CPET Interpretation Cheat Sheet

The first question that should be asked when reading an exercise test is 'what was the purpose of the test'?

- Maximum safe exercise capacity for Pulmonary Rehab?
- Rule in/rule out exercise-induced bronchospasm?
- Pre-operative assessment?
- Dyspnea of uncertain etiology?
- Is the primary limitation to exercise pulmonary or cardiac?
- Is deconditioning suspected?

The answer will determine what test data should have the most attention and will help to shape the interpretation. Exercise test interpretation consists of two parts: descriptive and interpretive. The descriptive part consists of the following categories:

- Spirometry/PFT Results
- Ventilatory response
- Gas exchange
- Cardiovascular response
- Electrocardiographic response.

The interpretation is a summary of the pertinent elements of the descriptions with a conclusion and, ideally, a diagnosis. When reading the results of an exercise, a series of questions should be posed:

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Patient's demographics/medications/breath and heart sounds

How old is the patient?	Maximum oxygen consumption, maximum minute ventilation and maximum heart rate all decline with age.
Is the patient overweight or underweight?	Obesity by itself does not necessarily decrease a patient's maximum oxygen consumption in liters/min (although ml/kg/min will be reduced), but because of increased energy expenditure there will be a higher VO2 for a given workload. Individuals with a low BMI will have a reduced muscle mass which may decrease their maximum VO2. VO2 when expressed as ml/kg/min can appear high.
Is the patient anemic?	Anemia reduces the oxygen carrying capacity of the blood. Anaerobic threshold is likely to be lowered for this reason. Dyspnea can occur because of the metabolic acidosis that accompanies the early AT. Increased carboxyhemoglobin levels have a similar effect, but this measurement is rarely available before testing. It can be inferred, however, from the patient's smoking history.
What were the patient's medications?	These often give valuable clues to the patient's medical conditions. Beta blockers can limit heart rate increases during testing. Bronchodilators can limit exercise-induced bronchoconstriction.
Were breath sounds normal before and after exercise?	If the patient was wheezing, were they coming from the upper airway or from within the lung? Were left and right breath sounds equal?
Were heart sounds normal before and after exercise?	RRR? Murmurs? Gallops?

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Spirometry/PFT Results

Was pre-exercise spirometry normal?	Pre-exercise spirometry can be normal, obstructive, or suggestive of restriction.
Are there prior TLC and/or DLCO results?	A low TLC will confirm restriction. A low DLCO can suggest gas exchange abnormalities. These results can lead to certain expectations about the patient's ventilatory response.
What was the post-exercise FEV1?	Post-exercise FEV1 is normally +/- 5% from baseline. A post-exercise FEV1 decrease by ≧15% suggests exercise-induced bronchoconstriction (or poor effort). A post-exercise FEV1 increase of ≧15% is occasionally seen in some asthmatics, but can also suggest poor baseline spirometry.

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Ventilatory response

What was the max Ve in %predicted?	Predicted maximum minute ventilation (Ve) is calculated from FEV1 x 40. MVV tests (hyperventilation x 12 seconds) are generally not useful in determining maximum exercise ventilation as they are of short duration and, more importantly, they are an artificial maneuver that many patients have difficulty performing correctly. A normal maximum minute ventilation at peak exercise is usually less than 60% of predicted. If Ve ≧ 85% of predicted then a ventilatory limitation is present and may be due to a: 1. Restrictive process 2. Obstructive process 3. Hyperventilation
What was the Ve at AT?	If testing is submaximal, a Ve > 45% of the predicted maximum at anaerobic threshold is an indication there is likely a pulmonary mechanical limit.
What was the resting and maximum tidal volume?	Tidal volume (Vt) normally increases by a factor of 2 to 3 from rest to peak exercise. When Ve increases during exercise tidal volume usually increases first, followed by respiratory rate. A blunted increase in tidal volume (increase less than 2x resting) can be seen in both restrictive and obstructive disease.
What was the resting and maximum respiratory rate?	A resting respiratory rate (RR) of >25 may be abnormal, as it suggests hyperventilation, but is also often seen in anxiety. A RR at max exercise > 55 is abnormal and suggests a restrictive process or hyperventilation syndrome. A blunted increase in RR (<30) is often seen in obstructive disease.
What was E/I ratio at peak exercise?	The Expiratory Time/Inspiratory Time (E/I) ratio is nominally 1.0 to 2.0 at rest in normal subjects. E/I ratio should approach 1.0 at max exercise. An E/I ratio > 1.5 at max exercise suggests an obstructive process. An inverse E/I ratio (<1.0) may be an indication that there may be inspiratory obstruction.
What was the max Vt/IC?	Inspiratory Capacity (IC) is measured from maneuvers performed at rest and during exercise. It can be underestimated from a suboptimal maneuver and the maneuver can be difficult to perform at the highest levels of exercise. A Vt/IC ratio at max exercise > 0.85 is likely abnormal and can be seen in both obstructive and restrictive diseases.
What changes	Changes in end-expiratory lung volume are calculated from the IC

occurred in end-expiratory lung volume?	maneuvers performed during testing. An increase in End-Expiratory Lung Volume (EELV) of ≧ 0.25 L suggests dynamic gas trapping (hyperinflation) and is usually seen in obstructive disease. No change or a decrease is normal. Even though the max Ve is less than 85% of predicted, dynamic hyperinflation may cause the Vt/IC to approach 1.0; at the same time the patient may have reached their maximum respiratory rate and therefore have a ventilatory limitation.

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Gas Exchange

What was the Max VO2 (LPM)?	The maximum oxygen consumption (VO2) is the prime indicator of exercise capacity. Predicted values are based on patient age, height and sex. >120% = elevated 80% - 119% = normal 60% - 79% = mild impairment 40% - 60% = moderate impairment < 40% = severe impairment
What was the Max VO2 (ml/kg/min)?	<10 ml/kg/min: Surgery is contraindicated. 10-15 ml/kg/min: unable to perform most jobs; at increased risk for invasive surgical procedures. 15-25 ml/kg/min: able to work at job that does not require frequent or extended work above 40% of max VO2. Surgical risk is low. >25 ml/kg/min: able to perform most jobs This value is affected by a patient's BMI. Underweight patients may have an elevated VO2 in ml/kg/min and those who are overweight may have a reduced VO2 in ml/kg/min even though when expressed as LPM it may be normal.
Was there a VO2 plateau?	A VO2 plateau is defined as stable, unchanging VO2 for > 1 minute, particularly while the work rate is still increasing. When present it suggests the patient has attained their maximum cardiac output. It can also occur normally in patients being exercised at very low work loads. When looking at raw test data, a VO2 plateau should be accompanied by an increase in Ve and VCO2. If these do not increase as well, the VO2 plateau is more likely due to the patient slowing down and exercising less.
What was the O2 Sat at rest and at max exercise?	A resting SaO2 < 95% is abnormal. Desaturation ≧ 3% is abnormal. Oximeter readings can be decreased at high heart rates because the sensor is unable to keep up, or due to motion artifact or poor peripheral circulation. In an adequate test, a decrease in SaO2 indicates that the primary exercise limitation is pulmonary (either mechanical or vascular). A normal SaO2 indicates that the primary limitation is cardiac.
What was the maximum PetCO2?	PetCO2 is an indirect measurement of ventilatory efficiency and is the product of PACO2 and ventilation. Although PetCO2 at rest is approximately 2 mm Hg below PaCO2 the relationship between PetCO2 and PaCO2 is much less exact during exercise and will be overridden by an exaggerated ventilatory response to exercise.

	PetCO2 should rise during exercise and peak near AT; decrease until maximum exercise is attained and drop following exercise. An arbitrary grading scale for maximum PetCO2 is: ≧ 35 = normal 30 – 35 = mildly reduced 25 – 30 = moderately reduced <25 = severely reduced
What was the RER pattern?	RER (Respiratory Exchange Ratio) is VCO2/VO2. Normal resting value is 0.7 to 0.9 and is influenced by diet (lower with high protein, higher with high carbohydrates). RER usually falls below the baseline value at the beginning of exercise and then increases thereafter. An RER of 1.10 (1.05 for treadmill exercise) or higher at peak exercise is an indicator of an adequate exercise test effort. When elevated at rest (>1.0) this often means nothing more than patient anxiety. If the RER is elevated at rest and does not decrease below 1.0 during the first level of exercise this suggests a metabolic disorder or continued hyperventilation.
What was the Ve/VCO2 at AT?	Ve/VCO2 is the amount of ventilation required per unit of CO2 production. High values suggest inefficient ventilation either due to mechanical or gas exchange causes. A Ve/VCO2 > 35 at AT is likely abnormal and raises the question of pulmonary vascular disease or hyperventilation. A diagnosis of pulmonary vascular disease needs desaturation and/or a reduced DLCO for confirmation.
What was the lowest observed Ve/VCO2?	This is more likely a reflection of ventilatory efficiency than the Ve/VCO2 at AT.
What was the Ve-VCO2 slope to AT?	Like the Ve/VCO2 at AT, the slope of Ve versus VCO2 is a way to measure the efficiency of gas exchange. The Ve-VCO2 slope is usually calculated from rest to AT, but peak exercise values can be substituted when a patient is unable to reach AT or AT is indeterminate. A Ve-VCO2 slope to AT > 34 is abnormal and carries an increased risk for surgical procedures.
What was the Ve-VCO2 slope to peak exercise?	A Ve-VCO2 slope to peak exercise > 40 is considered abnormal. <30 is considered normal. The Ve/VCO2 slope to peak exercise is highly dependent on how far a patient is willing to push themselves. An early termination will reduce the peak Ve-VCO2 slope.

Cardiovascular response

What was the maximum heart rate?	Maximum heart rate is calculated from 220-age. A maximum heart rate ≧85% of predicted indicates that there has been an adequate test.
What is the heart rate reserve?	The heart rate reserve is {predicted HR - observed HR}. A heart rate reserve that is greater than 20% of the {max predicted HR - resting HR} is elevated and may be an indication of chronotropic incompetence.
What was the heart rate recovery (HRR)?	The HRR is the {max HR - HR at 1 minute post-exercise}. A HRR <12 indicates the patient has a reduced vagal and parasympathetic tone and carries a higher mortality risk.
What is the chronotropic index?	The chronotropic index relates the change in heart rate to the change in oxygen consumption. A chronotropic index > 1.30 indicates a steep heart rate response and can suggest an increased dependence on heart rate to increase cardiac output secondary to a low stroke volume. A chronotropic index < 0.8 can indicate a blunted heart rate response (possible chronotropic incompetence) which in turn can suggest a variety of cardiac dysfunctions but can also be caused by medication (beta blockers). A low chronotropic index can also be seen in exceptionally fit individuals (elevated max VO2, elevated VO2 at AT), and in these cases, is normal. In an exceptionally fit individual a normal chronotropic index is likely abnormal.
What was the resting and max blood pressure?	A normal max systolic pressure is 160-220 mm. A normal increase in diastolic pressure is 10 mm. A diastolic pressure greater than 90 is likely abnormal and greater than 100 is definitely abnormal and suggests diastolic dysfunction. If systolic blood pressure did not increase > 130 mm, or dropped >10 mm during exercise, consider left ventricular dysfunction, possible CAD.
What was the systolic blood pressure 3 minutes post-exercise?	A {3 minute post-exercise systolic blood pressure / peak exercise systolic blood pressure} ratio greater than 0.95 indicates the patient is at greater risk for hypertension and stroke.
What was the VO2 at Anaerobic Threshold?	A low VO2 at AT indicates an abnormal cardiovascular limitation (specifically O2 delivery to the tissues). The threshold (in terms of percent of the predicted VO2) rises with age: Males: Females: Age: 20 LLN: 42 Age: 20 LLN: 41 Age: 30 LLN: 43 Age: 30 LLN: 44 Age: 40 LLN: 44 Age: 40 LLN: 47 Age: 50 LLN: 45 Age: 50 LLN: 49 Age: 60 LLN: 46 Age: 60 LLN: 52 Age: 70 LLN: 47 Age: 70 LLN: 54
What was the Heart	The Heart rate and VO2 should be graphed against each other. Normally when this is done there should be a nearly straight line as

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Rate – VO2 pattern?	the relationship between heart rate and VO2 tends to be linear. An upwards inflection in this line indicates that the heart rate is increasing faster than the VO2 and is an indication of a rate-related decrease in stroke volume which is often seen in valvular disease.
What was the O2 Pulse pattern?	O2 Pulse is VO2/Heart rate (ml of oxygen consumed per heart beat). A normal O2 Pulse response pattern shows an immediate upswing at the beginning of exercise and a steady increase thereafter with a peak at peak exercise. An early plateau can be abnormal. An O2 Pulse that increases and then decreases is definitely abnormal and is usually seen in conjunction with an abnormal HR/VO2 curve. O2 Pulse is the product of the arterial-venous O2 Content difference and Stroke Volume. If there is no desaturation during exercise then O2 Pulse can be an indicator of Stroke Volume. O2 Pulse usually decreases when exercise stops. An increase in O2 Pulse after the end of exercise is commonly seen in left ventricular dysfunction and other heart diseases.
What was the maximum O2 Pulse?	The maximum predicted O2 pulse is calculated from: (Predicted Maximum VO2 (ml) / Predicted Maximum Heart Rate) A maximum O2 pulse < 80% of predicted is likely abnormal and can indicate a stroke volume limitation or an inadequate exercise test effort.

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Interpretation:

Was the exercise capacity (maximum VO2) normal?	>120% = elevated 80%-120% = normal 60%-79% = mild impairment 40%-60% = moderate impairment < 40% = severe impairment
Why was the test terminated?	Does the reason it was terminated have any clinical significance?
Was the test adequate or submaximal?	Test was adequate if: a. Predicted maximal VO2 was reached. b. Exercise was terminated because of electrocardiographic abnormalities. c. Maximal heart rate was greater than 85% of predicted. d. Maximum minute ventilation > 85% of predicted. e. Significant (≧3%) desaturation occurred. f. RER (VCO2/VO2) was 1.10 or greater at test end. g. FEV1 declines by >15% post-exercise (EIA, not fatigue). h. VO2 plateau occurring for approximately 1 minute or longer at peak exercise. i. exercise was terminated because of hypertension (diastolic >110, systolic>250). j. test was terminated for patient safety If none of these criteria was achieved, test was submaximal.
Was there a ventilatory limitation?	Was the maximum minute ventilation > 85% of predicted, or was there hyperinflation (EELV ≧0.25 L) and a high Vt/IC (>0.85)? If test was submaximal, was the Ve at AT > 45% of predicted maximum? Is the pulmonary mechanical limitation due to obstructive or restrictive disease?
Was there post-exercise bronchoconstriction or bronchodilation?	Did the post-exercise FEV1 decrease or increase ≧ 15%? Was spirometry test quality good?
Was there evidence of pulmonary vascular disease?	Was there significant desaturation? Was there a high Ve-VCO2 slope and/or low DLCO?
Was there evidence of circulatory dysfunction?	Was the VO2 at AT low? Was there an abnormal blood pressure or heart rate pattern? Was there a VO2 plateau at a low VO2? Was the chronotropic index high or low? Was there a normal O2 pulse pattern? What was the maximum O2 pulse?

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Was there clinical or ECG evidence of cardiac ischemia?	Were there any significant ECG changes? Did the patient complain of chest pain?
Is the patient deconditioned?	A deconditioned person will have a normal maximum heart rate (unless the test is submaximal), but a high normal chronotropic index and a low normal maximum VO2.

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Normal patterns

VO2/VCO2/RER	VO2 is nominally 0.25 L/min at rest, but ranges from 0.10 to 0.35 depending on patient body weight. RER is nominally 0.8 at rest, but ranges from 0.7 to 0.9 based largely in diet (high protein = low RER, high carbohydrates = high RER). All resting values can be skewed upwards by patient anxiety/apprehension prior to starting exercise. VO2 usually rises abruptly at the beginning of exercise, frequently doubling the resting value within one or two breaths. VO2 should continue to rise throughout exercise. VCO2 initially increases more slowly than VO2, so RER usually decreases from its resting value during the initial phase of exercise and then increases later.
PetCO2	PetCO2 should be approximately 2 mm Hg below PaCO2 at rest, and so should be between 35-40 mm hg. PetCO2 should rise during exercise and peak near AT and then decrease until maximum exercise is attained. It should drop following exercise. The maximum PetCO2 during exercise is related to the Ve-VCO2 slope.
Ve/VCO2	Elevated at rest (40-50), decreases to minimum value at or shortly after AT, and can then increase or remain flat to peak exercise. Minimum value and/or value at AT should be less than 35.
Ve, Vt, IC	Ve is nominally 6-12 LPM at rest. Vt is nominally 0.5-1.0 L at rest. Vt/IC is usually 0.25-0.35 at rest. Ve and Vt can be skewed upwards by patient anxiety/apprehension prior to starting exercise. Vt should at least double from rest to peak exercise. IC should increase slightly or not change. Ve at AT should be less than 45% of predicted maximum. Vt/IC at peak exercise should be less than 0.75.

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Disease patterns

Pulmonary hypertension	PetCO2 decreases during exercise, reaching a minimum at peak exercise and rises following exercise. Ve/VCO2 is elevated (>35) at AT. The magnitude of the decrease in PetCO2 and increase in Ve/VCO2 is related to severity of the disease. Desaturation is likely but related to the severity of the disease. Ventilatory patterns are often restrictive.
Exercise-induced R-L shunt	Ve/VCO2 increases and PetCO2 drops abruptly at the point the shunt opens.
Pulmonary Fibrosis/ILD	There is usually a high respiratory rate, low tidal volume response to exercise. I:E ratio will likely be close to 1:1 throughout exercise. Ve-VCO2 slope will be elevated and desaturation is likely but both are related to the severity of the disease.
COPD/Emphysema	High E/I ratio (>1.5) throughout testing. Elevated Ve/VCO2 at AT and a high Ve-VCO2 slope overall. Significant desaturation (>5%) is likely. Significant dynamic hyperinflation (>0.25 L) is likely. Ve at AT will be > 45% of predicted maximum. Maximum minute ventilation likely >85% of predicted or Vt/IC > 0.90.
CHF	No desaturation. Normal PetCO2 pattern, but all values shifted downwards, with maximum PetCO2 likely below 35. High Ve-VCO2 slope (>35). VO2 at AT (if achieved) less than the LLN. Other findings can include noticeable Ve and VO2 oscillations and an increase in O2 pulse following exercise.

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Anaerobic Threshold

As exercise workload increases during the exercise test, there is a point where energy demands cannot be met solely with aerobic metabolic processes. Anaerobic metabolism is less efficient than aerobic and produces more CO2 and lactic acid. For these reasons ventilation usually increases significantly once the anaerobic threshold has been passed.

The "gold standard" for determining AT is lactic acid levels, but this requires drawing blood samples from an indwelling arterial catheter at regular intervals during the test (Level II exercise test). Since most exercise tests are non-invasive (Level I exercise tests), ventilatory parameters are used to determine AT.

The first technique for determining AT is the "V-Slope" technique. VO2 and VCO2 are plotted against each other. VO2 and VCO2 tend to have a linear relationship with each other, but the slope of the relationship is different below and above AT. An upwards inflection point (change in slope) usually occurs at AT.

The second technique is the "Ventilatory Equivalents" technique. Ve/VO2 (units of ventilation per unit of VO2) and Ve/VCO2 (units of ventilation per unit of VCO2) are plotted against time. Ideally, the Ve/VO2 will dip to a nadir and then climb, followed shortly by Ve/VCO2 which also dips to a nadir then either levels off or climbs again. The nadir of the Ve/VO2 should occur at AT.

Finally, end-tidal O2 and end-tidal CO2 can be plotted against time. When ventilation increases at AT because of the increase in lactic acid and VCO2, end-tidal O2 rises and end-tidal CO2 drops. This inflection point should occur at AT.

Ideally, the AT determined by all three techniques will concur with each other, but this is often not the case. The reported AT is usually determined from the technique with the clearest signal, but even so AT is still occasionally indeterminate.

The VO2 at which AT occurs tracks cardiovascular health and to some extent "fitness". Exceptionally fit and active people tend to have AT's at 60% or higher of their predicted max VO2. A low or early AT suggests cardiovascular disease. AT can be indeterminate if exercise is terminated before it occurs, which happens frequently in patients with a pulmonary mechanical limitation. A "missing" or indeterminate AT, however, does not necessarily mean anything more than a noisy physiological signal.

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Wasserman's VO2 calculation algorithm

Male:

Cycle factor = 50.72 – (3.72 x age)
Predicted weight (kg) = (0.79 x height (cm)) – 60.7

If actual weight = predicted weight then:
VO2 (ml/min) = Actual weight x cycle factor

If actual weight < predicted weight then:
VO2 (ml/min) = ((Predicted weight + actual weight) / 2) x cycle factor

If actual weight > predicted weight then:
VO2 (ml/min) = (predicted weight x cycle factor) + (6 x (actual weight – predicted weight))

If treadmill is used rather than a bicycle ergometer then multiply VO2 by 1.11

Female:

Cycle factor: 22.78 x (0.17 x age)
Predicted weight (kg) = (0.65 x height (cm)) – 42.8

If actual weight = predicted weight then:
VO2 (ml/min) = (actual weight (kg) + 43) x cycle factor

If actual weight < predicted weight then:
VO2 (ml/min) = ((predicted weight + actual weight + 86) / 2) x cycle factor

If actual weight > predicted weight then:
VO2 (ml/min) = ((predicted weight + 43) x cycle factor) + (6 x (actual weight – predicted weight))

If treadmill is used rather than a bicycle ergometer then multiply VO2 by 1.11

Note: Wasserman et al does not specify over what range an actual weight should be considered the same as the predicted weight (particularly since they are very rarely if ever identical). As a rule of thumb +/- 10% is an acceptable "normal" range.

Reference:

Wasserman K, Hansen JE, Sue DY, Stringer WW, Whipp BJ. Principles of exercise testing and interpretation, 4th edition, page 166. Lippincott, Williams and Wilkins, publisher.