, 2002 and by the ACCP Health Science Policy Committee, November 1, 2001

## TABLE 7. OVERVIEW OF CARDIOPULMONARY EXERCISE TESTING

**Clinical Status Evaluation**

Clinical diagnosis and reason(s) for CPET
Health questionnaire (cardiopulmonary); physical activity profile
Medical and occupational history and physical examination
PFTs, CXR, ECG, and other appropriate laboratory tests
Determination of indications and contraindications for CPET

↓

**Pretest Procedures**

Abstain from smoking for at least 8 h before the test
Refrain from exercise on the day of the test
Medications as instructed
Consent form

↓

**Conduct of CPET**

Laboratory procedures
- Quality control
- Equipment calibration

Protocol Selection
- Incremental versus constant work rate; invasive versus noninvasive

Patient preparation
- Familiarization
- 12-lead ECG, pulse oximetry, blood pressure
- Arterial line (if warranted)

Cardiopulmonary exercise testing

↓

**Interpretation of CPET Results**

Data processing
Quality and consistency of results
Comparison of results with appropriate reference values
Integrative approach to interpretation of CPET results
Preparation of CPET report

*Definition of abbreviations*: CPET = cardiopulmonary exercise testing; CXR = chest X-ray; ECG = electrocardiogram; PFTs = pulmonary function tests.

American Thoracic Society (ATS) / American College of Chest Physicians (ACCP) Statement on Cardiopulmonary Exercise Testing (American Journal of Respiratory and Critical Care Medicine, 20

# PRETEST PATIENT INSTRUCTIONS FOR ISSUE TO PATIENTS AHEAD OF ATTENDING FOR CARDIOPULMONARY EXERCISE TESTING APPOINTMENT:

- Refrain from exercise on the day of the test and be well rested.
- Eat a light meal or breakfast no less than 2 hours previously.
- Maintain hydration by drinking water.
- Avoid caffeine and alcohol prior to the test.
- Take all routine/normal medication and bring along a medication list.
- Bring along all rescue medications, for example, inhalers or nitro lingual sprays.
- Wear light comfortable clothing and shoes suitable to exercise in.
- Avoid use of body lotion on the upper body, as this may affect ECG electrode placement.
- Abstain from smoking for at least 8 hours prior to the test.
- Refrain from wearing any nail varnish or false nails.

Adapted from the American Thoracic Society and American College of Chest Physicians.

# PATIENT PREPARATION:

**Attire:** must wear suitable clothing for exercise and sneakers or walking shoes.

**Medications:** Take all medications as the  usual times. For diabetic medications must check with patient's doctors about holding after the test.

**Meals:** Must not eat or drink tree hours before the test.

No caffeine drink in the day of the test.

No smoking in the day of the test

Remove nail polish and lip steak prior to the test.

No vigorous exercise in the day of the test.

| Level of risk | Known infection | Community prevalence | Recommended PPE |
|---|---|---|---|
| Level 1 | No known infection risk | No pandemic | Three-ply surgical mask, disposable apron, surgical gloves |
| Level 2 | Upper respiratory tract infection, lower respiratory tract infection, influenza | Pandemic with low community prevalence | Face shield, three-ply surgical mask, disposable apron, surgical gloves |
| Level 3 | Tuberculosis, family Coronaviridae, SARS, pandemic influenza | Global pandemic with high community prevalence | FFP3 mask with face shield or respirator hood, isolation gown, surgical gloves |

**Table 1** Recommended levels of PPE in relation to levels of infection risk

PPE, personal protective equipment.

**Table 2** Common sources of error in CPET testing

| | Source of error | Description | Impact on data |
|---|---|---|---|
| Patient | Failure to follow information disclosed on patient information leaflet | All patients should be given a patient information leaflet and/or advice on what to avoid prior to performing an exercise test. | Various implications, specifically limiting exercise tolerance and impairing gas exchange data |
| | Poor effort/cooperation/motivation to perform exercise test | Patients need to understand the reason why the test is being performed. Failure to do so may result in suboptimal effort. | Underestimation of all indices, including workload, AT, $VO_2$ and $VCO_2$. |
| Test operator | Failure to give standardised instruction and encouragement during exercise | Throughout the different phases of exercise, there should be clear and standardised instructions to patients. | Various implications, specifically lack of consistency in data across different test operators |
| | Failure to select correct load (watts) in view of patient's activity level/ fitness | Incremental workloads that result in exercise duration of <8 or >12 min do not accurately reflect aerobic status. | Various implications, although more commonly underestimation of gas exchange indices |
| | Lack awareness/guidance on the use of well-defined end of test criteria | Exercise may be stopped too early or too late in what should be a symptom limited exercise test. | If exercise is stopped early (eg, pulse rate), gas exchange indices can be underestimated. |
| | Incorrect determination/ identification of the AT | There should be a clear definition of what AT is and processes in place to promote discussion and review agreement. | Inappropriate estimation of level of fitness or degree of impairment in $O_2$ delivery/use |
| | Incorrect determination/ measurement of slopes ($\Delta V_E/\Delta VCO_2$, OUES and $\Delta VO_2/\Delta WR$) | The determination of slopes based on linear regression models require correct identification of the start and end points. | Incorrect inferences from data ($V_E/VCO_2$ mismatch, cardiovascular impairment, among others) |
| Equipment | Inaccurate output of power by treadmill/ergometer | Treadmill (speed/grade) and ergometer (resistance) power outputs require yearly servicing (more often if regularly moved). | Various implications, particularly overestimation or underestimation of gas exchange indices |
| | Non-calibrated weighing scales and stadiometer | Weighing scales and stadiometers require regular servicing and calibration if there is a suspicion of erroneous measurements. | Incorrect estimation of predicted data and consequent inaccurate inferences from recorded data |
| | Excessive condensation at the point of gas analysis | Gas analysis should meet BTPS conditions, particularly humidity/water vapour pressure. | Various implications, although more commonly underestimation of gas exchange indices |
| | Volume drift | Thermal or offset volume drift may occur as a result of large fluctuations in temperature or incorrect calibration | Various implications, particularly inaccurate ventilatory and gas exchange indices |
| | Delayed response time and transit time in gas exchange parameters | Under certain testing conditions, there may be delay from the point of sampling to the point of gas analysis. | Normally, underestimation of gas exchange data due to dispersion of expired gases |
| | High/low sampling rates/delta time/ data averaging of gas exchange data | Data averaging below 30 or above 60 s will affect validity of gas exchange measurements. | Either high fluctuations or excessive attenuation in gas exchange data |

AT, anaerobic threshold; BTPS, body temperature and pressure saturated; CPET, cardiopulmonary exercise testing; OUES, oxygen uptake efficiency slope; $V_E/VCO_2$, ventilatory equivalent for carbon dioxide production; $\Delta V_E/\Delta VCO_2$, slope of the ventilatory response; $\Delta VO_2/\Delta WR$, slope of the metabolic response.

ARTP statement on cardiopulmonary exercise testing 2021 Andrew Pritchard,1 Paul Burns,2 Joao Correia ,3 Patrick Jamieson,4 Peter Moxon,1 Joanna Purvis,5 Maximillian Thomas,6 Hannah Tighe,7 Karl Peter Sylvester8,9, 2021

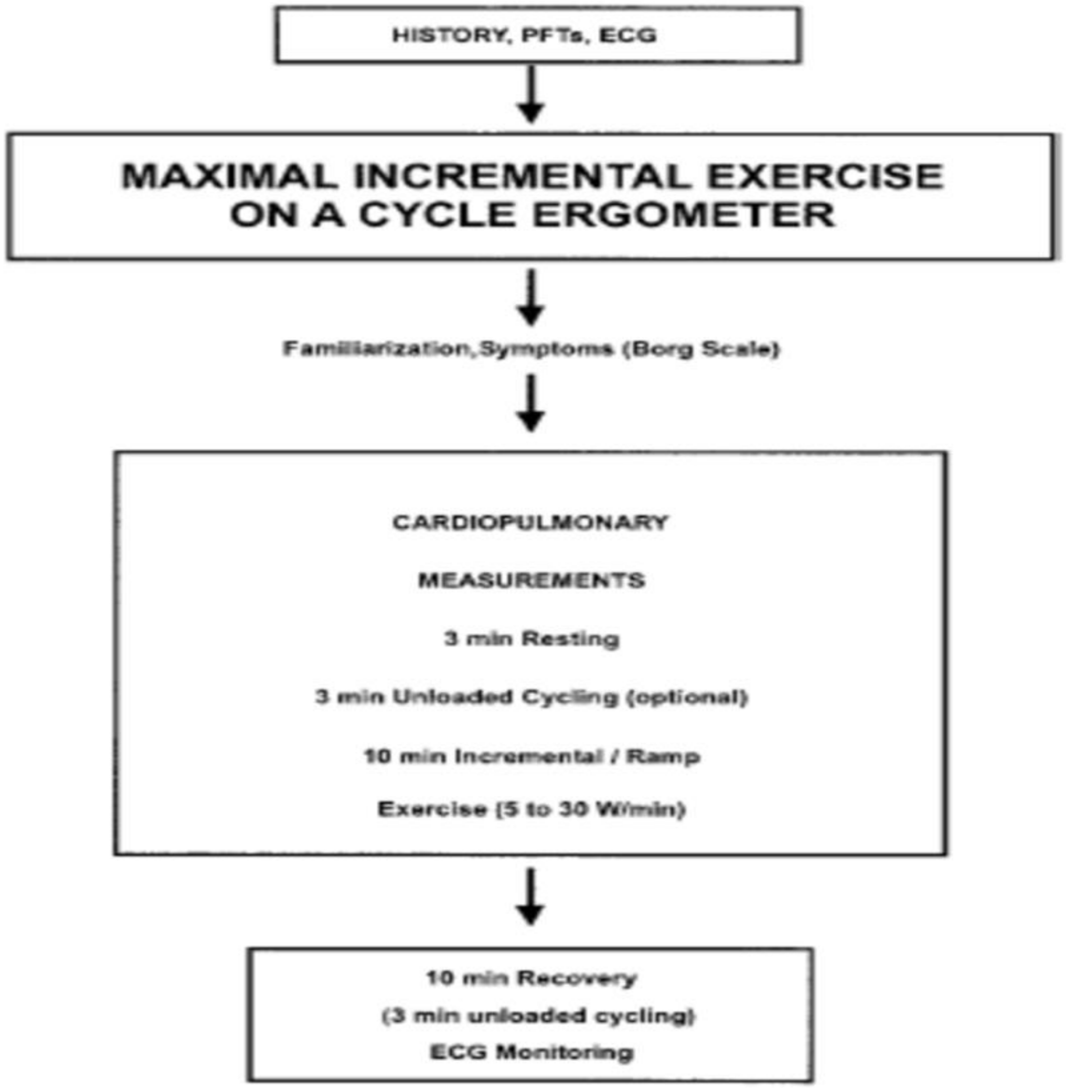
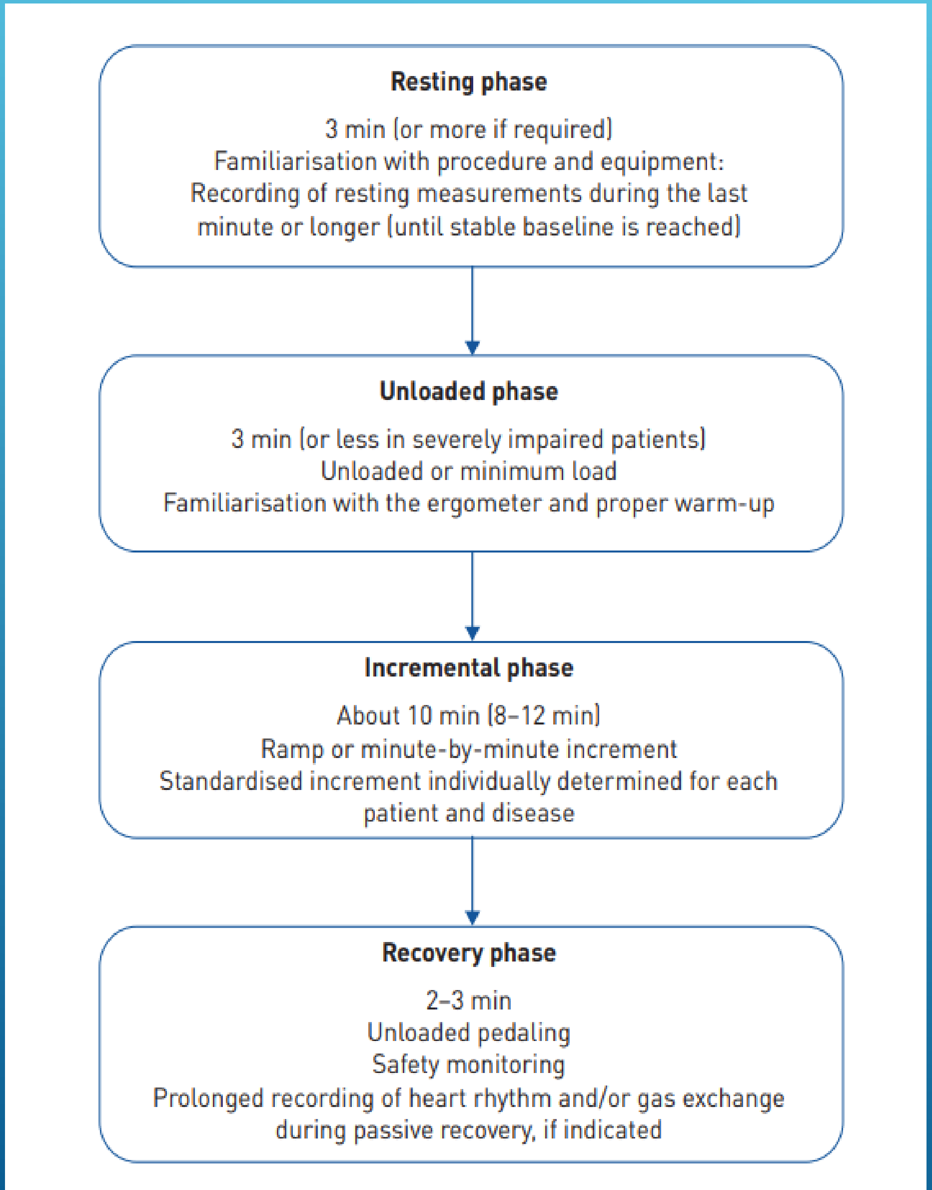



*Figure 3.* Flow chart of a maximal symptom-limited cardiopulmonary incremental protocol on a cycle ergometer. *ECG* – electrocardiogram; *PFT* – pulmonary function test.

American Thoracic Society (ATS) / American College of Chest Physicians (ACCP) Statement on Cardiopulmonary Exercise Testing (American Journal of Respiratory and Critical Care Medicine, 20

# FLOW CHART DESCRIBING THE USUAL PRACTICE BY TASK FORCE MEMBERS ON DIFFERENT PROTOCOL PHASES AND SPECIFICATIONS DURING CARDIOPULMONARY EXERCISE TESTING. IT IS NOT INTENDED AS A RECOMMENDATION FOR CLINICAL PRACTICE.

ERS STATEMENT ON STANDARDISATION OF CARDIOPULMONARY EXERCISE TESTING IN CHRONIC LUNG DISEASES. RADTKE T, CROOK S, KALTSAKAS G, ET AL. ERS STATEMENT ON STANDARDISATION OF CARDIOPULMONARY EXERCISE TESTING IN CHRONIC LUNG DISEASES. EUR RESPIR REV 2019; 28: 180101 [HTTPS://DOI.ORG/ 10.1183/16000617.0101-2018].



# SPECIFIC RISKS OF PERFORMING CPET

LIKELIHOOD RISK :

Common – more than 5% of tests performed

Shortness of breath, musculoskeletal discomfort, mild angina

Uncommon ( 1 to 5% )

Low blood pressure, chest pain

Rare(less than (1% )

Fainting, prolonged cardiac arrhythmia, myocardial infarction

Extremely rare (2to 5 per 100,000 tests )

Death

American Thoracic Society (ATS) / American College of Chest Physicians (ACCP) Statement on Cardiopulmonary Exercise Testing (American Journal of Respiratory and Critical Care Medicine, 2003)

# HOW TO DO A CPET

- use of a cycle or treadmill ergometer
- an incremental ramp increase in load
- continued to maximum effort
- limited by symptoms
- results presented in a breath-by-breath format

**TABLE 2. EXERCISE EQUIPMENT: CYCLE ERGOMETRY VERSUS TREADMILL**

| | Cycle | Treadmill |
|---|---|---|
| $\dot{V}O_2max$ | lower | higher |
| Work rate measurement | yes | no |
| Blood gas collection | easier | more difficult |
| Noise and artifacts | less | more |
| Safety | safer | less safe? |
| Weight bearing in obese | less | more |
| Degree of leg muscle training | less | more |
| More appropriate for: | patients | active normal subjects |

*Definition of abbreviation:* $\dot{V}O_2$ max = maximal oxygen uptake.

ATS/ACCP Statement on Cardiopulmonary Exercise Testing was adopted by the ATS Board of Directors, March 1, 2002 and by the ACCP Health Science Policy Committee, November 1, 2001

## TABLE 10. MEASUREMENTS DURING CARDIOPULMONARY EXERCISE TESTING

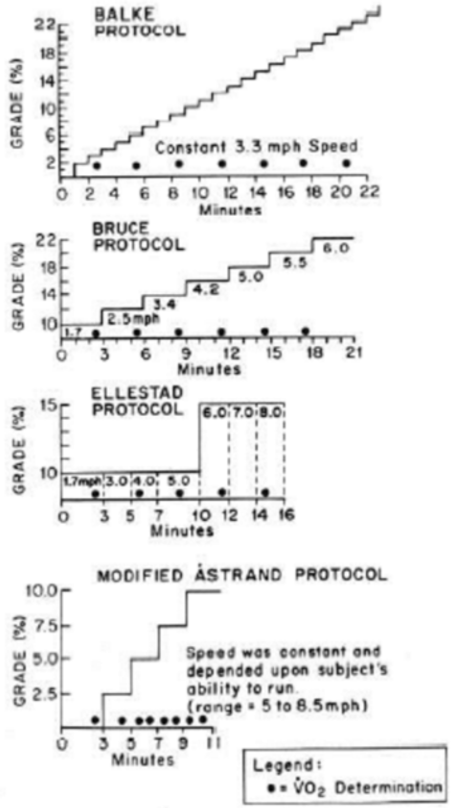
| Measurements | Noninvasive | Invasive (ABGs) |
|---|---|---|
| External work | WR | |
| Metabolic gas exchange | $\dot{V}O_2$, $\dot{V}CO_2$, RER, AT | Lactate |
| Cardiovascular | HR, ECG, BP, $O_2$ pulse | |
| Ventilatory | $\dot{V}E$, VT, fR | |
| Pulmonary gas exchange | $Sp_{O_2}$, $\dot{V}E/\dot{V}CO_2$, $\dot{V}E/\dot{V}O_2$, $PET_{O_2}$, $PET_{CO_2}$ | $Pa_{O_2}$, $Sa_{O_2}$, $P(A–a)O_2$, VD/VT |
| Acid–base | | pH, $Pa_{CO_2}$, standard $HCO_3^-$ |
| Symptoms | Dyspnea, fatigue, chest pain | |

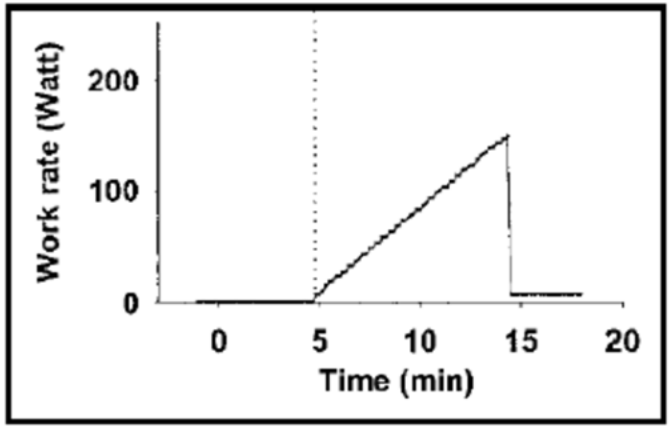
*Definition of abbreviations*: ABGs = Arterial blood gases; AT = anaerobic threshold; BP = blood pressure; ECG = electrocardiogram; fR = respiratory frequency; HR = heart rate; $P(A–a)O_2$ = alveolar–arterial difference for oxygen pressure; $Pa_{CO_2}$ = arterial carbon dioxide pressure; $Pa_{O_2}$ = arterial oxygen pressure; $PET_{CO_2}$ = end-tidal $PCO_2$; $PET_{O_2}$ = end-tidal $PO_2$; RER = respiratory exchange ratio; $Sa_{O_2}$ = arterial oxygen saturation; $Sp_{O_2}$ = arterial oxygen saturation as indicated by pulse oximetry; $\dot{V}CO_2$ = carbon dioxide output; $\dot{V}E$ = minute ventilation; VD/VT = ratio of physiologic dead space to tidal volume; $\dot{V}O_2$ = oxygen uptake; VT = tidal volume; WR = work rate. Adapted by permission from Reference 28.

ATS/ACCP STATEMENT ON CARDIOPULMONARY EXERCISE TESTING WAS ADOPTED BY THE ATS BOARD OF DIRECTORS, MARCH 1, 2002
AND BY THE ACCP HEALTH SCIENCE POLICY COMMITTEE, NOVEMBER 1, 2001

# Ramp-incremental Exercise Test

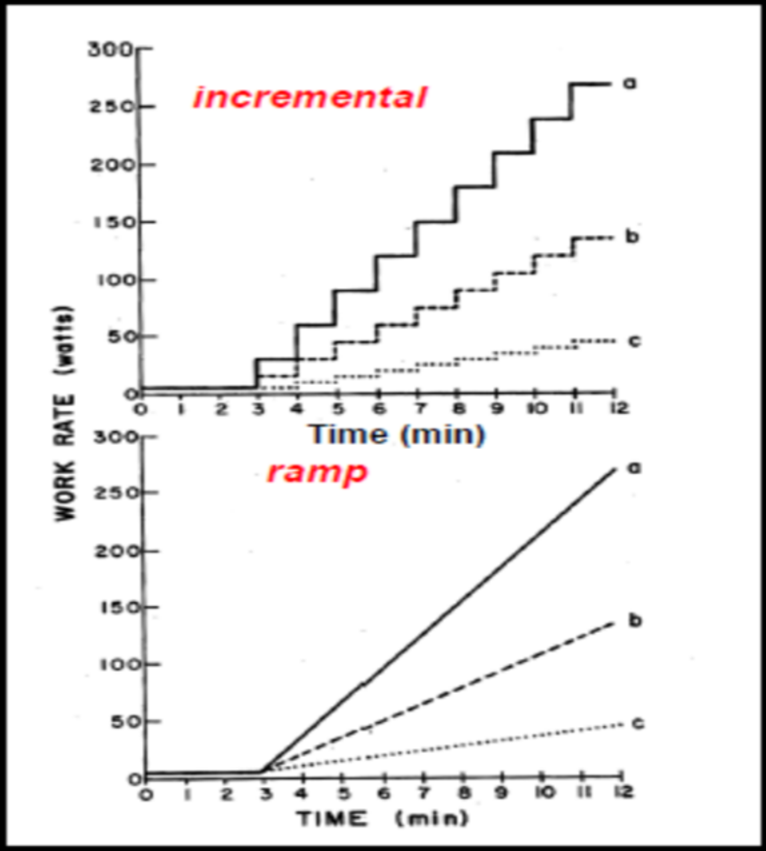
UCLA LABioMed




**Ramp-Incremental Exercise Test**

*A smooth increase in work rate, from 'unloaded' exercise, until the limit of tolerance is reached*




Wasserman et al. *"PETI"*, 2011

# Indications for Exercise Termination :

Orthopedic impairment
Chest pain suggestive of ischemia
Ischemic ECG changes, specifically ST elevation (> 1mm) in leads without Q waves (other than V1 or aVR), ST or QRS changes such as excessive ST displacement (horizontal or down sloping of > 2mm) or marked axis shift[8]
Complex ectopy
Second or third degree heart block
Fall in systolic pressure > 20 mmHg from the highest value during the test
Hypertension (>250 mmHg systolic; > 120 mmHg diastolic)
Severe desaturation; $SpO_2$ 80% with accompanied symptoms and signs of hypoxemia
Sudden pallor
Loss of coordination
Mental confusion
Dizziness or faintness
Signs of respiratory failure

American Thoracic Society (ATS) / American College of Chest Physicians (ACCP) Statement on Cardiopulmonary Exercise Testing (American Journal of Respiratory and Critical Care Medicine, 2003)

# SYMPTOMS SCORES:

- The Rating of Perceived Exertion (RPE) scale

  (6 :No exertion at all-11 :Light-15: Hard-20 :Maximal exertion)

- The Borg breathlessness or dyspnoea scale(0-10)

# RECOVERY PERIOD:

- Slow recovery of the heart back to a normal rate once exercise ceases can be an indicator of significant cardiac impairment and overall poor cardiorespiratory fitness.
- A fall in FEV1 of 15% or more during the ten minutes or so after a CPET is a strong pointer to the diagnosis of EIB, but this diagnosis is not excluded if the FEV1 does not fall

## Suggested components of a cardiopulmonary exercise testing report

**History and clinical context**
Relevant medical history, specifics of exercise intolerance, prior exercise test results, relevant studies (eg, echocardiography, pulmonary function tests, complete blood cell count), relevant medications (eg, beta-blockers)

**Resting data**
Weight, body mass index, percent body fat, heart rate, blood pressure, pulse oximetry, screening spirometry, hemoglobin, electrocardiogram

**Exercise protocol**
Treadmill, cycle, or arm geometry; rate of ramp increase; peak workload

**Reason for test termination**
Fatigue, symptoms, abnormal electrocardiographic findings

**Subjective responses**
Peak rating of perceived exertion
Specific symptoms and comparison to index symptoms

**Validity of test**
Peak respiratory exchange ratio ≥ 1.1, rating of perceived exertion ≥ 17

**Oxygen responses**
Peak $\dot{V}O_2$ relative to norms, $\dot{V}O_2$ per ideal weight, $\dot{V}O_2$ at ventilatory threshold

**Specific cardiac responses**
Reflected in exercise and recovery heart rate, blood pressure, $O_2$-pulse, electrocardiogram

**Specific pulmonary responses**
Peak respiratory rate, ventilations; ventilatory reserve ($\dot{V}E$/MVV), pulse oximetry, blood gases

**Markers of central cardiopulmonary inefficiency**
$\dot{V}E/\dot{V}CO_2$ slope, end-tidal $PCO_2$ responses, exercise oscillatory breathing, oxygen uptake efficiency slope

**Summary statement**
The bottom line for referring provider; normal vs abnormal; if abnormal, suggest differential diagnoses; CPET score for heart failure (see **Table 3**)

**Recommendations**
To guide referring provider
Reassurance if normal
Formal exercise program for fitness or weight loss
Suggest adjunctive tests if abnormal (eg, formal spirometry, right heart catheterization, chest computed tomography, natriuretic peptide measurement)
Beta-blocker modification or pacemaker if chronotropically incompetent

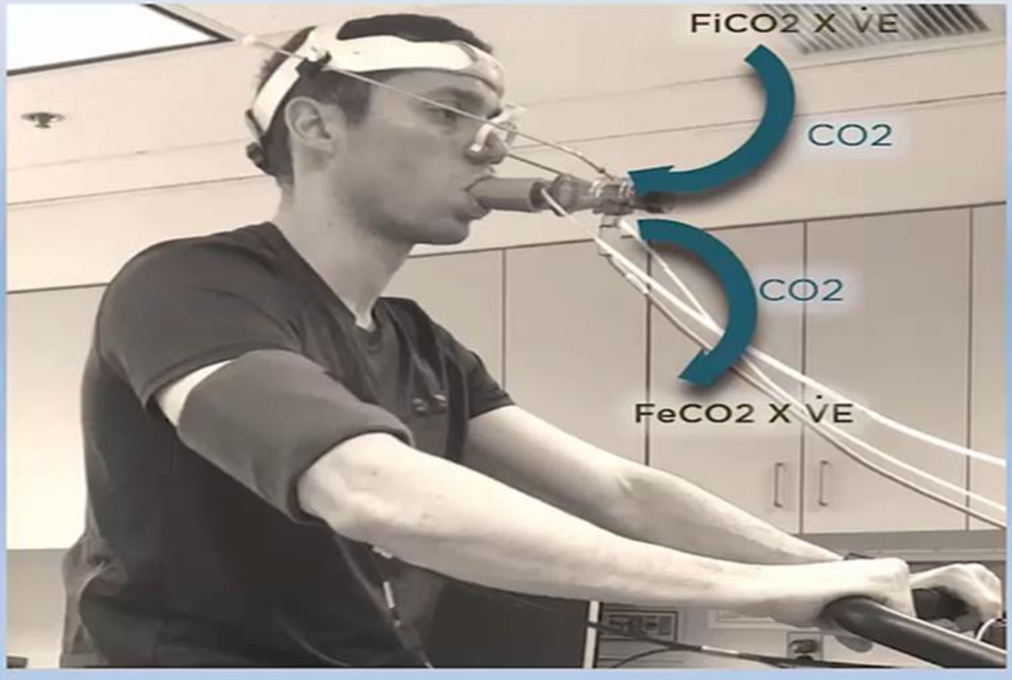
CARDIOPULMONARY EXERCISE TESTING: A CONTEMPORARY AND VERSATILE CLINICAL TOOL.CLEVELAND CLINIC JOURNAL OF MEDICINE VOLUME 84 • NUMBER 2 FEBRUARY 2017

# KEY CARDIOPULMONARY EXERCISE TEST PARAMETERS

- VO2
- RER and AT
- Cardiovascular
- Metabolic
- Gas exchange
- Respiratory

# OXYGEN UPTAKE( VO2):

- • The maximum oxygen uptake (VO2 max) is the most important CPET parameter.
- • Many people consider VO2 max as the first place to start the CPET interpretation process.
- • A VO2 max <80% of predicted is abnormal.
- • The lower the VO2 max, the worse the outcome.
- • The ‘functional’ exercise capacity is affected by weight, and thus VO2 max is often presented as a weight-adjusted value


$$\dot{V}O_2 = \dot{V}E \times (FiO_2 - FeO_2)^*$$

$$\dot{V}CO_2 = VE \times (FiCO_2 - FeC0_2)$$

# REFERENCE VALUES IN ADULTS

## VO2max

- Normal values (35 y)
  - Rest: 6 l x 0.04 = 0.240 litres $O_2$ per minute ***(3,5 ml/min/kg)***
  - « Normal » effort : 18 l x 0.17 = 3.060 l/min or **40 ml/min/kg** (75 kg)
  - Athletes (cyclists): 30 l x 0.19 = 5.700 l/min or ***87 ml/min/kg*** (65kg)
  - ePO doped cyclists : 30l x 0.21 = 6.2 l/min or ***95 ml/min/kg***
- Decreases with age
- Increases with training (30-40%)

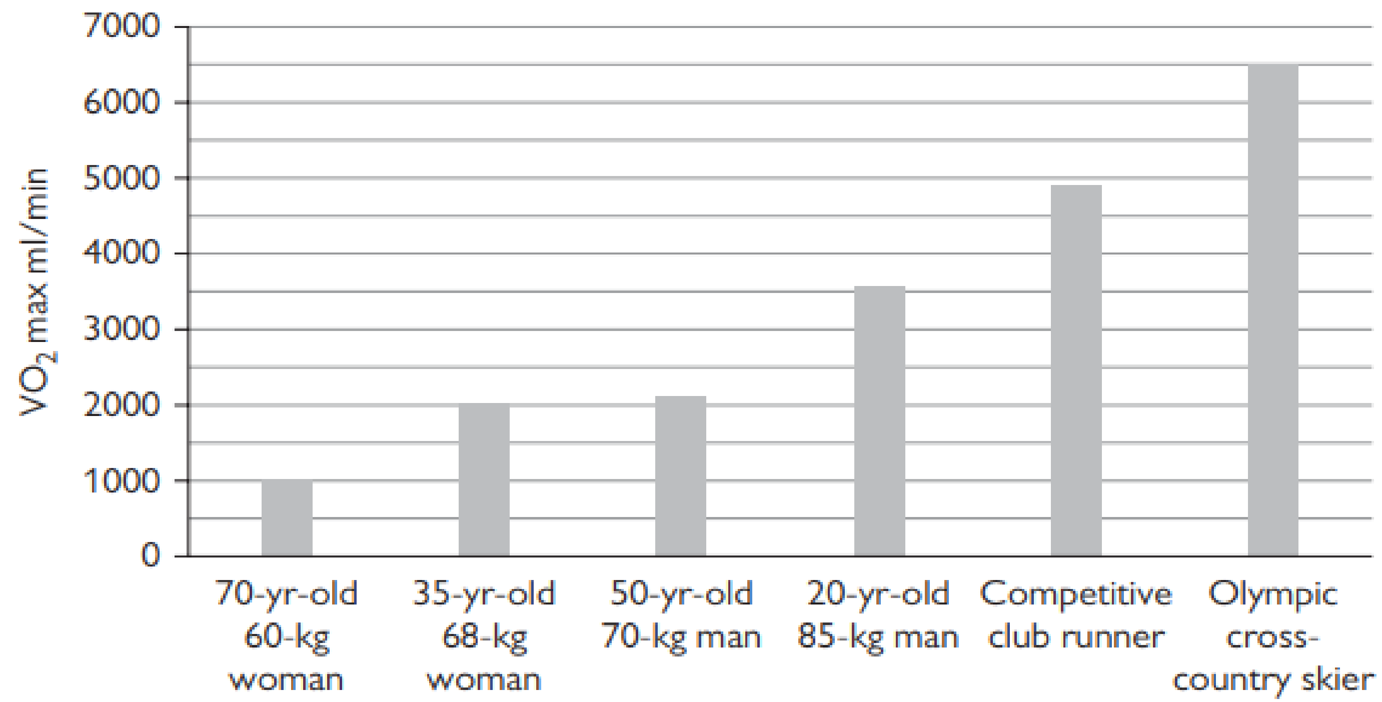



Fig. 5.2 Examples of $VO_2$max seen with different subjects on a cycle ergometer.

OXFORD RESPIRATORY MEDICINE LIBRARY
WILLIAM KINNEAR, JAMES H. HULL

# $VO_2$ ml/min/kg

## Controversial: Corrected for Ideal Body Weight?

**Used prognostically for**

- **Pulmonary surgical risk**
- **Pulmonary rehabilitation planning**
- **Cardiac failure & transplant evaluations**

**Prognostic value varies if patient is on beta blockers or had resynchronization therapy**

## Achieving a normal predicted $VO_2$ at low workload is pathognomonic of deconditioning and/or obesity

Interpretation of cardiopulmonary exercise test , Zachary Q Moris . American college of chest physician

# RER( RESPIRATORY EXCHANGE RATIO):

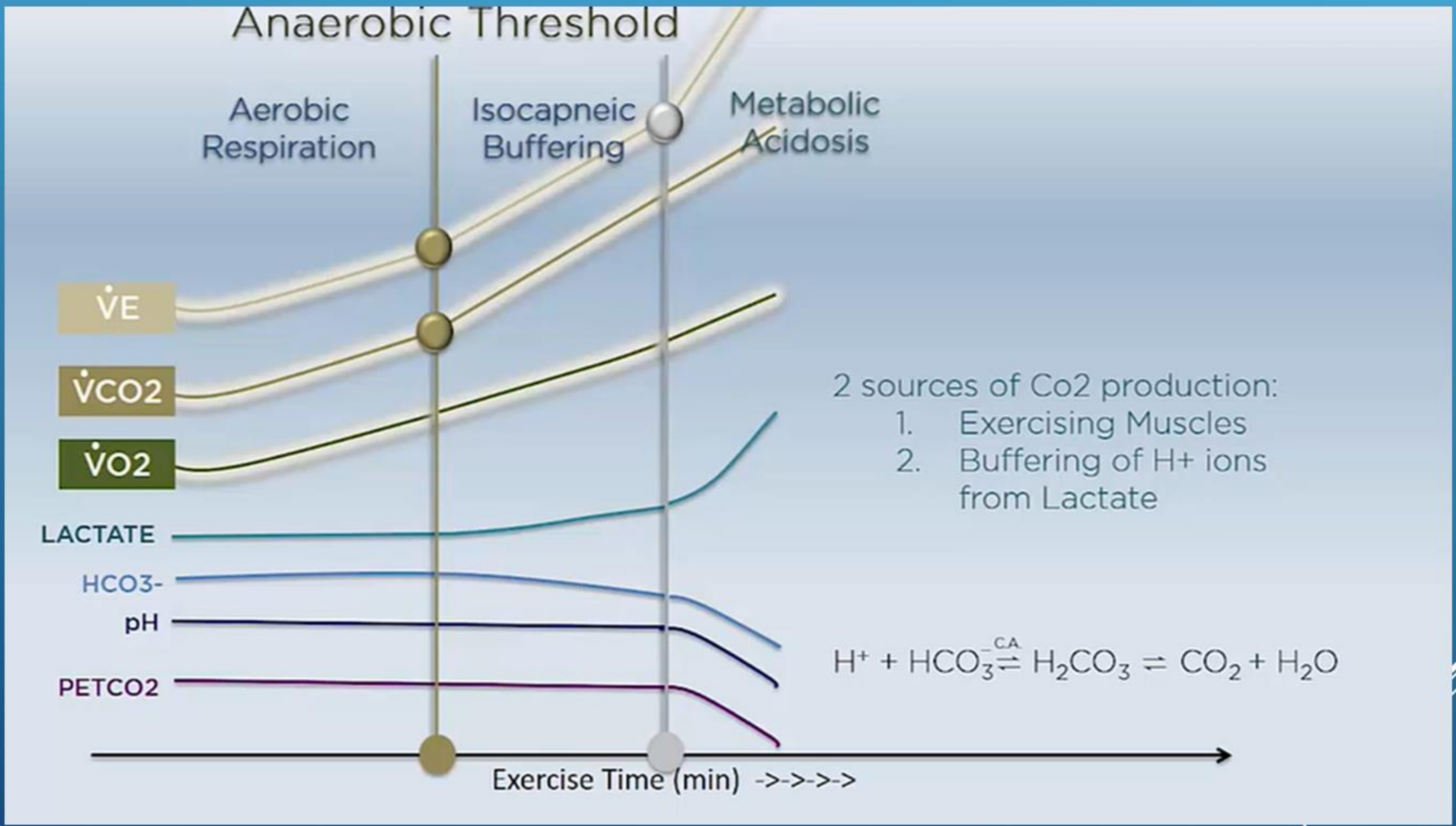
- The RER (VCO2 /VO2 ) should be <1 in the early part of a CPET and rises above 1.0 as exercise progresses past the AT (and will continue to rise after exercise stops).
- Some also report that an RER >1.1 is a good marker of effort during a CPET. (This is not a reliable marker in patients with severe obstructive lung disease who will often stop exercise, completely exhausted, with an RER 1.4), as metabolic processes continue to compensate for the preceding exercise bout.

Oxford respiratory Medicine library
William Kinnear, James H. Hull

# AT( ANAEROBIC THRESHOLD):

- AT is thought to represent a point during CPET where anaerobic processes increasingly supplement aerobic metabolism, with increasing production of lactic acid.
- Lactic acid is buffered by HCO3 – to produce more CO2 .
- The AT should occur when the VO2 is >40% of an individual's predicted VO2 max.
- A low AT is primarily caused by impaired O2 delivery to muscles, usually because of heart disease or peripheral vascular disease.
- Always look at the graphical display to check which point has been chosen to call the AT.

Oxford respiratory Medicine library
William Kinnear, James H. Hull


Anaerobic Threshold
Aerobic Respiration
Isocapneic Buffering
Metabolic Acidosis
VE
VCO2
VO2
LACTATE
HCO3-
pH
PETCO2
2 sources of Co2 production:
1. Exercising Muscles
2. Buffering of H+ ions from Lactate
H+ + HCO3- ⇌ H2CO3 ⇌ CO2 + H2O
C.A.
Exercise Time (min) ->->->->

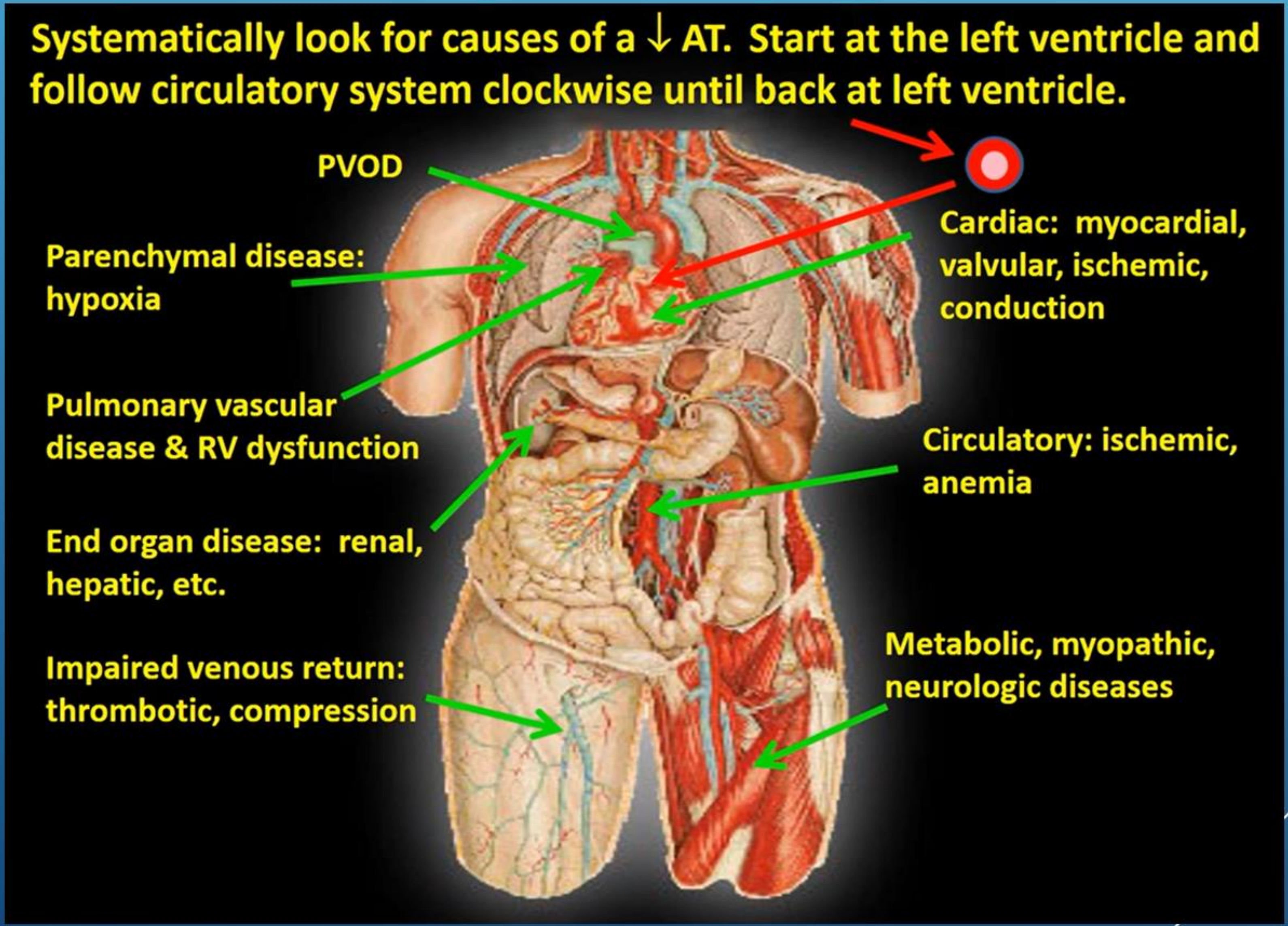
# FOUR WAYS OF LOOKING FOR THE AT:

- 1. On a plot of VCO2 and VO2 against time, the VCO2 starts to increase faster and crosses the VO2 line.
- 2. When the VCO2 is plotted against the VO2 , the slope changes to become steeper.
- 3. The RER increases to a value >1.0.
- 4. The VeqO2 and etO2 start to increase, whilst the VeqCO2 and etCO2 remain constant

**Table 12.1** AT in different clinical states

| | AT (% predicted $VO_2$max) |
|---|---|
| Trained athlete | 61–80 |
| Normal | 51–60 |
| Deconditioned/mild disease | 40–50 |
| Abnormal | <40 |

OXFORD RESPIRATORY MEDICINE LIBRARY
WILLIAM KINNEAR, JAMES H. HULL




Interpretation of cardiopulmonary exercise test , Zachary Q Moris . American college of chest physician

# CARDIOVASCULAR SYSTEM:

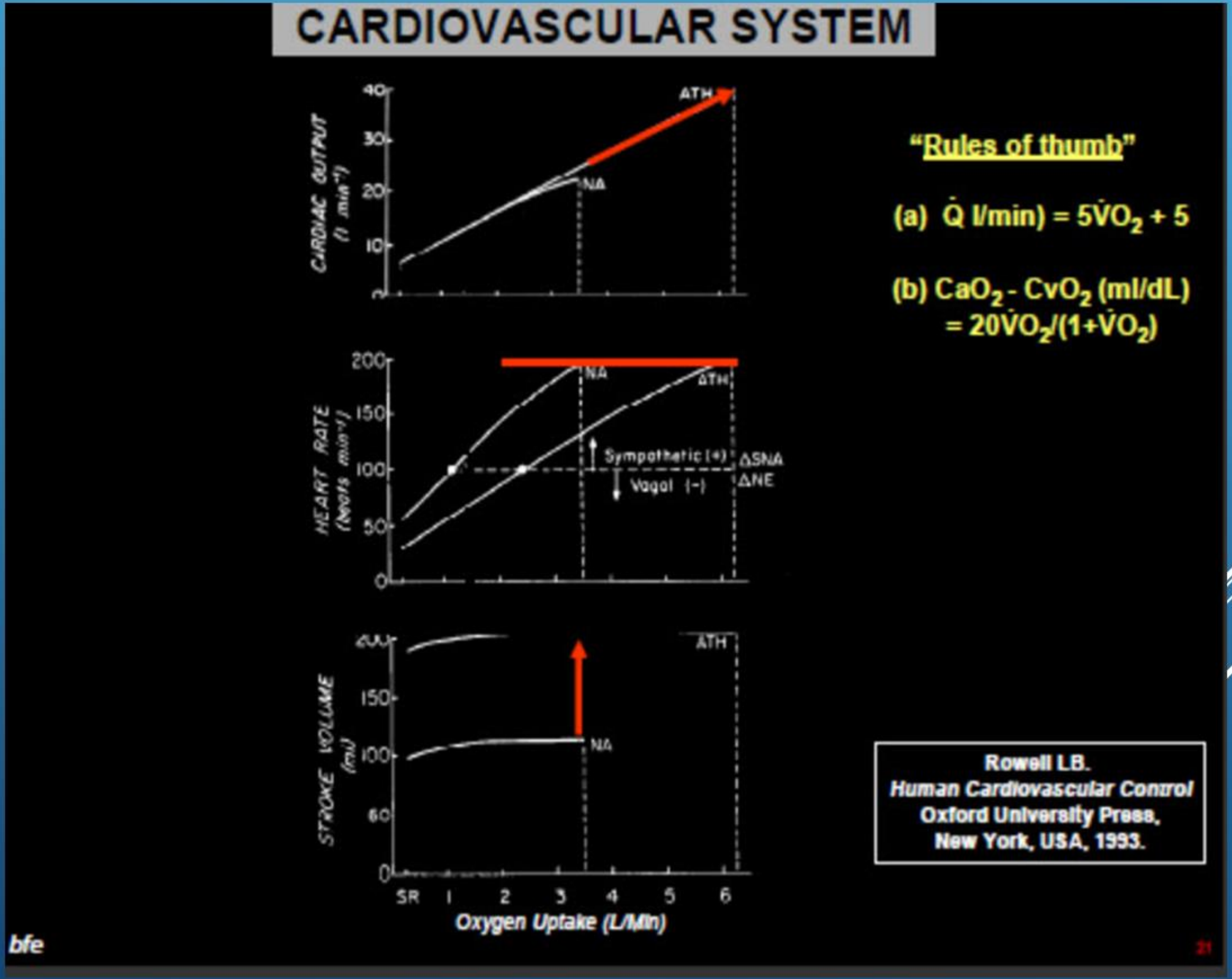
Heart rate

Systemic Blood Pressure

O2 pulse

ECG

$\frac{\Delta Vo_2}{\Delta WR}$



# (FUNCTIONAL CAPACITY) METABOLIC ACTIVITY

Peak VO2

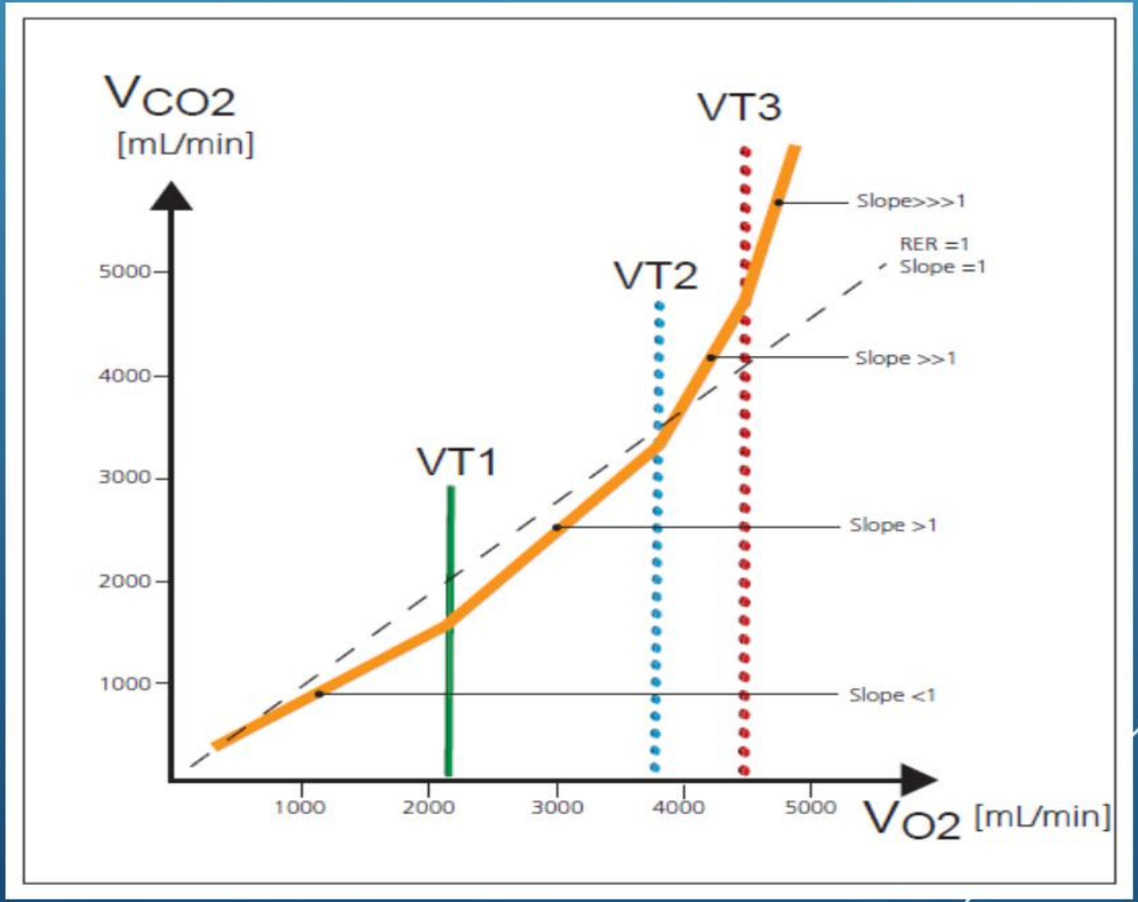
O2 Pulse

RER

AT

$\frac{\Delta Vo_2}{\Delta WR}$

Peak WR



# (RESPIRATORY RESPONSES) VENTILATORY RESPONSE

(Minute ventilation) VE

(Breathing  Reserve) BR

Ventilatory Equivalents for oxygen and $Co_2$

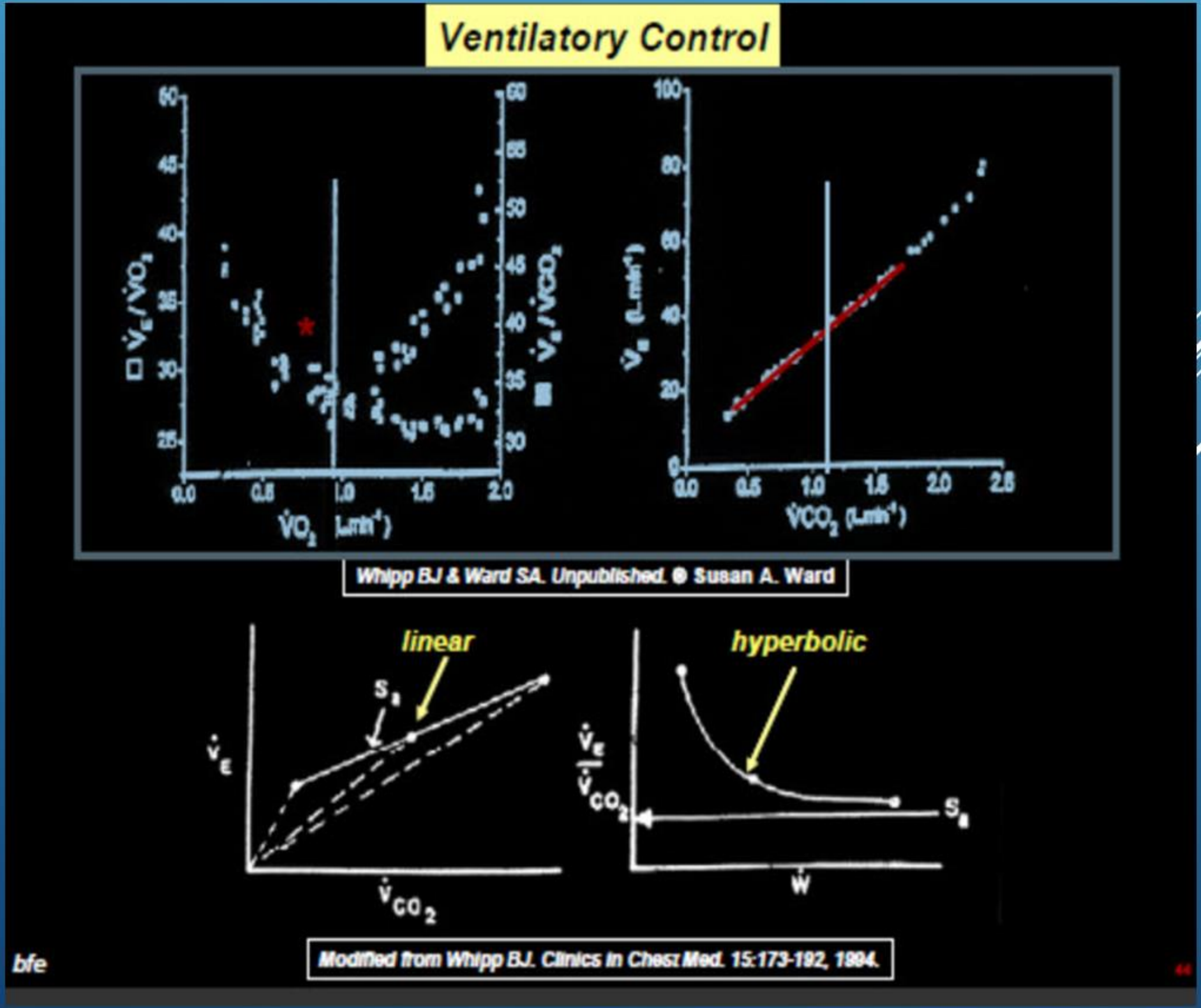
$(\,{}^{VE}/_{Vo_2}\,,\ {}^{VE}/_{VCo_2})$

$\frac{V_D}{V_T}$

Spo2

Breathing pattern

Tidal flow_vlume loop



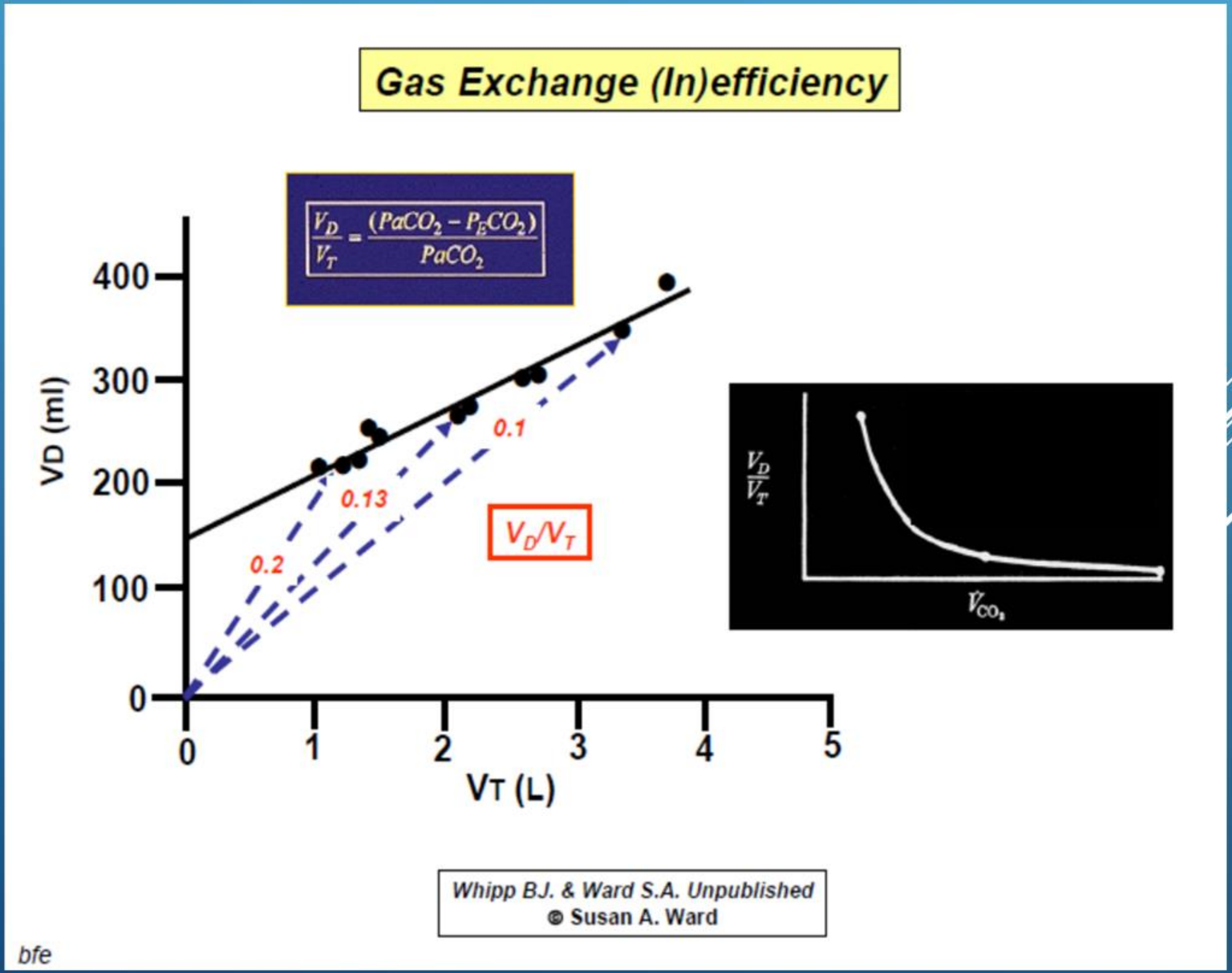
# GAS EXCHANGE:

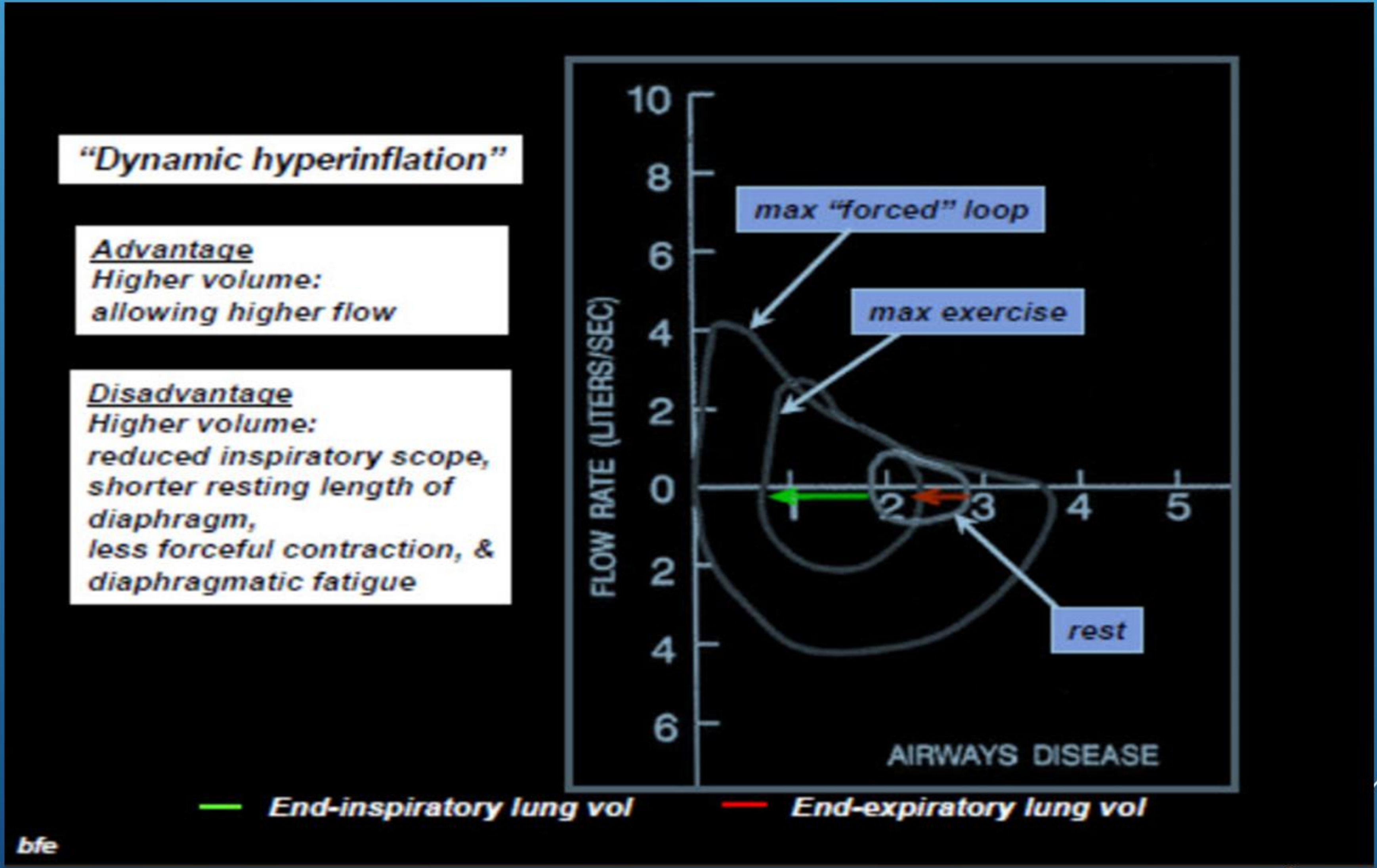
$Spo_2$

Arterial & End tidal pressure of $Co_2$

Arterial & End Tidal partial pressure of $O_2$

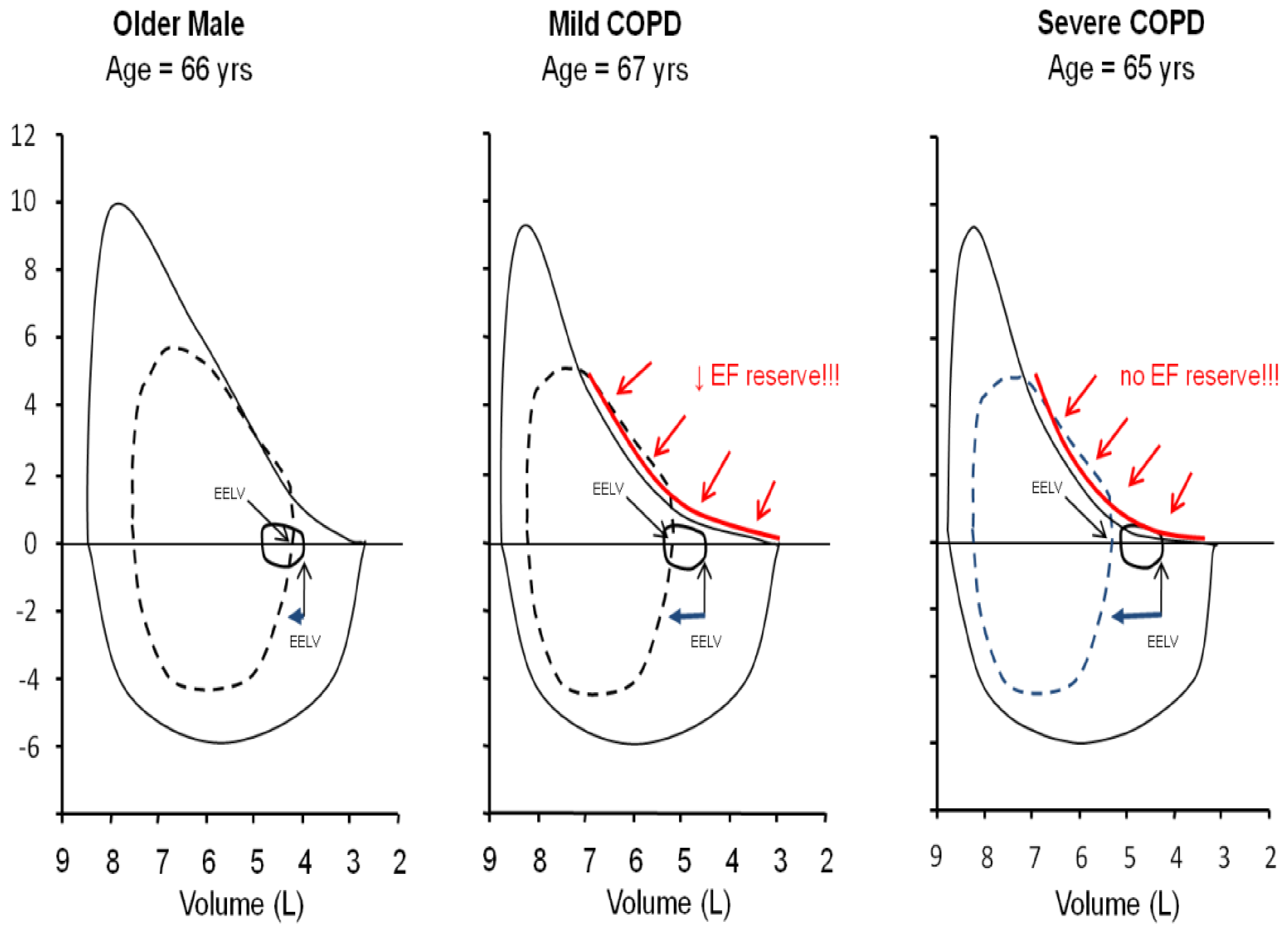
$\frac{V_D}{V_T}$






PHYSIOLOGICAL RESPONSES TO EXERCISE IN PATIENTS WITH RESPIRATORY DISEASE ,
ERS SCHOOL COURSE 2015, CLINICAL EXERCISE TESTING , 19-21 FEBRUARY 2015 ROME, ITALY , SUSAN A. WARD, D.PHIL.

# Ventilatory Mechanics: Healthy vs COPD




Laveneziana P, et al. Appl. Physiol. Nutr. Metab. 2007

# EXERCISE INDUCED BRONCHOCONSTRICTION( EIB):

- IB is usually diagnosed when there is a ≥10% fall in FEV1 from the pre-test or baseline value in the 20 minutes following exercise.

- The peak expiratory flow rate (PEFR) is not a reliable marker of EIB as it is more effort-dependent; if the subject is tired following an exercise test, the PEFR may fall.

## Physiological markers of a maximal test include the following:

80% PREDICTED WORK RATE (AS PER DEMOGRAPHICS)

80% MAXIMAL HR (PREDICTED MAXIMUM ( 220 BEATS/MIN/AGE)

HEART RATE RESERVE (HRR) OF <15%

ACHIEVING AN RER 1.15

ACHIEVING MAXIMAL PREDICTED V E

# POINTERS TO SUB-MAXIMAL EFFORT AT PEAK EXERCISE IN A CPET:

- Physiology staff report of early cessation/problems reported. Low ratings of perceived work or breathlessness
- Low VO2 max
- High HRR (i.e. lots of HR left), but a normal chronotropic profile, i.e. if you plot a mark between the predicted HR max and the predicted VO2 max and then extrapolate this line, you can determine if the HR was 'behaving' in the right direction prior to exercise cessation
- High VE reserve (i.e. lots of ventilation left)
- Normal AT
- No RCP reached
- Low blood lactate( <4mmol/l)
- RER<1.0

Oxford respiratory Medicine library
William Kinnear, James H. Hull

**Table 2** Normal cardiopulmonary exercise testing variables

| Variables | Normal value |
|---|---|
| Peak oxygen content ($PVO_2$) | >84% Predicted |
| Ventilatory anaerobic threshold (VAT) | >40% $PVO_2$ (40–80%) |
| Maximum heart rate (HRmax) | >90% Age predicted |
| Heart rate reserve (HRR) | <15 Beats/min |
| Blood pressure (BP) | <220/90 |
| $O_2$ pulse ($VO_2$/HR) | >80% |
| Ventilatory reserve (VR) | MVV−VEmax >11 litres or VEmax/MVV × 100 <85% |
| Respiratory rate (RR) | <60 Breaths/min |
| Minute ventilation/carbon dioxide output ratio (VE/$VCO_2$) at VAT | <34 |

MVV, maximal voluntary ventilation; VE, expired ventilation.
Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.[1]

# SELECTED REFERENCE EQUATIONS FOR MAXIMAL INCREMENTAL CPET :

Jones et al., 1985[19]:

| Variable | Equation | SEE |
|---|---|---|
| Work rate, *kpm/min* | 20.4(Ht) – 8.74(Age) – 288(Sex) - 1909 | 216 |
| $VO_2$, *L/min* | 0.046(Ht) – 0.021(Age) – 0.62(Sex) – 4.31 | 0.458 |
| $VO_2$, *ml/min/kg* | **Male**: 55 – 0.44(Age)<br>**Female**: 43 – 0.36(Age) | 6.5<br>6.6 |
| Heart-rate, *beats/min* | 202 - 0.72(Age) | 10.3 |
| $O_2$ pulse, *ml/beat* | 0.28(Ht) – 3.3(Sex) – 26.7 | 2.8 |
| Ventilation, *L/min* | 26.3(VC) - 34 | 23.1 |
| $VO_2$ at anaerobic threshold, *L/min*: | 0.024(Ht) - 0.0074(Age) - 2.43 | 0.316 |

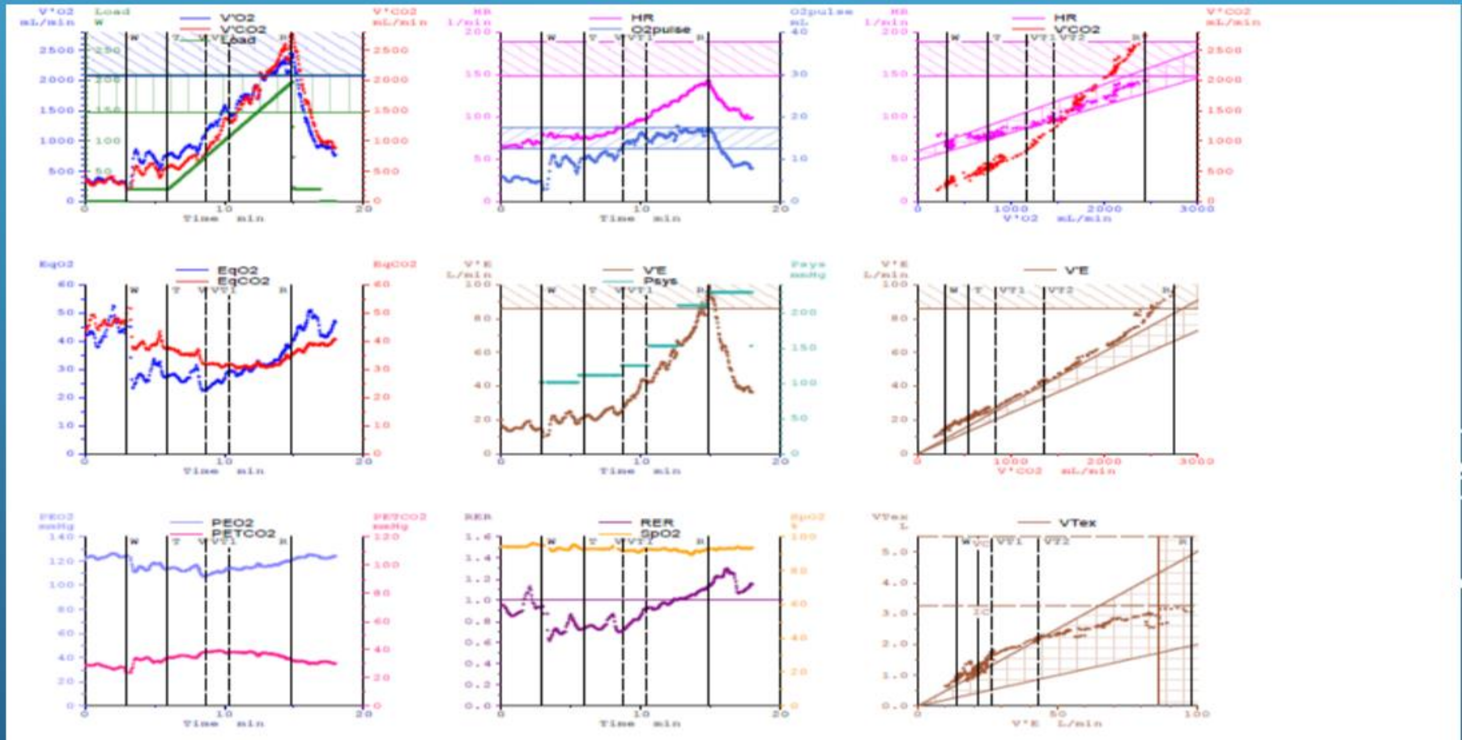
Hansen et al., 1984[20]:

| Variable | Equation |
|---|---|
| $VO_2$, *L/min* | **Male**: [Wt x {50.75 – 0.372(Age)}] / 1000<br>**Female**: [(Wt + 43) x {22.78 – 0.17(Age)}] / 1000 |
| Heart-rate, *beats/min* | 210 - 0.65(Age) |
| $O_2$ pulse, *ml/beat* | Predicted $VO_2$max / predicted heart-rate max |
| $V_E$/MVV, *%* | ~72 +/- 15 |
| $VO_2$ at anaerobic threshold, *L/min*: | > 40% $VO_2$ predicted |

Predicted weight (men) = 0.79 x Ht – 60.7. Predicted weight (women) = 0.65 x Ht – 42.8. When actual weight > predicted, the predicted weight should be used in the Hansen equations.

Ht = height in cm; Wt = weight in kg; Age = age in years; Sex, male = 0, female = 1; VC = measured vital capacity in L; SEE = standard error of estimate

# PLOT GRAPH EXAMPLES (NORMAL RESPONSES TO EXERCISE) :




A. Oxygen uptake ($VO_2$) versus work rate (W)
B. Heart rate (HR) and $O_2$ pulse versus $VO_2$
C. Indirect determination of the anaerobic threshold (AT) using the modified V slope method, in which carbon dioxide production ($VCO_2$) is plotted versus $VO_2$
D. Minute ventilation ($V_E$) versus carbon dioxide output ($VCO_2$)
E. Tidal volume ($V_T$) and respiratory frequency ($f_R$) versus $VO_2$
F. Ventilatory equivalent for $O_2$ ($V_E/VO_2$), ventilatory equivalent for $CO_2$ ($V_E/VCO_2$) versus $VO_2$
G. Minute ventilation ($V_E$) versus $VO_2$
H. Pulse oximetry ($SpO_2$) versus $VO_2$
I. End-tidal pressure for $O_2$ ($P_{ET}O_2$) and end-tidal pressure for $CO_2$ ($P_{ET}CO_2$) versus $VO_2$

Exercise testing and Interpretation .Fifth edition .Karlman Wasserman et all.2012

# THE ABCDEF APPROACH TO CPET INTERPRETATION AND REPORTING:

- **A—Accuracy**. Do you believe the accuracy of the data? Was it precise, valid, and with relevant predicted values?
- **B—Best effort**. Did the patient try their best/put in maximum effort or was the test sub-maximal?
- **C—Capacity**. Was exercise capacity impaired, i.e. was the VO2 max low when compared with predicted indices (usually taken as 80%)
- **D—Determine what limited the test**. Broadly speaking, was it a cardiac or a ventilatory limitation to exercise?
- **E—Extra value**. Think about the additional variables and parameters. This is probably best undertaken by reviewing: (i) cardiovascular traces; (ii) ventilation traces; and (iii) gas exchange traces in this order .
- **F—Finish with a purpose**. Think about the letter/report and what it means to the referring clinician, suggestions for the next step of management/investigation.

Oxford respiratory Medicine library
William Kinnear, James H. Hull

# QUESTION TO ASK BEFORE INTERPRETING:

- Was the test conducted on bicycle or treadmill? ( 10% more VO2 on treadmill)
- Which protocol? Graded, Constant work rate, stages?
- Gender, Body Weight, height, fitness level
- Normal predicted values( Wasserman, Johns, Cooper…)
- Was exercise conducted until maximum

-Plateau VO2 max

-Or MPHER, max RER>1.10-1.20, VT largely surpassed…..

- If not reason of stopping

# SYSTEMATIC APPROACH TO INTERPRETING THE NINE-PANEL PLOT:

1. Is the test maximal in terms of effort?
2. . What is the VO2peak in panel 3?
3. Is the VO2ework relationship normal?
4. Can I determine AT in this test?
5. If so, what is the VO2 at AT?
6. Was the HR response normal?
7. Does the oxygen pulse increase with exercise?
8. . Is there any ventilatory limitation?
9. Were there any ECG changes?

Cardiopulmonary exercise testingda beginner's guide to the nine-panel plot D.J. Chambers1 and N.A. Wisely2, * 1 Salford Royal NHS Foundation Trust, Salford, UK and 2 Wythenshawe Hospital, Manchester University NHS Foundation Trust, Manchester, UK, 2019

# KEY ELEMENTS IN PREOPERATIVE CARDIOPULMONARY EXERCISE TESTING INTERPRETATION:

1.Determine the reason for cardiopulmonary exercise testing

2. Review pertinent medical history and laboratory information

3. Note overall test quality, assessment of patient effort and reasons for test termination

4. Use tabular and graphical presentation of the data

5. Report exercise capacity using anaerobic threshold and VO2peak values

6. Report other indices related to perioperative risk e.g. VE_ VCO 2 at the anaerobic threshold

7. Evaluate exercise limitation and primary cause(s) for this, e.g. cardiovascular, respiratory, deconditioning

8. Comment on perioperative risk implications of the exercise test and suggestions for further investigation/ referral/preoperative interventions

Perioperative cardiopulmonary exercise testing (CPET): consensus clinical guidelines on indications, organization, conduct, and physiological interpretation D.Z.H. Levett1,2,10, *, S. Jack1,2,10, M. Swart3,10, J. Carlisle3 , J. Wilson4 , C. Snowden5 , M. Riley6 , G. Danjoux7 , S.A. Ward8 , P. Older9 , M.P.W. Grocott1,2,10 and For the Perioperative Exercise Testing and Training Society (POETTS), 2018

**Table 6** American Thoracic Society/American College of Chest Physicians: usual cardiopulmonary exercise response patterns

| Measurement | Heart failure | COPD | ILD | Pulmonary vascular disease | Obesity | Deconditioned |
|---|---|---|---|---|---|---|
| $PV_{O_2}$ | ↓ | ↓ | ↓ | ↓ | ↓ for actual, N for ideal weight | ↓ |
| VAT | ↓ | N / ↓ /indeterminate | N or ↓ | ↓ | N | N or ↓ |
| Peak HR | Variable, N in mild | ↓ , N in mild | ↓ | N /slightly ↓ | N /slightly ↓ | N /slightly ↓ |
| $O_2$ Pulse | ↓ | N or ↓ | N or ↓ | ↓ | N | ↓ |
| VE/MVV × 100 | N or ↓ | ↑ | N or ↑ | N | N or ↑ | N |
| $VE/V_{CO_2}$ at VAT | ↑ | ↑ | ↑ | ↑ | N | N |
| VD/VAT | ↑ | ↑ | ↑ | ↑ | N | N |
| $Pa_{O_2}$ | N | Variable | ↓ | ↓ | N/may ↑ | N |
| $P(A-a)_{O_2}$ | Usually N | Variable, usually ↑ | ↑ | ↑ | May ↓ | N |

COPD, chronic obstructive pulmonary disease; HR, heart rate; ILD, interstitial lung disease; MVV, maximum voluntary ventilation; N, normal; $P(A-a)_{O_2}$, alveolar–arterial difference for oxygen pressure; $PV_{O_2}$, peak oxygen uptake; VAT, ventilatory anaerobic threshold; VD/VAT, ratio of physiological dead space to tidal volume; VE, minute ventilation; $V_{CO_2}$, carbon dioxide output.

Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.[1]

## What cardiopulmonary exercise test patterns suggest

**Nonspecific: suggest significant cardiopulmonary or metabolic impairment of any sort**
Peak $\dot{V}O_2$ < 80% of predicted
$\dot{V}E/\dot{V}CO_2$ slope > 34
Ventilatory (anaerobic) threshold < 40% of peak $\dot{V}O_2$

**Deconditioning**
Low-normal peak $\dot{V}O_2$
Low ventilatory (anaerobic) threshold
Absence of any other abnormal responses

**Obesity**
Increased $\dot{V}O_2$/work slope
Indexed peak $\dot{V}O_2$ (mL/kg/min) less than predicted
Absolute $\dot{V}O_2$ (L/min) normal or greater than predicted
Oxygen indexed to lean body mass normal or greater than predicted

**Cardiac limitations**
Oxygen pulse ($O_2$-pulse) < 80% predicted or flattened or falling curve
Chronotropic incompetence
Heart rate recovery ≤ 12 beats per minute after 1 minute of recovery
Standard electrocardiographic criteria for ischemia

**Pulmonary limitations**
Peak exercise respiratory rate > 50 per minute
Ventilatory reserve (peak $\dot{V}E$/MVV) < 15%
Oxygen desaturation by pulse oximetry
Abnormal results on pretest screening spirometry
Abnormal exercise flow-volume loops

**Muscular disease**
Submaximal cardiac and respiratory responses
Ventilatory (anaerobic) threshold < 40% of peak $\dot{V}O_2$
Elevated lactate at any given level of submaximal work

Cardiopulmonary exercise testing: A contemporary and versatile clinical tool.CLEVELAND CLINIC JOURNAL OF MEDICINE VOLUME 84 • NUMBER 2 FEBRUARY 2017

# EXERCISE PRESCRIPTION:

- Some training parameters can be derived from the CPET results. Specifically, HR zones can be constructed and advice given around training based on the AT and RCP.

- This being said, most modern-day training programmers for athletic training are built around power concepts such as a functional threshold power (FTP) or sustainable or critical power and thus require more specific exercise protocols/dedicated algorithms.


# THANKS FOR YOUR ATTENTION