Full interpretation of CPET data with the nine-panel plot, and the identification of subtle condition specific abnormalities, requires expertise and training. Therefore the aim of this flash card is to give clinicians a broad overview of the basic understanding of CPET data.

Cardiopulmonary Exercise Testing (CPET)

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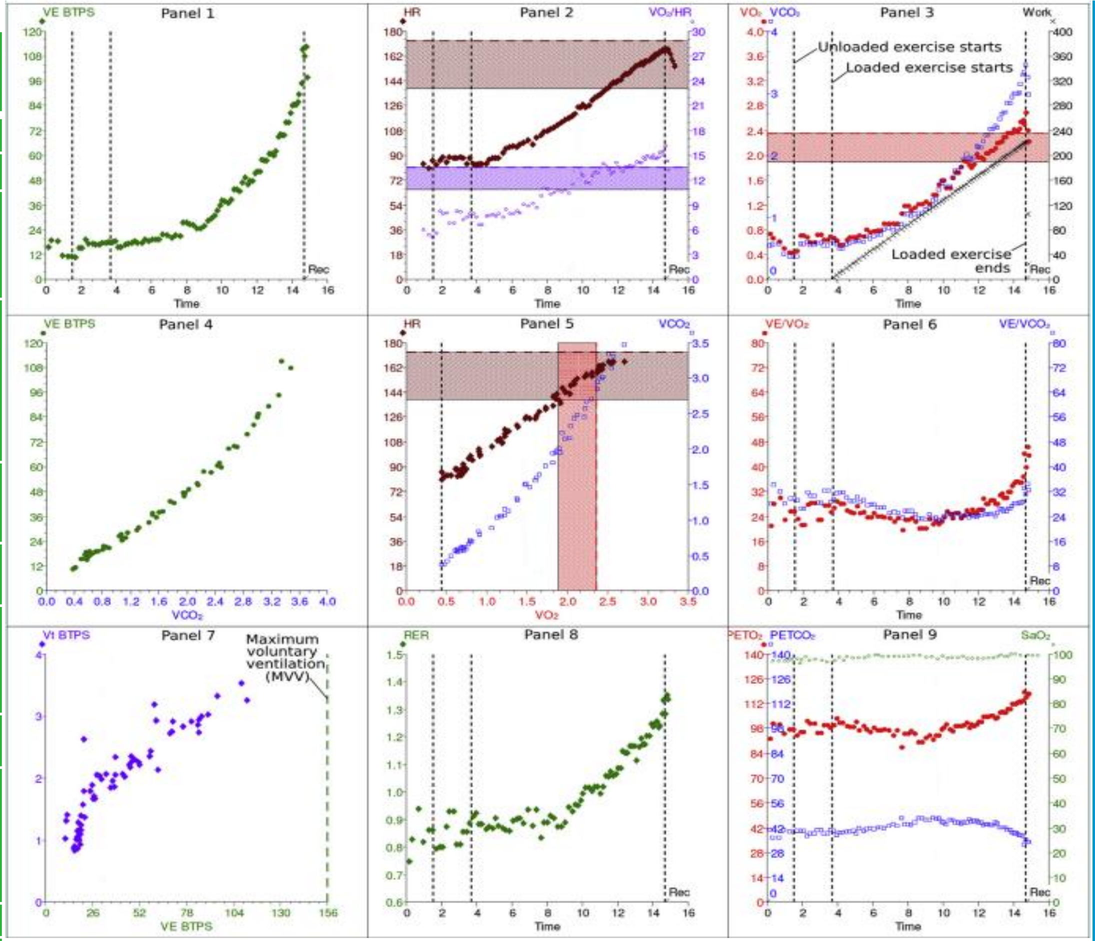
CPET is the gold standard method used to objectively assess functional capacity. It allows clinicians to define the pathophysiological limitation to exercise. This is a non-invasive maximal exercise test, which uses gas exchange analysis to provide information about the respiratory, cardiovascular, metabolic and muscular responses to physical activity.

CPET variables	Definitions	Normal values at peak exercise
VO_2	Oxygen consumption	
VCO_2	Carbon dioxide production	
MVV	Maximum voluntary ventilation (FEV_1 x 40.): the volume of air breathed in and out per minute at rest, with maximal effort.	
peakVO_2	Maximum O_2 consumption: the gold standard parameter in the assessment of cardiovascular fitness. Reported as mL/min/kg or as a percentage of predicted value normalised to sex, age, weight and height.	>80% of predicted
AT	Anaerobic threshold: represents the point when anaerobic metabolism sets in.	>40% of pred. VO_2max.
RER	The respiratory exchange ratio (VCO_2/VO_2): determines whether the test is maximal.	>1.15
VO_2/HR	The ratio of VO_2 to HR expressed as ml of O_2 consumed per heartbeat. It is a surrogate for stroke volume. Also known as O_2 Pulse.	>80% predicted
Max HR	220 – age.	>90% predicted
HR reserve	The difference between max. predicted HR and the observed maximum HR during CPET. It can identify the presence of chronotropic incompetence.	≥85% of Pred (<15bpm).
HR recovery	Max recorded HR – HR at 1 min post exercise.	>12 beats
V_E	Maximal ventilation, reflects ventilatory demand.	<85% of MVV
Ventilatory reserve (VR)	VR = (MVV –Max Ve) ÷ MVV x 100. A VR <15% indicates a ventilatory limitation to exercise.	>20-40%
VE/VCO_2 ($VeqCO_2$)	The ratio between pulmonary ventilation and CO_2 production. It is a marker of ventilatory efficiency.	25-30
$PETCO_2$	End-tidal CO_2 partial pressure reflects ventilation-perfusion within the pulmonary system.	>36mmHg
VO_2/WR	O_2 consumption to work rate relationship at peak work rate. Values below the normal range indicate abnormalities with oxygen delivery.	>9 mL/min/W



The traditional Wasserman nine panel plot above allows us to approach CPET interpretation systematically, analysing key variables and their relationships. Panels 1, 2 & 3 display information regarding cardiovascular response & oxygen transport. Panels 4, 6 & 7 are for pulmonary gas exchange and V/Q mismatch. Panels 5, 8 & 9 can indicate whether there is a limitation to ventilatory capacity.

To accurately interpret CPET, It is crucial to understand the Fick Equation:

$$\text{At rest} = VO_2 = (SV \times HR) \times (Ca_{o2} - Cv_{o2})$$

$$\text{At maximal exercise} = VO_2max = (SVmax \times HRmax) \times (Ca_{o2}max - Cv_{o2}max)$$

Step 1: *Determine whether the test was conducted at maximal effort.* Did the patient achieve an RER >1.15 (panel 8), Was maximum HR >90% predicted or maximum work load reached? (panel 2). Find out why the patient stopped exercising, e.g. leg fatigue, SOB etc.

Step 2: *Determine whether exercise capacity is reduced.* Analyse panel 3 to determine the peak VO_2 i.e. the highest VO_2 achieved at the point when exercise was terminated. A low peak VO_2 indicates the presence of exercise intolerance. A peak VO_2 <80% of predicted is abnormal. This is associated with increased risk of post-operative complications and mortality. It is also a useful predictor of survival rates in heart failure.

Step 3: Determine the presence of an oxygen delivery abnormality. Assess the VO_2/WR (panel 3). VO_2 should increase parallel to WR and VO_2/WR should not be < 9 mL/min/W.

Step 4: Determine when AT occurred. See panels 5 & 6. At the start of exercise, VO_2 & VCO_2 increase at the same rate until there is an abrupt increase in VCO_2. In panel 5 this point is identified via the V-slope method where there is a sudden change observed in the VCO_2 gradient. In panel 6 its identified at the point were VE/VCO_2 increases while VE/O_2 stays relatively constant. These points indicate when anaerobic metabolism sets in, known as AT. It represents the point when the demand of the working muscles exceeds the ability of the cardiopulmonary system to supply O_2. This causes a switch to anaerobic metabolism which in turn produces lactic acid that gets buffered by circulating bicarbonate, yielding more CO_2 production. The early onset of AT is deemed to occur at <40% of the predicted peak VO_2 and is associated with poor morbidity and mortality postoperatively.

Step 5: Determine whether there is a cardiac limitation to exercise. See panel 2. A linear increase in HR to the increasing exercise intensity should be observed in healthy patients. To relate back to the Fick equation: cardiac output = HR x SV. VO_2/HR data <80% of predicted would indicate a cardiac limitation to exercise as VO_2/HR is a surrogate of SV. A HR reserve <85 % of Pred. (>15bpm) would indicate the presence of chronotropic incompetence i.e. a cardiac limitation to exercise. Heart rate recovery 1 minute post exercise is another useful marker of chronotropic health. An abnormal HRR (<12bpm) indicates significantly reduced parasympathetic tone. It is an indicator of increased mortality.

Step 6: Determine whether there is a ventilatory limitation to exercise. See panel 7. In healthy patients exercise is never limited by ventilatory capacity as they should have a substantial capacity. However if a patient achieves a V_E >85% of MMV (or VR <15%) they have breached this celling, confirming a ventilatory limitation to exercise. This hallmark abnormality is observed in patients with respiratory conditions such as COPD or IPF. During CPET V_E is tightly coupled with VCO_2. **VE/VCO_2** allows us to elevate this relationship and is a marker of ventilatory efficiency. High VE/VCO_2 data >30 is a physiological abnormality observed in heart failure, pulmonary arterial hypertension (PAH), interstitial lung disease and COPD. VE/VCO_2 has key prognostic role in these conditions and is arguably the most important ventilatory parameter.

$PETCO_2$ (panel 9) reflects the ventilation-perfusion of the pulmonary system. A reduced $PETCO_2$ (<33mmHg at rest, <36mmHg during exercise) indicates a state of poor perfusion, or more precisely an increased ventilation/perfusion mismatch (V/Q mismatch). It inversely correlates with cardiac output, and is reduced in conditions of circulatory impairment such as PAH or heart failure.