5th iHEFCARD
The 5th Indonesian Symposium on Heart Failure and Cardiometabolic Disease

Indonesian Working Group on Heart Failure and Cardiometabolic Disease

Cardiopulmonary Exercise Testing 101: Heart Failure Edition

I Nyoman Wiryawan
Working Group of Indonesian Heart Failure and Cardiometabolic Disease
Indonesian Heart Association

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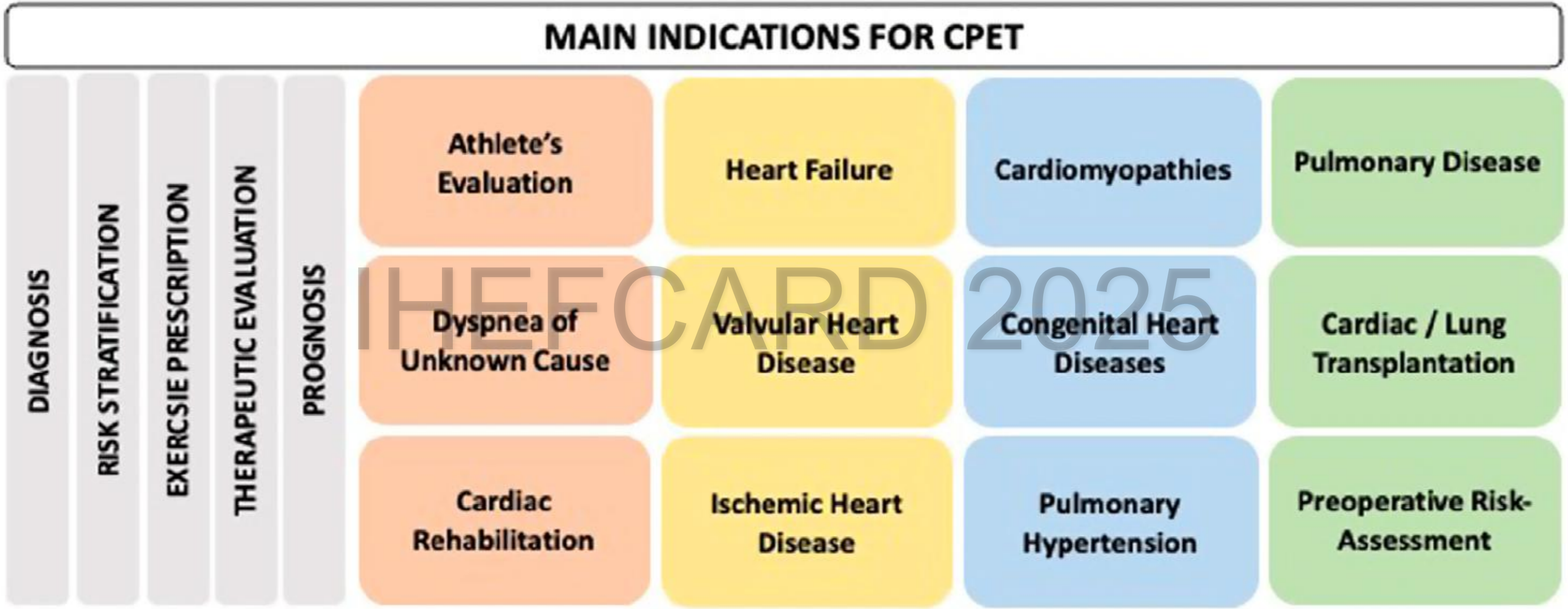
Sheraton Grand Jakarta Gandaria City, Jakarta, Indonesia
0811-1900-8855 | scientific_ihefcard@inahfcarmet.org | @ina.hf | ihefcard.com

Introduction

- Universal definition of HF → a clinical syndrome with diverse etiologies, marked with symptoms and/or signs caused by a structural and/or functional cardiac abnormality, and corroborated by elevated NP levels and/or objective evidence of pulmonary or systemic congestion.
- Prevalence of HF continues to increase globally → growing need for precise diagnostic and prognostic tools to guide therapeutic strategies to improve patient outcomes and to provide the basis for clinical trials.
- CPET is an examination that allows the HCP to simultaneously study the responses of the cardiovascular and ventilatory systems to a defined progressive (or incremental) exercise stress performed to the limit of tolerance.
- Cardiopulmonary exercise testing (CPET) is a valuable and versatile tool used in the classification of HF based on their functional capacity, exercise tolerance, and response to exertion.

JACC: Asia 2024;4:249–264. https://doi.org/10.1016/j.jacasi.2024.01.013. Wasserman & Whips. Principles of Exercise Testing and Interpretation. 6th ed. 2021

Indication



Dores, et al. Revista Portuguesa de Cardiologia 43 (2024) 525---536. https://doi.org/10.1016/j.repc.2024.01.005.

What Guidelines Say

Recommendations for Exercise and Functional Capacity Testing
Referenced studies that support the recommendations are summarized in the Online Data Supplements.

COR	LOE	RECOMMENDATIONS
1	C-LD	1. In patients with HF, assessment and documentation of NYHA functional classification are recommended to determine eligibility for treatments (1-3).
1	C-LD	2. In selected ambulatory patients with HF, cardiopulmonary exercise testing (CPET) is recommended to determine appropriateness of advanced treatments (e.g., LVAD, heart transplant) (4-8).
2a	C-LD	3. In ambulatory patients with HF, performing a CPET or 6-minute walk test is reasonable to assess functional capacity (4,5,9-16).
2a	C-LD	4. In ambulatory patients with unexplained dyspnea, CPET is reasonable to evaluate the cause of dyspnea (17,18).

Heidenreich et al. 2022 AHA/ACC/HFSA Heart Failure Guideline. https://doi.org/10.1016/j.jacc.2021.12.012

Contraindication

- **Absolut**

Acute myocardial infarction (3---5 days)
Unstable angina
Uncontrolled arrhythmia causing symptoms or hemodynamic instability
Active endocarditis
Acute myocarditis or pericarditis
Symptomatic severe aortic stenosis
Decompensated HF
Acute aortic dissection
Uncontrolled asthma
Acute pulmonary embolism
Arterial desaturation at rest on room air <85%
Physical disability that precludes safe and adequate testing

- **Relative**

Untreated left main coronary stenosis or its equivalent
Asymptomatic severe aortic stenosis
Severe untreated arterial hypertension at rest (SBP >200mmHg; SBP >110 mmHg)
Significant tachyarrhythmias
High-degree atrioventricular block or other significant bradyarrhythmia
Thrombosis of the lower limb until treated
Severe abdominal aortic aneurysm
Recent stroke or transient ischemic attack
Advanced or complicated pregnancy
Psychiatric or mental impairment (inability to cooperate)
Uncorrected medical conditions, such as significant anemia, important electrolyte imbalance, and hyperthyroidism.

Dores, et al. Revista Portuguesa de Cardiologia 43 (2024) 525---536. https://doi.org/10.1016/j.repc.2024.01.005.

Standard CPET Equipments

Mask, vol sensor, gas analyzer tubing

BP monitor

ECG leads

Ergometers: cycle, treadmill, arm crank, etc)

Pulse oxymeter

Display exercise ECG

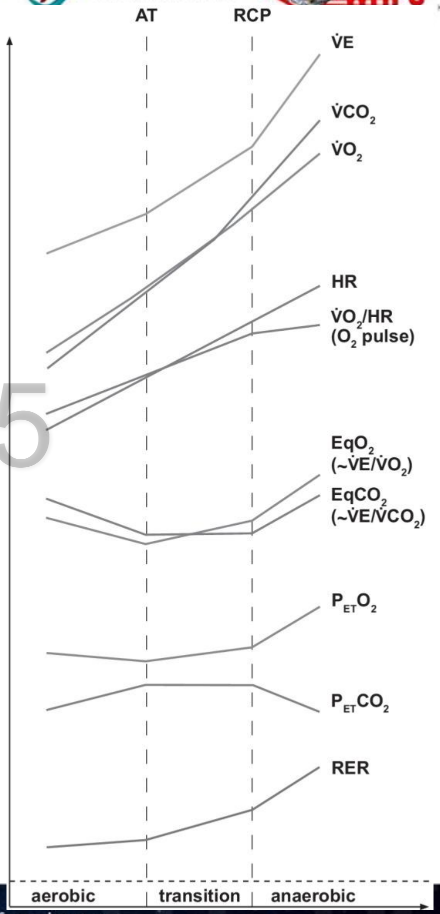
Display breath by breath data

Gas analyzer

Cardiopulmonary Response During Exercise

- Increase SBP
- Decrease SVR
- Increase muscle perfusion
- Increase in venous return to the heart facilitated by the calf muscle pump
- Increase CO, HR, SV
- Increase Minute ventilation (VE), Tidal volume (VT) & ventilatory frequency

Any limitation of these physiological cardiovascular or respiratory responses will eventually cause exercise intolerance and an overall decrease in exercise capacity.



Chambers et al. *BJA Education, 19(5): 158e164 (2019).* Datta, et al. Ann Thorac Med. 2015;10(2):77-86.

Box 7.3.5.1 Pretest considerations

- Patient consent and collaboration
- Protocol selection and explanation of test protocol
- History and clinical examination
- Assessment of comorbidities (e.g. orthopaedic limitations)
- Anthropometric measurements: weight, height, body mass index, body surface area
- Resting electrocardiogram, blood pressure, and oxygen saturations
- Pretest spirometry

Moderato, et al. The ESC Textbook of Heart Failure. Cardiopulmonary exercise testing. https://doi.org/10.1093/med/9780198891628.003.0038

Protocol

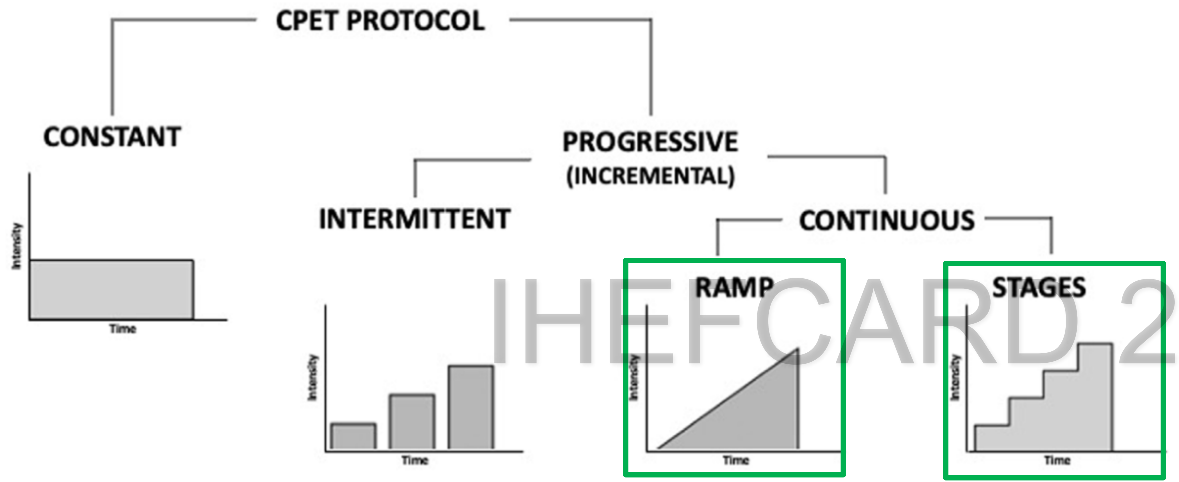


Table 15 Steep protocol															
	Stage (min)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Speed (mph)	1.5	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0	3.5	3.5	3.5	4.2	5.0
Speed (kph)	2.4	3.2	3.2	3.2	4.0	4.0	4.0	4.8	4.8	4.8	5.6	5.6	5.6	6.7	8.0
Incline (degrees)	0	0	1.5	3	3	5	7	7	9	11	11	13	16	16	16

- Incremental rate protocols (the work rate progressively increase) → Ramp protocols are preferred over conventional incremental tests (5 Watts/min, 7 Watts/min, 10 Watts/min, and 15Watts/min).

  or
- constant work rate protocols (remains constant during the test)
- The test should last between 8 and 12 min
- Warm-up for 1-3 min, Recovery phase at least 5 min

Albouaini, et al. (2007). Cardiopulmonary exercise testing and its application. *Postgraduate Medical Journal*, *83*(985), 675–682.
Dores, et al. Cardiopulmonary exercise testing in clinical practice: Principles, applications, and basic interpretation. Elsevier. 2024 April; 43: 525-536

Four Parts CPET Procedure

Unloaded phase

3 min (or less in severely impaired patients)
Unloaded or minimum load
Familiarisation with the ergometer and proper warm-up

→

Unloaded phase

3 min (or less in severely impaired patients)
Unloaded or minimum load
Familiarisation with the ergometer and proper warm-up

↓

Incremental phase

About 10 min (8–12 min)
Ramp or minute-by-minute increment
Standardised increment individually determined for each patient and disease

←

Recovery phase

2–3 min
Unloaded pedaling
Safety monitoring
Prolonged recording of heart rhythm and/or gas exchange during passive recovery, if indicated

Dores, et al. Revista Portuguesa de Cardiologia 43 (2024) 525---536. https://doi.org/10.1016/j.repc.2024.01.005.

Parameters Need to be Interpreted During CPET

Table 1. Common cardiopulmonary exercise testing variables with definitions and ranges.

Term/symbol	Definition	Units	Common ranges (l/min)
Oxygen uptake (VO_2)	Amount of oxygen taken up by the patient, measured at the mouth per min. Marker of the extent of aerobic energy (ATP) regeneration	l/min or weight-adjusted (l/min/kg weight)	0.2–4
Carbon dioxide output (VCO_2)	Amount of CO_2 exhaled by the patient, measured at the mouth, per min. CO_2 sources include metabolism, lactic acid buffering by bicarbonate and CO_2 stores	l/min	0.2–4
G_ELAT	Gas exchange value used to identify the point in the CPET where additional CO_2 production from bicarbonate buffering of lactic acidosis occurs. Refers to ventilatory threshold 1	l/min	>40% of the predicted VO_2max
Respiratory exchange ratio	CO_2 output divided by the O_2 uptake	Dimensionless	Usual 0.8 (rest) to 1.3 (end of exercise)
Minute ventilation (V_E)	Pulmonary ventilation per minute. Compare this with the maximum ventilatory capacity from the pulmonary function tests	l/min	5–150
Ventilatory equivalents for CO_2 and O_2 (V_E/VCO_2, V_E/VO_2)	V_E divided by VCO_2 or VO_2. Amount of ventilation required to take up 1 l of oxygen or excrete 1 l of CO_2	Dimensionless. Roughly an efficiency marker for the amount of ventilation required to exchange 1 l of gas (either CO_2 or O_2)	Normal <34 at G_ELAT
O_2 pulse	Oxygen uptake divided by the heart rate. The amount of oxygen extracted from the volume of blood ejected with each heart beat. O_2 pulse is equal to the stroke volume × the arterial–venous O_2 content difference	ml O_2 per beat	Normal 5–20 ml/beat

CPET: Cardiopulmonary exercise testing; G_ELAT: Gas exchange lactic acid threshold.
Definitions taken from [2].

Stringer. 2010. Expert Review of Respiratory Medicine, 4:2, 179-188

Target Values for Key CPET Variables (Cycle Ergometry)

Variable	Target value	Abnormal
Peak $\dot{V}O_2$ (exercise capacity)	≥ 85% based on $\dot{V}O_2$ pred. or > 20 mL O_2/min/kg	< 85%/ < 70%/ < 50% (mild/moderate/severe)
$\dot{V}O_2$/WR (aerobic capacity)	≥ 9–10 mL/min/watt[1]	≤ 8 mL/min/watt
$\dot{V}O_2$ at AT	≥ 40–80% pred. $\dot{V}O$ (usually 50–65% of peak $\dot{V}O_2$)	< 40%/ < 30%/ < 25% (mild/moderate/severe)
Blood pressure	Increase by 10 mmHg per 30 watts	Decrease, inadequate increase
O_2 pulse ($\dot{V}O_2$/HR)[2]	≥ 80%	< 70% pred. during peak exercise
Heart rate reserve (HRR)	≥ 85% pred. (< 15 bpm)	< 85% predicted (but wide range)
Breathing reserve (BR)	≥ 15–20% (or ≥ 11–15 L/min)	< 15–20% (or < 11–15 L/min)
Breathing frequency (BF)	≤ 50/min	≥ 60/min
$EqCO_2$ at AT	25–30 at AT, ≤ 40 after AT	≥ 35 at AT, > 40 after AT;
EqO_2 at AT	20–30 at AT, ≤ 40 after AT	≥ 35 at AT, > 40 after AT
$\dot{V}E/\dot{V}CO_2$ slope	25–30 (slightly lower than $EqCO_2$ at AT)	≥ 35 or < 20
RER	≥ 1.05 (ill) or ≥ 1.1 (healthy); > 1.1–1.5 in recovery phase; at rest: > 0.7, < 1.0	< 1 (peak exercise)
$PETCO_2$ (≈ $PACO_2$ ≈ $PaCO_2$)	> 35 mmHg (at rest); > 40 mmHg (during exercise)	< 33 mmHg (at rest), < 3 mmHg increase or > 50 mmHg (peak exercise)
$PETO_2$ (≈ PAO_2)	≥ 90 mmHg (at rest), 20–30 mmHg increase during exercise	Lack of increase or decrease during exercise
P(A-a) O_2[3]	20 mmHg (at rest); 30 mmHg (during exercise)	> 35 mmHg
P(a-ET) CO_2[4]	At rest: minimally positive; during exercise: slightly negative	> 5 mmHg

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9.

Identification of Abnormal Reaction Pattern(s)

Individual findings	Patient	Cardiovascular	Pulmonary vascular	Pulmonary	Lack of fitness
Reduced peak $\dot{V}O_2$		X	X	X	X
Low $\dot{V}O_2$ at AT		X	X	X	(X)
Steep HR increase relative to $\dot{V}O_2$ and shallow rise in O_2 pulse, respectively		X	X		X
Low $\dot{V}O_2$/WR slope during incremental exercise		X	X		
Elevated $\dot{V}E/\dot{V}CO_2$ slope or elevated $EqCO_2$ at AT		*	X	X	
Normal breathing reserve		X	X		X
ECG changes, inadequate BP behaviour		X			
Low peak HR				X	X
Low $PETCO_2$ or $PaCO_2$ at rest and/or decrease during exercise		*	X		
SpO_2 or PaO_2 decrease during exercise			X	(X)	
Low breathing reserve				X	
Abnormal breathing pattern**				X	

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9.

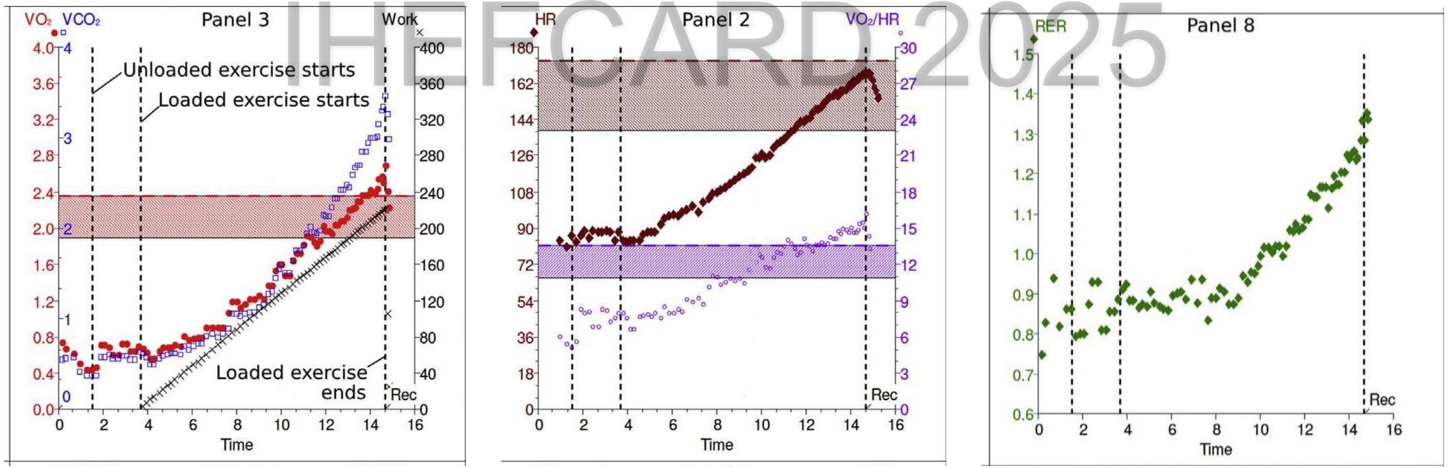
CPET Validity Check

- **Adequate minute ventilation?**
  - Implausible if the increase of VE does not follow an increase in work rate (mask leakage, anxiety, poor effort?)
  - Increase per 25 W needs VE 9 L + VE at rest (9L)
- **Adequate VO2 increase for a given work rate (VO2 increase/WR)?**
  - Implausible if the increase during early exercise (first 1–2 min) is too low (e.g., mask leakage)
  - VO2 increase/WR ≥ 10 mL/min/watt
- **Adequate respiratory exchange rate (RER)?**
  - Implausible if RER at rest is < 0.7 or RER at early exercise is > 1 (volitional or anticipatory hyperventilation, gas analyser malfunction, clogged sample tube, mask leakage)

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9

Is The Test Maximal in Terms of Effort?

- Achieving ≥80% of the predicted work
- Achieving an HR of ≥80% of the predicted maximum HR
- Achieving a RER (VCO_2/VO_2) ≥ 1.15
- Achieving Borg scale 17
- Achieving blood lactate > 8 mmol/L



Chambers et al. *BJA Education, 19(5): 158e164 (2019)*

9 Panels of CPET

- **Cardiovascular parameters (panel 1,2,3)**

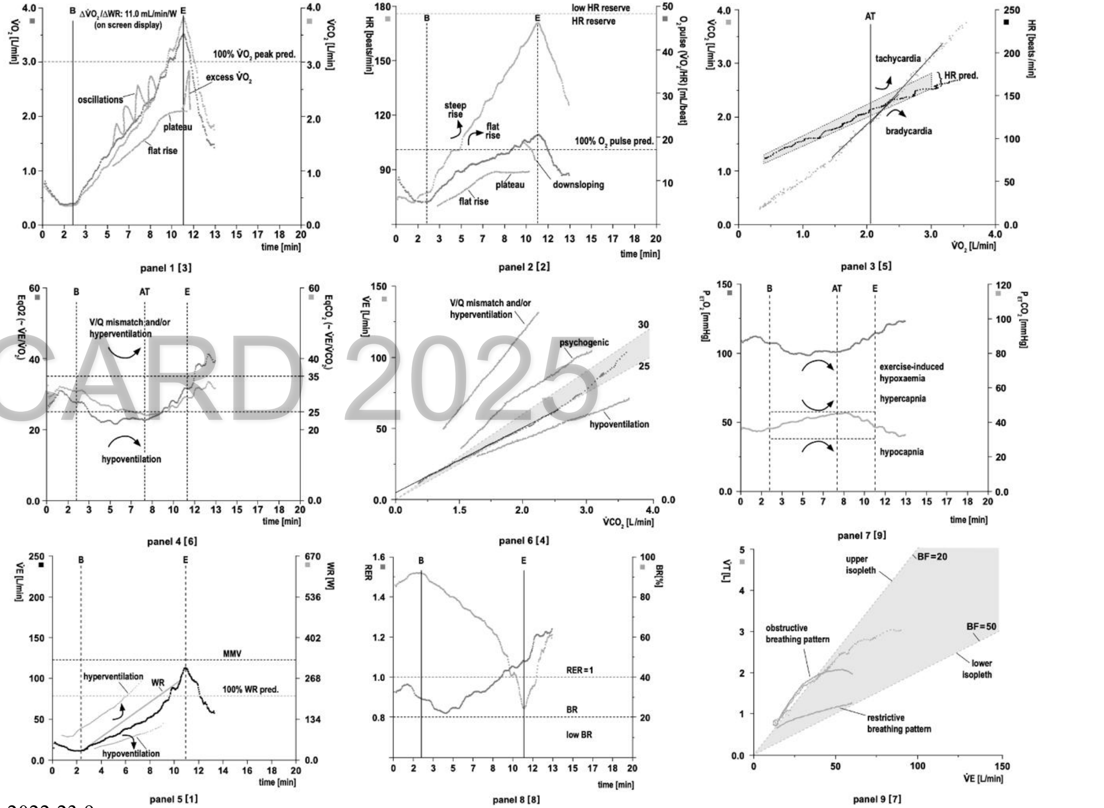
HR & O2 pulse against time
VO2, VCO2, & load against time
HR & VCO2 against VO2

- **Ventilatory aspect (panel 4,6,7)**

VE and load against time
VE against CO2
VT against VE

- **Gas exchange information (Panel 5,8,9)**

VE against CO2
VE/VO2 & VE/VCO2 against time
PETO2 & PETCO2 against time



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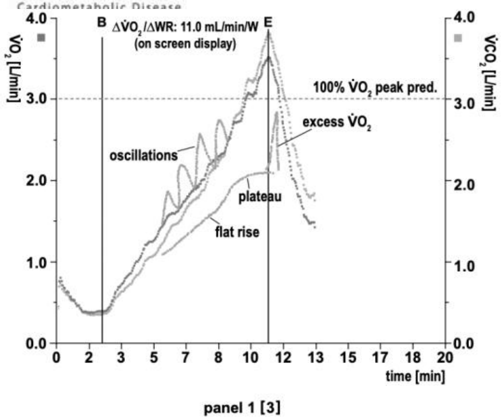
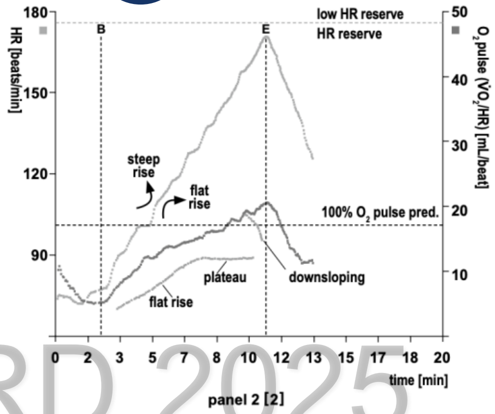
1



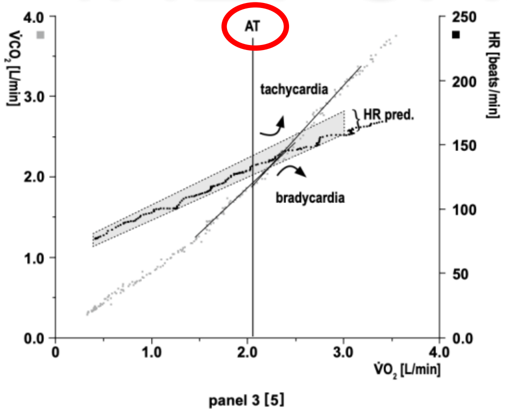
Panel 1: O2 uptake (VO2) and CO2 output (VCO2) vs. time plus relationship of peak VO2 and work rate (WR)

2



Panel 2: Relationship of HR and O2 pulse vs. time

3



Panel 3: Relationships of CO2 output (VCO2) (y-axis) and O2 uptake (VO2 (x-axis) and the relationship between HR and VO2

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9.

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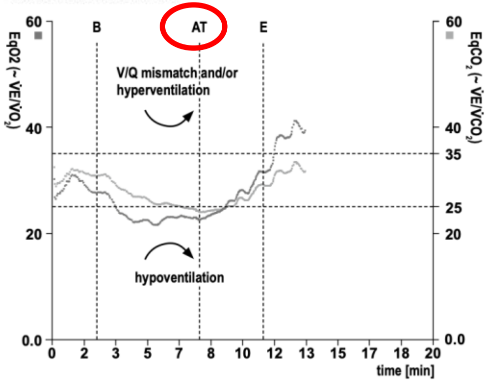
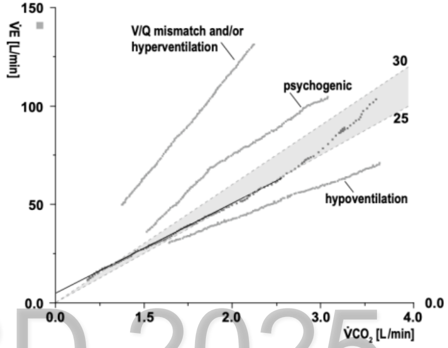


panel 4 [6]

Panel 4: The relationships of minute ventilation (VE) vs. O2 uptake (VO2) and vs. CO2 (VCO2) output (ventilatory equivalents)
as a function of time

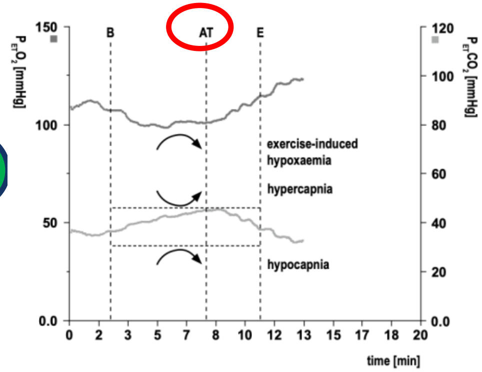
6



panel 6 [4]

Panel 6: The relationship of ventilation (VE) and CO2 production (VCO2): VE/VCO2 slope.

7



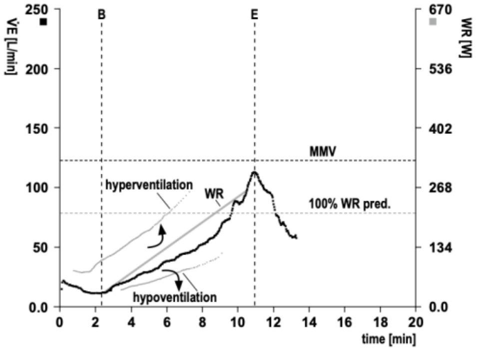
panel 7 [9]

Panel 7: End-tidal partial pressures of O2 (PETO2) and CO2 (PETCO2) vs. time

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9.

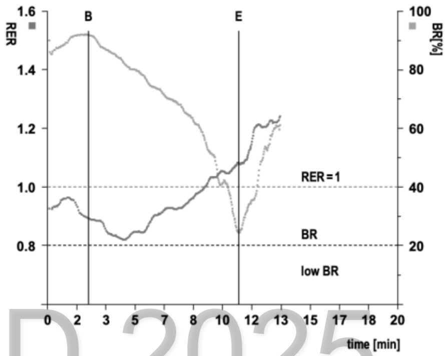
5



panel 5 [1]

Panel 5: Relationship between minute ventilation (VE) and work rate (WR) vs. time (x-axis).

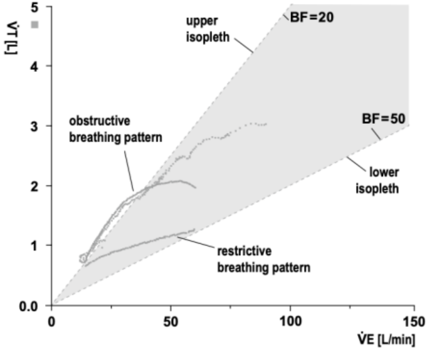
8



panel 8 [8]

Panel 8: Respiratory exchange rate (RER) and breathing reserve (BR).

9



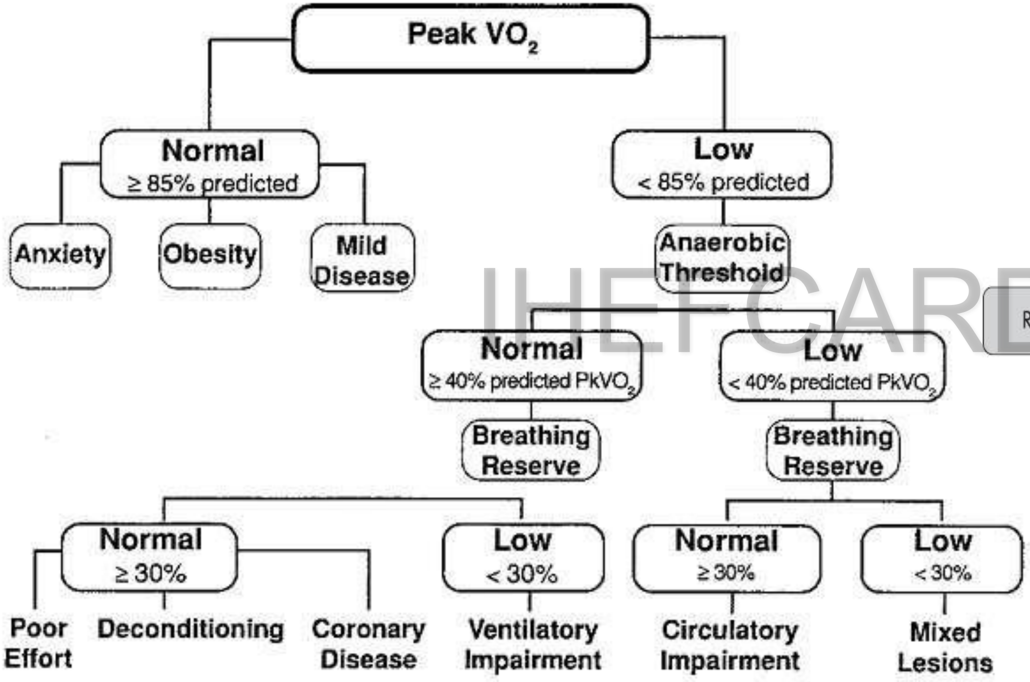
panel 9 [7]

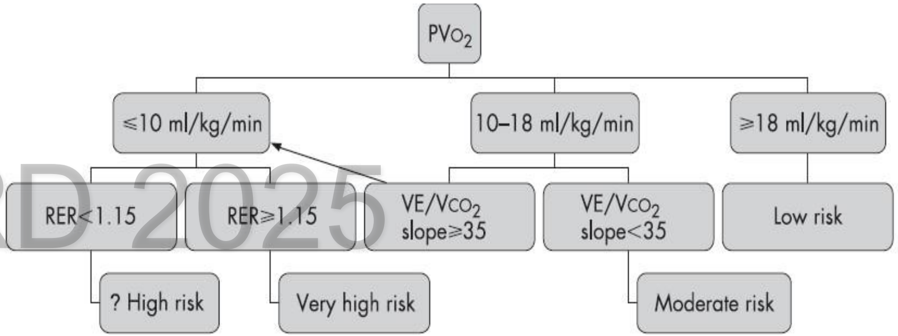
Panel 9: Breathing pattern. Relationships of tidal volume (VT) (y-axis), minute ventilation (VE) (x-axis) and breathing frequency (BF).

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9.

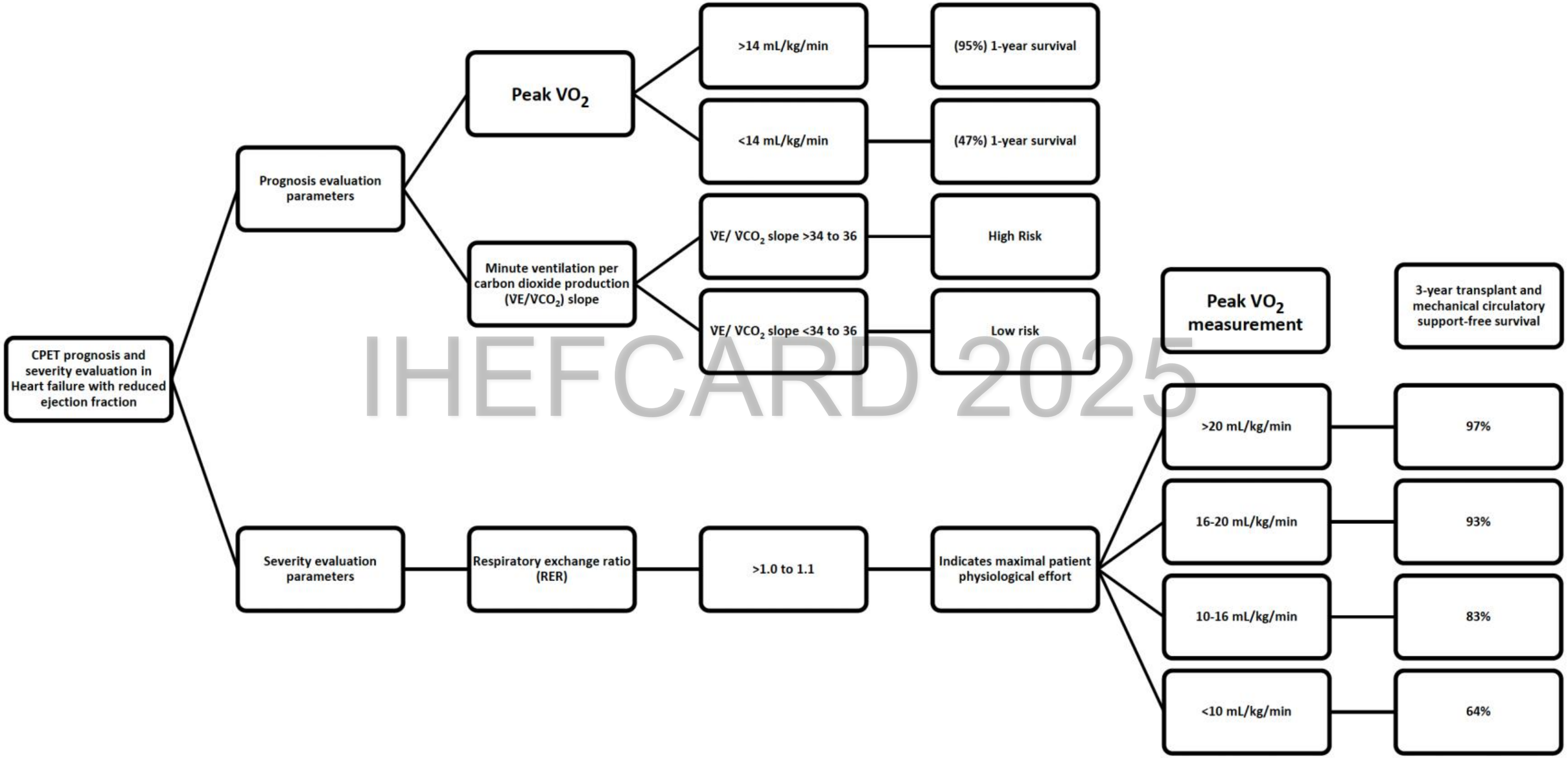
CPET Diagnostic Flowchart





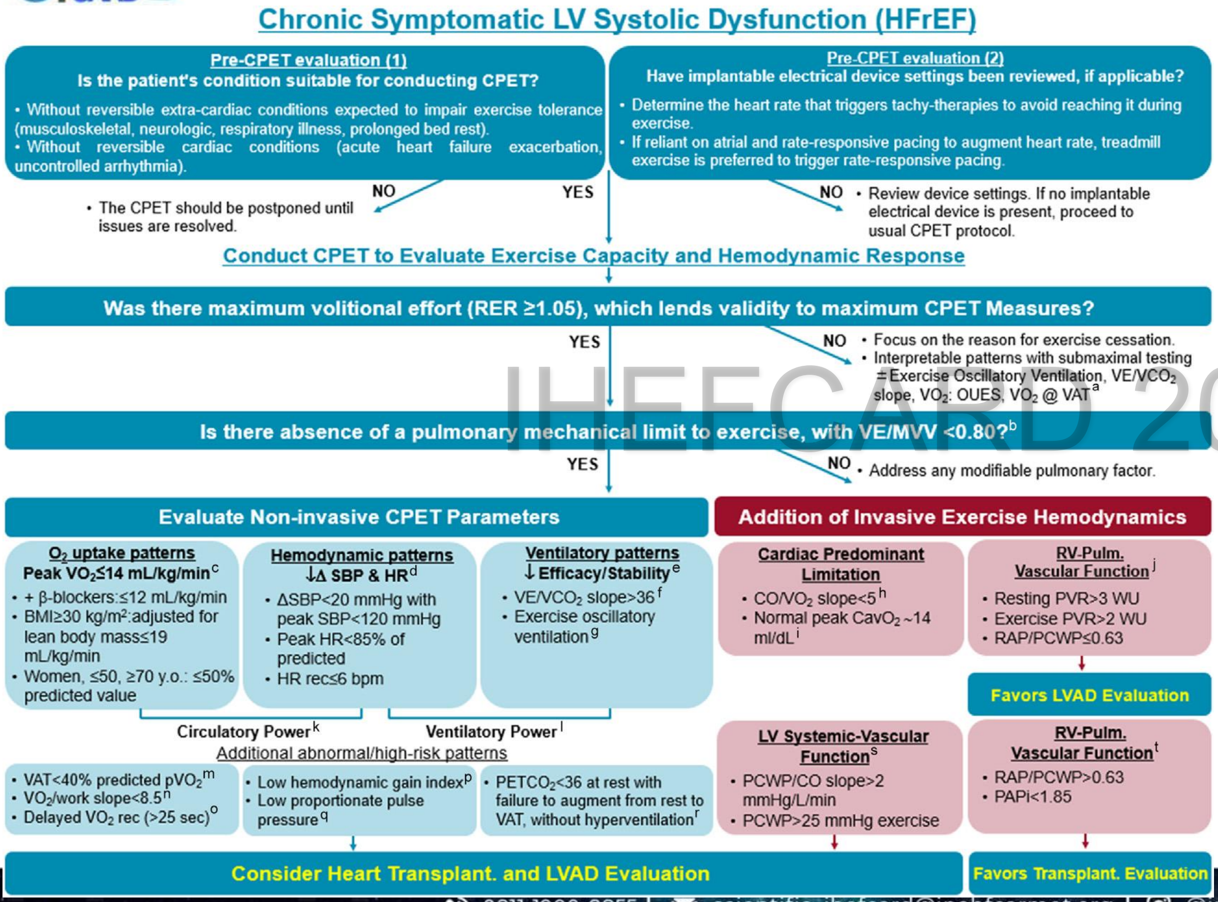
Milani et al. Circulation. 2004;110:e27-e31.

Prognostic Roles of CPET in HF Patients



Juarez, et al. J. Cardiovasc. Dev. Dis. 2024, 11, 70. https://doi.org/10.3390/jcdd11030070

The Role CPET in Advanced HF



Bossone, et al. Exercise Testing in Pulmonary Hypertension and Heart Failure. Vol.1. Elsevier. 2025

Conclusions

- CPET is a dynamic, non-invasive assessment of the cardiopulmonary system at rest and during exercise
- Using a systematic approach, the nine-panel plot can be used to identify limitations in cardiac and respiratory capacity
- The exercise is performed on a bicycle or treadmill, with use of a ramp protocol and wearing a nonrebreathing valve that measures O2 and CO2 gas and ventilation.
- During the test, ECG, BP, and oxygen saturations are recorded; the test should last 8–12 minutes.
- The VO2 is the most important parameter to evaluate disease severity, whereas other parameters such as VE/VCO2, VO2/HR, RER, and VE complete the picture.
- CPET is useful in HFrEF, HFmrEF, and HFpEF to determine severity of the disease, provide important prognostic information, facilitate exercise prescription, and assess the efficacy of new drugs and devices.
- In Advanced-HF, CPET-derived parameters enable clinicians tomore accurately assess risk, guide the selection of candidates for advanced therapies such as heart transplantation and LVAD implantation,

Thank you

Indications for exercise termination!

Chest pain suggestive of ischaemia
Ischaemic ECG changes
Complex ectopy
Second- or third-degree heart block
Fall in systolic pressure >20 mm Hg from the highest value during the test
Hypertension (>250 mm Hg systolic; >120 mm Hg diastolic)
Severe desaturation: $SpO_2 \leqslant 80\%$ when accompanied by symptoms and signs of severe hypoxaemia
Sudden pallor
Loss of coordination
Dizziness or faintness
Signs of respiratory failure
Mental confusion

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

Criteria for determining if effort is maximal

- Achieves a plateau in VO_2 (indicating the patient has reached their VO_{2max}).
- Heart rate reaches 90% of predicted or heart rate reserve is ≤15 beats/min
- There is evidence of ventilation limitation (breathing reserve <15%, expiratory flow limitation, also consider significant increase in end-expiratory lung volume).
- mBorg for leg fatigue or breathlessness is ≥9/10.
- Peak exercise blood lactate concentration ≥8 mmol/L (if measured).

Test termination by patient

- Dyspnoea.
- Leg fatigue.
- Chest pain.
- Pain/physical discomfort.
- Dizziness.
- Saddle discomfort.
- Palpitations

Pritchard, A., Burns, P., Correia, J., Jamieson, P., Moxon, P., Purvis, J., Thomas, M., Tighe, H., & Sylvester, K. P. (2021). ARTP statement on cardiopulmonary exercise testing 2021. *BMJ Open Respiratory Research*, *8*(1), e001121. https://doi.org/10.1136/bmjresp-2021-001121

Comparison Between Cycle and Treadmill Ergometers

Feature	Cycle	Treadmill
Familiarity with exercise	Lower	Higher
Predicted VO_2	Lower	Higher
Quantification of external work	Yes	With some algorithms
Quality of ECG monitoring	Good	With artifacts
BP measurement	Easier	Harder
Ease to take arterial blood gas	Easier	Harder
Muscles in lower limbs	Dependent	Less dependent
Patients with pacemakers, ICDs, or CRTs	Less appropriate	More appropriate
Safety	Higher	Lower (risk of falls)
Size of equipment	Lower	Higher
Mobility of equipment	Higher	Lower
Costs	Lower	Higher

CRT: cardiac resynchronization therapy; ICD: implanted cardioverter-defibrillator.

Dores, et al. Revista Portuguesa de Cardiologia 43 (2024) 525---536. https://doi.org/10.1016/j.repc.2024.01.005.

Prognostic Roles of CPET (1)

- **Peak VO2**
  - Peak VO2 > 14 mL/kg/min was a predictor of event free-survival in CVD patients
  - Peak VO2 < 14 mL/kg/min higher morbidity & mortality in HF patients
  - When AT can't be identified, peak VO2 < 10 ml/kg/min shows a high risk of events in CVD patients while patients with peak VO2 > 18 ml/kg/min have a good prognosis
- **AT**
  - HF Patients with peak $\dot{V}O_2$ of ≤14 mL/kg per minute had a >3-fold-increased risk (OR=3.4; CI, 1.3 to 9.1), with $\dot{V}O_2$ AT <11 mL/min per kg or $\dot{V}_E$ versus $\dot{V}CO_2$ slope >34 a 5-fold increased risk for early death (OR=5.3; CI, 1.5 to 19.0; OR=4.8; CI, 1.7 to 13.8, respectively).
- **VE/CO2 slope**
  - HF patients with both $\dot{V}O_2$AT <11 mL/kg per minute and $\dot{V}_E$ versus $\dot{V}CO_2$ slope >34, the risk of early death was 10-fold higher (OR=9.6; CI, 2.1 to 44.7)

PERKI. Pedoman Uji Latih Jantung: Prosedur dan Interpretasi 2016

Prognostic Roles of CPET (2)

- **Chronotropic incompetence** = (max HR – baseline HR) / (max predicted HR by age – baseline HR) x 100%
  - Chronotropic index does not reach 80% or does not reach 62% for patients using beta blockers
  - Heart rate does not reach 85% of the maximum predicted heart rate by age (220-age).
  - Heart rate does not reach 120 x/minute with adequate EST
- **Heart rate recovery**
  - HRR 1: ≥ 12
  - HRR 2: ≥ 22
- **Hemodynamic response**
  - Exercise-induced hypertension: Increase SBP ≥ 210 mmHg, Increase DBP > 10 mmHg, Increase SBP > 40 mmHg per stage of the Bruce protocol
  - Exercise-induced hypotension: Decrease SBP ≥ 10 mmHg

PERKI. Pedoman Uji Latih Jantung: Prosedur dan Interpretasi 2016

Prognostic Roles of CPET (3)

- **Ventricular arrhythmia**
  - Frequent
  - Multifocal
  - Couplet
  - VT
  - VF
- **Duke Treadmill Score**
  - = EST duration – 5 x ST segmen depression – 4 x angina score
    > 5 = low risk; -10 – 4 = moderate risk; < - 11 = high risk

PERKI. Pedoman Uji Latih Jantung: Prosedur dan Interpretasi 2016

CPET Report

1. **Metabolics**
   - includes oxygen uptake (VO_2)
   - Carbon dioxide excretion (VCO_2)
   - Respiratory exchange ratio (RER)

2. **Cardiac**
   - HR
   - BP

3. **Ventilation**
   - Minute ventilation
   - RR
   - Dead space ventilation

4. **Gas Exchange**
   - FiO_2
   - SpO_2
   - pH
   - $PaCO_2$
   - PaO_2
   - arterial–alveolar oxygen difference pressure
   - Lactate levels

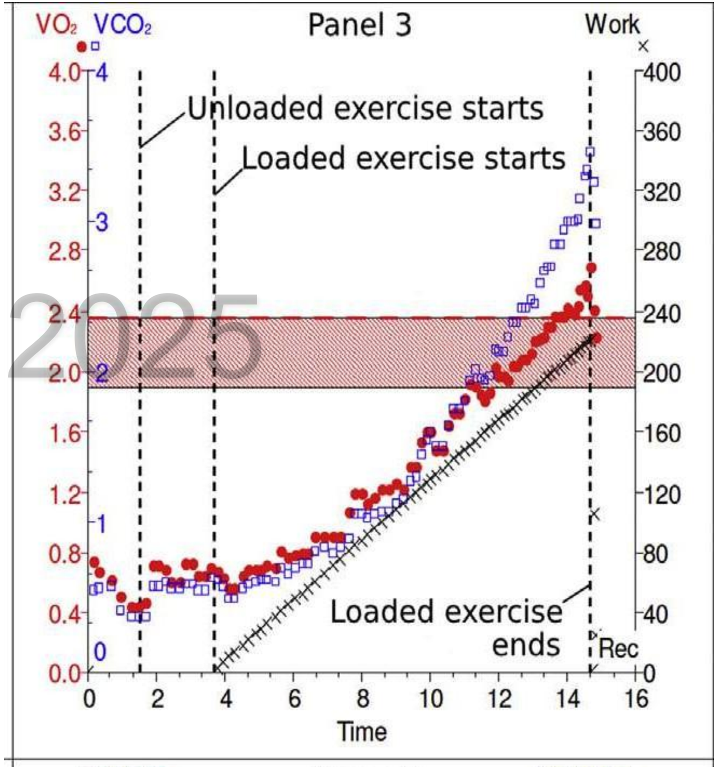
CPET provides invaluable diagnostic and prognostic information about clinical disorders associated with exercise intolerance

Juarez, et al. J. Cardiovasc. Dev. Dis. 2024, 11, 70. https://doi.org/10.3390/jcdd11030070

What is the VO2 Peak in Panel 3?

- VO2 peak → 2.7 L/min ~ weighed 71 kg, equates to a VO2peak of 38 ml O2/kg/min

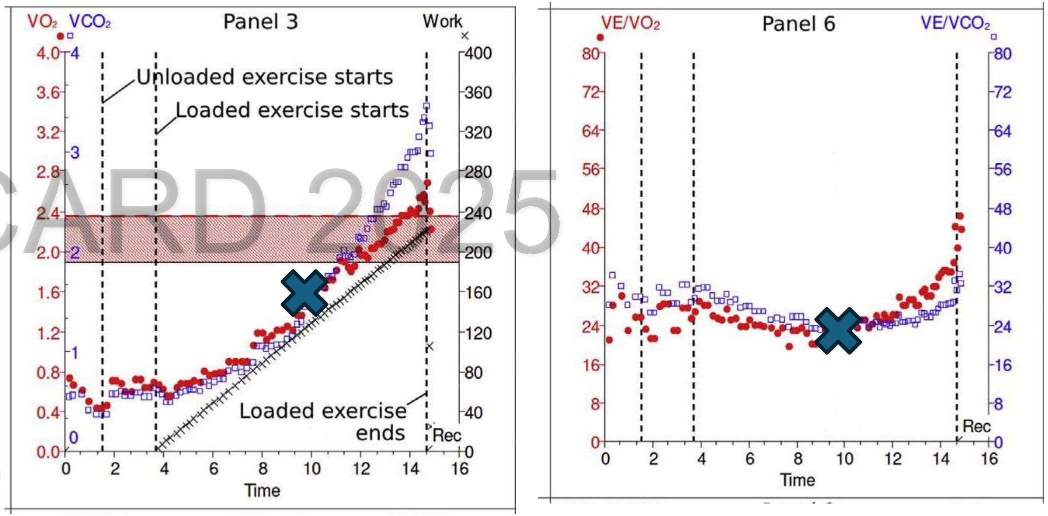
- **Is the VO2 - work relationship normal?**
  - As resistance is added to the cycle ergometer,VO2 normally increases at 10 ml O2/min/W



Chambers et al. *BJA Education, 19(5): 158e164 (2019)*

Can I Determine AT in This Test?

- VCO2 increases disproportionately when compared with VO2
- VE/VO2 starts to increase (lowest point)
- VE/VCO2 remains relatively constant or decreases slightly



- **If so, what is the VO2 at AT?**

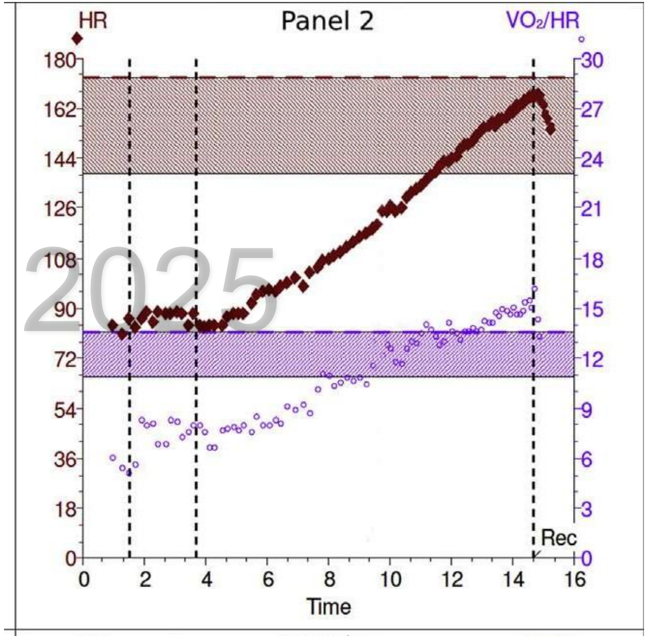
- AT occurs at VO2 of 1.45 L/min
- In this 71 kg patient, AT ~ 20.4 ml O2/kg/min

Chambers et al. *BJA Education, 19(5): 158e164 (2019)*

Was the HR Response Normal?

- HR increase linearly with exercise intensity
- 1 METS ~ + 10 bpm

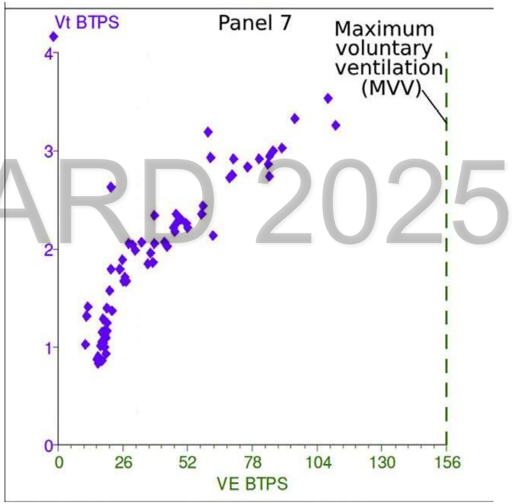
- **Does the oxygen pulse increase with exercise?**
  - The oxygen pulse is the VO2/HR, and represents the product of the stroke volume and the arterial-venous oxygen difference

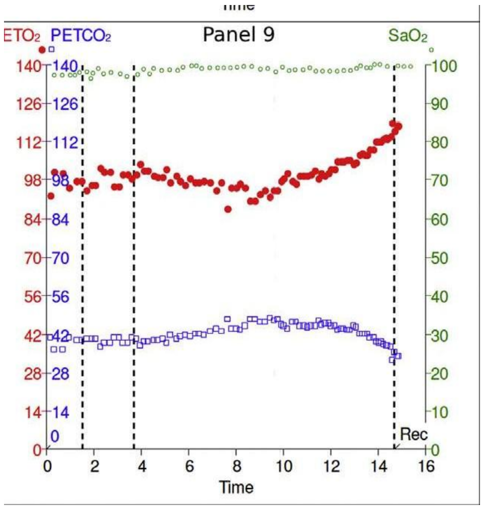


Chambers et al. *BJA Education, 19(5): 158e164 (2019)*

Is There any Ventilatory Limitation?

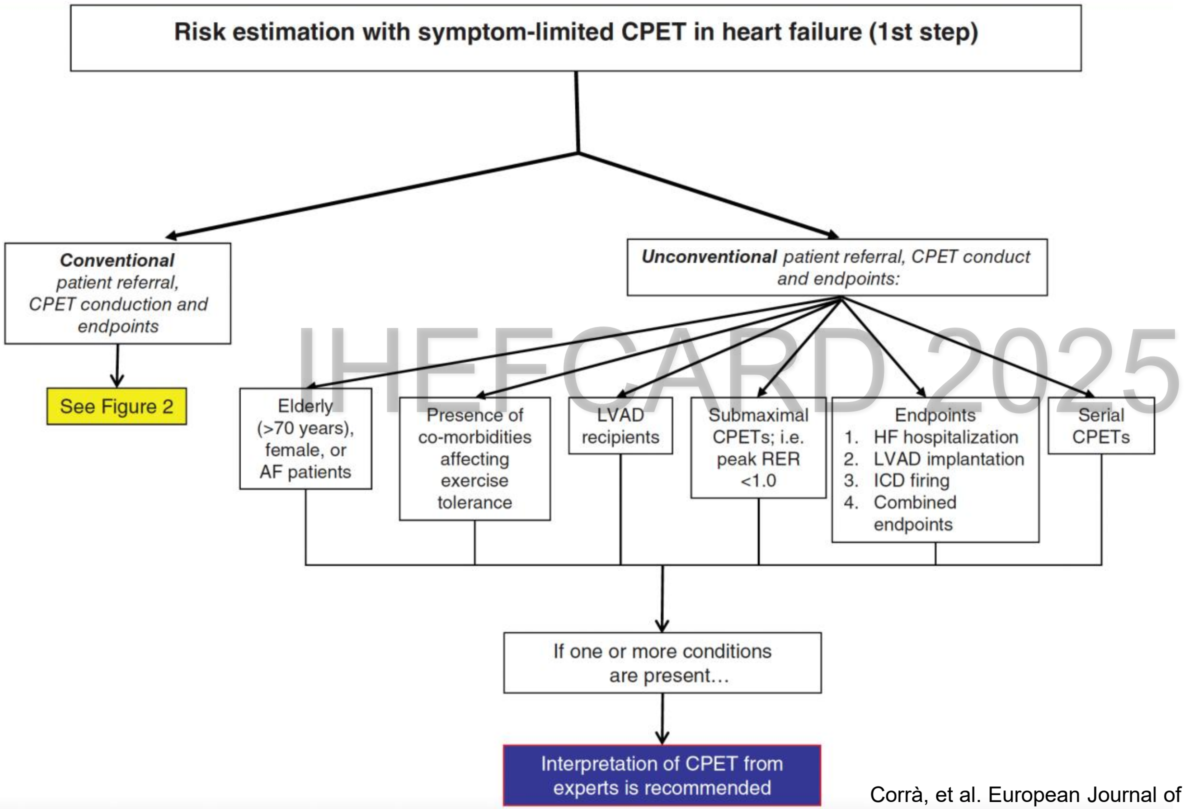
- Measure forced expiratory volume in first second (FEV1) & forced vital capacity (FVC) using static spirometry
- Maximum voluntary ventilation (MVV) is a measure of the max volume of air that can be inhaled and exhaled within 1 min.
- MVV = FEV1 x 40
- Max VE normal <u><</u>80% MVV
- Ventilatory reserve = MVV – VEmax > 11 L
- SpO2 should remain <u>></u>95% throughout the test





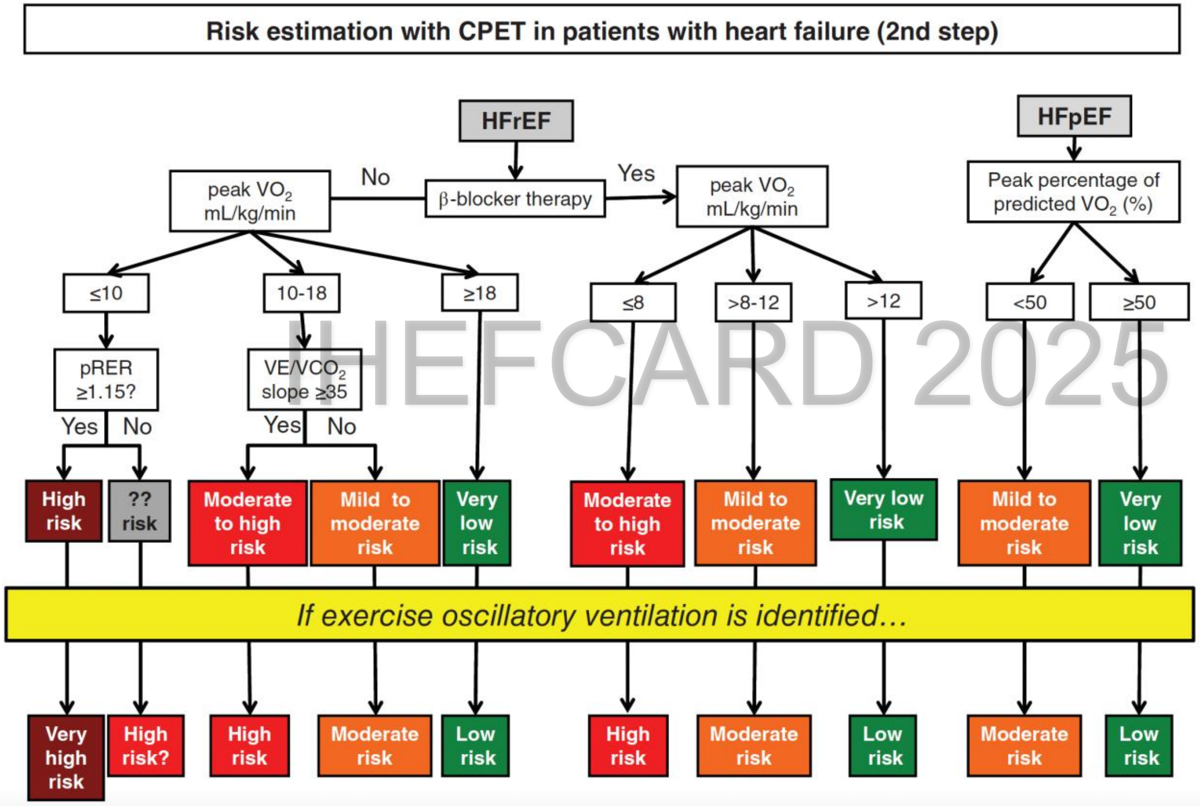
Chambers et al. *BJA Education, 19(5): 158e164 (2019)*

Risk Estimation with Symptom-limited CPET in HF



Corrà, et al. European Journal of Heart Failure (2018) 20, 3–15. doi:10.1002/ejhf.979

Risk Estimation with Symptom-limited CPET in HF



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RECENT FIELDS OF APPLICATION

Respiratory Medicine

- Obstructive and restrictive ventilatory disorders
- Interstitial disorders
- Pulmonary hypertension
- Diffusion and distribution disorders
- Flow limitations
- Exercise related dyspnea of unknown origin
- Suspected limited exercise capacity due to circulatory or pulmonary vascular disorders
- Suspected exercise-induced asthma
- Trending for subtle respiratory disease changes
- Pre-operative risk assessment for lung transplant patients

Cardiology

- Coronary heart disease
- Cardiomyopathy
- Heart disease, valvular heart failure
- Congenital cardiac defects
- Pre-operative risk assessment for heart transplant patients
- Cardiac insufficiency

Sports Medicine / Science

- Measurement of physical exercise capacity
- Threshold determination
- Training management
- Quantification of training success

Occupational Medicine

- Exercise-related career proficiency tests
- Determining the degree of disability or work limitation/inability
- Fitness checkups (high altitude, air travel, tropical climate, diving)

Intensive Care

- Pre-operative risk assessment
- Nutrition control (adjusting parenteral nutrition of intensive care patients)

Rehabilitation

- Optimizing rehabilitative measures
- Assessing and documenting rehabilitative and therapeutic progress

Nutrition

- Determination of Resting Energy Expenditure
- Energy Expenditure during Exercise
- Substrate utilization
- Nutritional counselling
- Dietary advice

Special Edition Cardiopulmonary Exercise Testing, 2017

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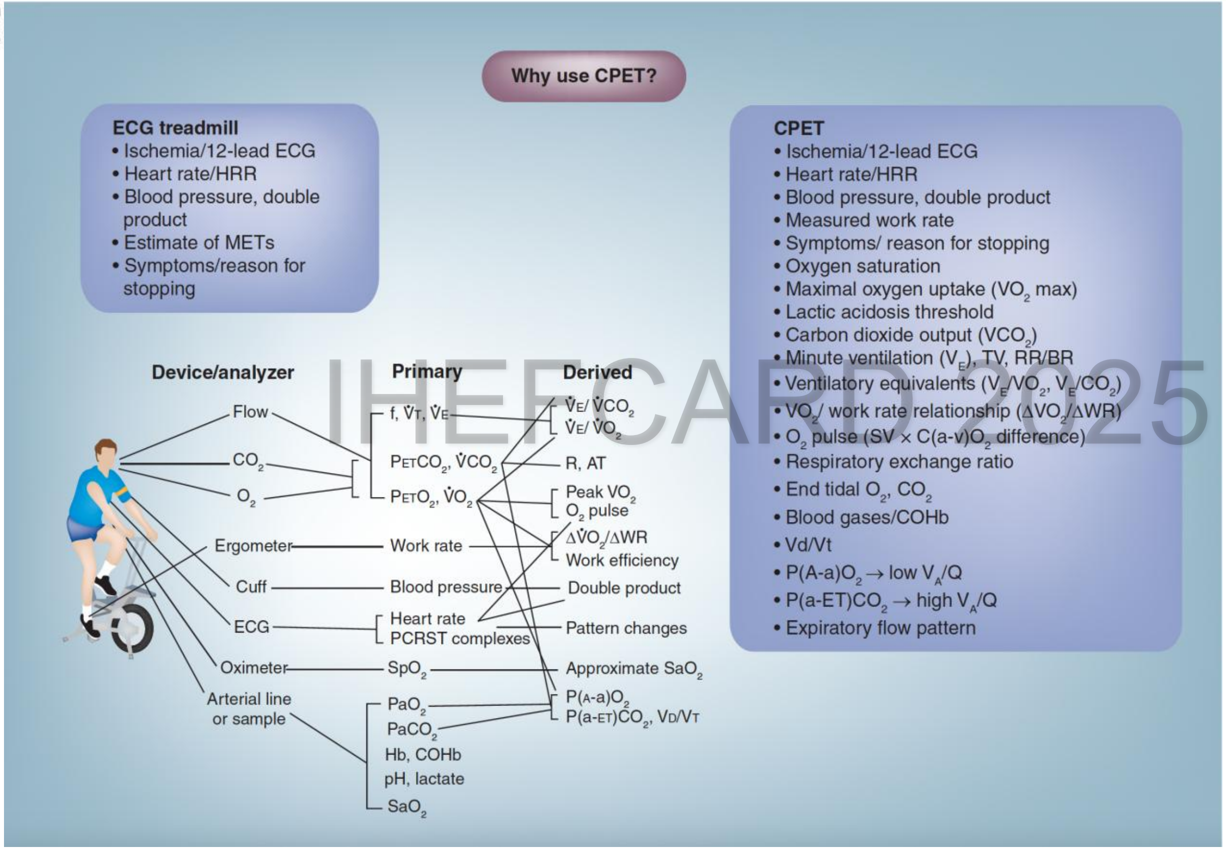

Multiple Advantages of Cardiopulmonary Exercise Testing Over ECG Treadmill Exercise Testing

Stringer. 2010. Expert Review of Respiratory Medicine, 4:2, 179-188

Indication

- Evaluation of exercise tolerance
- Determination of functional impairment or capacity (peak VO2)
- Determination of exercise-limiting factors and pathophysiological mechanisms
- Evaluation of undiagnosed exercise intolerance
- Assessing the contribution of cardiac and pulmonary aetiology in coexisting disease
- Symptoms disproportionate to resting pulmonary and cardiac tests
- Unexplained dyspnoea when initial cardiopulmonary testing is non-diagnostic (or standard pulmonary function test is not diagnostic)
- 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
- Chronic obstructive pulmonary disease
- Establishing exercise limitation(s) and assessing other potential contributing factors, especially occult heart disease (ischaemia)
- Determination of magnitude of hypoxaemia and for oxygen 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 hypoxaemia and for oxygen 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
- Clinically relevant research purpose
- Lung resection surgery
- Elderly patients undergoing major abdominal surgery
- Lung volume resection surgery for emphysema (currently investigational)
- Exercise evaluation and prescription for pulmonary rehabilitation
- Evaluation for impairment–disability
- Evaluation for lung and heart–lung transplantation

Indication

- Determining the cause(s) and severity of exertional dyspnoea, exercise intolerance or exercise-induced hypoxaemia;
- Assessing exercise capacity and estimating prognosis in various disease states (including chronic heart failure);
- Assessing perisurgical and postsurgical complication risk (e.g., for thoracic, heart and visceral surgery; surgical and bronchoscopic lung volume reduction);
- Early detection and risk stratification of cardiovascular, pulmonary vascular and lung diseases, and musculoskeletal disorders;
- Measuring the response to treatment (e.g., drugs, rehabilitation);
- Guiding and monitoring individual physical training in rehabilitation (e.g., cardiac, pulmonary), and in preventive and sports medicine;
- Evaluating the limitations/impairments of individual maximum and continuous exercise capacity in occupational medicine.

Glaab T, Taube C. Practical guide to cardiopulmonary exercise testing in adults. Respir Res. 2022;23:9

Measurement	Heart failure	COPD	ILD	Pulmonary vascular disease	Obesity	Deconditioned
PVO_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/VCO_2 at VAT	↑	↑	↑	↑	N	N
VD/VAT	↑	↑	↑	↑	N	N
PaO_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; PVO_2, peak oxygen uptake; VAT, ventilatory anaerobic threshold; VD/VAT, ratio of physiological dead space to tidal volume; VE, minute ventilation; VCO_2, carbon dioxide output.
Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.[1]

Albouaini, K., Egred, M., Alahmar, A., & Wright, D. J. (2007). Cardiopulmonary exercise testing and its application. *Postgraduate Medical Journal*, *83*(985), 675–682. https://doi.org/10.1136/hrt.2007.121558