Introduction to Cardiopulmonary Exercise Testing

2nd Edition

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Section 6

Interpreting the Results of the Cardiopulmonary Exercise Test

Interpreting the Results of the Cardiopulmonary Exercise Test

When the test is complete and the pulmonary function technician has printed out and collated the data, it is your responsibility to interpret the information, prepare the report and communicate with the requesting provider. This section of the syllabus will provide general information regarding the data interpretation.

Test Interpretation

Your test interpretation, as well as your report preparation will be easier if you break the process down into the following steps. Aside from the first section ("Do the Numbers Make Sense"), which does not go in the report, the remaining steps essentially become separate sections that you document in your report. A sample report and a table of normal and/or predicted values for many of the parameters you will assess are provided at the end of this section of the syllabus.

Do The Numbers Make Sense?

There is some basic troubleshooting of the data that you should always do to make sure that there are no systematic errors that may cloud result interpretation:

- Check the VO_2 at rest and during unloaded pedaling: At rest, the VO_2 should be around 250 ml/min for a normal-sized person while during unloaded pedaling, you should expect to see a value around 400 ml/min. In obese individuals, both the resting and unloaded pedaling values will be higher (eg. 1000 ml/min with unloaded pedaling).

- Check the R values: R should remain between 0.8 and 0.95 for the first 30-40% of the test before rising thereafter. It should never be below 0.7. If the patient gave a good maximal effort, R will rise to between 1.1 and 1.3 at peak exercise and should continue to rise for 1-2 minutes after the test is complete as the muscles wash out accumulated CO_2 but oxygen consumption declines. Abnormal values suggest that the oxygen fuel cell is defective. If R decreases as the work load increases, there is something wrong with the gas sensor or there is a leak in the mask or sampling catheter.

- Check the relationship between oxygen consumption and watts expended: Once the subject begins loaded pedaling, oxygen consumption and watts should increase in a linear and predictable manner; oxygen consumption should increase at roughly 10-12 ml O_2/watt. Smaller rates of increase are suggestive of fuel cell or calibration problems, improper (or lack of) nose clip placement or, most commonly, the use of too steep a ramp for the test.

- Check the oxygen saturation data: If you notice that the oxygen saturation fell during the test, you need to confirm that this was a true result. Subjects who truly desaturate do so in a steady, progressive manner with the lowest numbers observed in the first minute after the bicycle load is removed. When there are problems with sensor placement or poor signal, the oxygen saturation data will be more chaotic and will not follow a clear trend.

- Was there a leak in the system? In rare situations, gas leaks occur from the mask or other connections in the system and distort the test data. Clues to the presence of this problem include a very early plateau in VO_2 (i.e. VO_2 fails to rise as work rate continues to rise for more than a 1-2 minute period), inappropriate R-values, and inappropriately high $P_{ET}O_2$ values.

Indications For the Test and Other Relevant Clinical Data

You should begin your report with a short paragraph in which you review the primary reasons for performing the test. In this section, you should also note whether the patient is on any relevant cardiac or pulmonary medications (eg. beta-blockers) and whether they have undergone any cardiac or thoracic surgical procedures.

Factors Limiting Exercise

Document the power increment used (eg. 10 watt/minute ramp), the maximum power attained and the subject's stated reason for stopping the test. For example, did they stop because of leg fatigue, dyspnea, chest pain or lightheadedness. You should also document whether the exercise-limiting symptoms during the test duplicated the exertional symptoms they have at home. In your report, you will want to document whether the patient gave a full effort. You will have a sense of this by looking at the patient at the end of exercise (sweating, clearly working hard) but the best sign will be if the patient reached a ventilatory threshold (although you should remember that people with ventilatory limitation will not generally reach one). Maximal exercise heart rate is not a good indicator of whether someone gave a full effort because of the wide range of maximal exercise heart rates in normals. In addition, many test subjects will be on beta-blockers and their heart rates will not rise as they would in others not on these medications.

Maximal Exercise Capacity

Note the maximum oxygen uptake ($VO_{2,max}$) and how this compares to the predicted values based on age, height and gender. You will want to report the values in ml/min as well as the weight-normalized values. Be aware that our calculated normal values are not appropriate for people under the age of 20 and that there is poor data for the elderly, especially elderly women.

Another important point to remember is that a subject's $VO_{2,max}$ may fall within the "normal" range or even exceed the predicted values yet that person may still have exercise limitation. To illustrate this point, consider the case of an elite rower we saw in the lab several years ago. After a long plane flight, he developed increased dyspnea on exertion and could no longer keep up in the boat at crew practice. He did a cardiopulmonary exercise test and achieved a $VO_{2,max}$ of over 60 ml/kg/min. That number was well above his predicted value and, on the surface appeared “normal.” However, it is likely that had we tested him prior to his plane flight, that number might have been 75 ml/kg/min. He could clearly tell us that something was different and the 60 ml/kg/min value was not “normal” for him. It turned out that he experienced a pulmonary embolism on his plane flight and now had pulmonary vascular limitation to exercise.

Whether or not the subject is obese will also affect your interpretation of maximum exercise capacity. “Normal” obese subjects all should have maximal oxygen uptake at or above a height-predicted (i.e. ideal body weight) normal value.

The Cardiovascular Response

Note the predicted maximum heart rate and the maximal heart rate attained. The difference between these two values, the heart rate reserve, should also be noted. You should also review the EKG report and note whether there were any ST depressions or arrhythmias and when in the progression of the test they were observed. Describe the blood pressure response to exercise. It should rise progressively with exercise, with marked increases beyond the ventilatory threshold. A falling blood pressure, as noted in other portions of this syllabus is a sign of significant coronary artery disease. Note the changes in the O_2 Pulse, a surrogate marker for stroke volume. This should rise progressively through exercise and plateau once the patient achieves their $VO_{2,max}$. Finally, identify whether or not a ventilatory threshold was present. This last step, described in greater detail in Section 4 of this syllabus, is a key part of interpreting the source of exercise limitations. You should note the point at which it occurred (eg. at 60% of the $VO_{2,max}$). In most individuals, this will occur at about 60% of the $VO_{2,max}$ while in highly trained endurance athletes, it may occur at 80% of their maximum exercise capacity. In addition, the ventilatory threshold comes later with age and active patients over the age of 80 may show a threshold either very late in exercise or not at all.

Ventilatory Response

The goal in this part of the interpretation is to identify whether the patient has any signs of ventilatory limitation. After noting the peak respiratory rate and the maximum tidal volume achieved, compare the maximum minute ventilation at peak exercise with the maximum voluntary ventilation (MVV). In patients with ventilatory limitation, the minute ventilation at peak exercise will be over 70% of the MVV, although you should remember that very fit athletes can raise their minute ventilation up to or above their MVV.

You should also examine the ventilatory equivalents for carbon dioxide and oxygen as these values are reflective of alveolar ventilation and the extent of ventilation-perfusion matching. Normal V_E/VCO_2 values should be about 25-35 at low level exercise below the ventilatory threshold. They will rise to higher levels once a subject passes their ventilatory threshold. Values lower than that suggest the patient is hypoventilating while higher values are suggestive of hyperventilation or increased dead space. Be aware that many fit athletes get "amped up" when they get on the bicycle and hyperventilate while sitting at rest or during unloaded pedaling. They will demonstrate elevated ventilatory equivalents as a result of this but the values tend to come back down to normal levels once they begin loaded pedaling.

Gas Exchange and Blood Gases

Note whether or not there were changes in oxygen saturation and trend in the end-tidal CO_2. Oxygen saturation should remain constant in normals and patients with cardiac limitation whereas it will fall in patients with ventilatory limitation and pulmonary vascular or interstitial lung disease. End-tidal CO_2 will fall after patients reach their ventilatory threshold but will increase or remain stable in patients with ventilatory limitation or neuromuscular disease.

You will not have blood gases in every patient. If you do obtain them, note the alveolar-arterial oxygen difference. It should remain between 10-15 mm Hg until after the ventilatory threshold at which point it will increase. Normal subjects should still have an AaO_2 difference less than 20 mm Hg at maximum effort, however. You should then identify changes in the bicarbonate and the arterial P_aCO_2. The bicarbonate starts to fall around the ventilatory threshold and the P_aCO_2 should drop progressively in response to this metabolic acidosis. A stable or increasing P_aCO_2 is evidence of ventilatory limitation or neuromuscular disease.

Finally, you should then use to the blood gas values to help you calculate the dead-space fraction (V_D/V_T) at each point at which you drew blood gases. This calculation can be done using the following equation.

$$\frac{V_D}{V_T} = \frac{P_aCO_2 - P_ECO_2}{P_aCO2}$$

P_ECO_2 is the end-tidal CO2 and this data is provided as part of the data output from the test. There is an Excel spread sheet that has been created to do this calculation for you. It can be found on the computer in the physician workroom of the pulmonary function laboratory (described below). The dead-space calculation is important as it provides clues to the presence of pulmonary vascular/ILD pattern of limitation. In normals and in patients with cardiac limitation, V_D/V_T will decrease with exercise while in pulmonary vascular and interstitial lung disease patients, it will remain stable or increase.

Patterns of Exercise Limitation

In this section – which essentially serves as the meat of your test interpretation – you identify what you believe to be the source of the patients exercise limitation – cardiac problems, ventilatory problems, pulmonary vascular disease or neuromuscular disease. The different patterns of limitation have been described more thoroughly in the Section 3 of the syllabus ("The Cardiac and Respiratory Response to Exercise.") Some texts such as the Wasserman's Principles of Exercise Testing and Interpretation recommend using a flowchart approach to identify the source of exercise limitation. At our institution, we prefer to use a different approach, one based more on pattern recognition rather than strict decision algorithms. This approach is best conceptualized as a balance. Cardiac limitation is present when the preponderance of data shifts the balance in the direction of cardiac limitation whereas ventilatory limitation is felt to be present when the preponderance of data points to problems mounting an adequate ventilatory response to exercise. This concept is illustrated in Figure 1 below. The main forms of exercise limitation and their characteristic data patterns are summarized in Table 1 below.

Figure 1. The Balance Approach to Exercise Test Interpretation

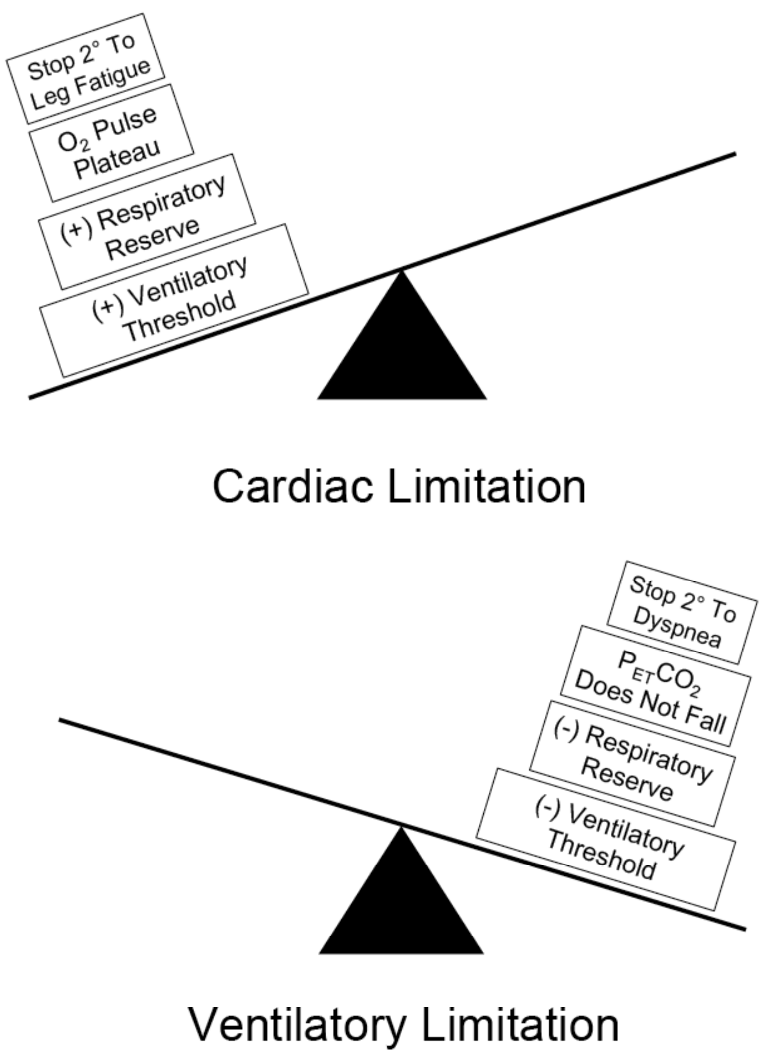

Table 1. Basic Patterns Observed On Cardiopulmonary Exercise Testing in Normals and Patients With Various Forms of Disease

	Disease Category				
Variable	**Normal Patient**	**Cardiovascular Disease**	**Obstructive Lung Disease**	**Pulmonary Vascular Disease /ILD #**	**Neuromuscular Disease**
$VO_{2,max}$	Normal *	Decreased	Decreased	Decreased	Decreased
Heart Rate Reserve	Absent to small reserve (< 20 bpm)	Absent to small reserve (< 20 bpm)	Large (> 30 bpm)	Small (< 20-30 bpm)	Large (> 30 bpm)
$V_{E,max}$/MVV (Ventilatory Reserve)	< 0.8	< 0.8	> 0.8	< 0.8	< 0.8
Ventilatory Threshold	Present	Present	Absent	Present	Usually present
Dead Space (V_D/V_T)	Decreases	Decreases	Decreases	Remains stable or increases	Decreases
Oxygen Saturation	Stable	Stable	Decreases	Decreases	Stable
End-Tidal CO_2 (in late exercise)	Decrease	Decrease	Increase or stable	Decrease	Increase or stable
Reason for Stopping	Leg Fatigue	Leg Fatigue	Dyspnea	Dyspnea, leg fatigue	Fatigue

Note:
* "Normal" or "decreased" refers to how the variable changes relative to age, gender and size matched individuals.

Interstitial lung disease patients demonstrate a pattern very similar to the pulmonary vascular pattern and can only be differentiated based on their PFTs and chest imaging.

Predicted and Normal Values for Test Parameters

Parameter	Predicted Value	Range
$VO_{2,max}$ (ml/min)	Based on gender, age, height	Lower limit of normal < 80% predicted
Resting VO_2 (ml/min)	150 + (6 X weight in kg)	250 -300 (larger in obese individuals)
Peak Heart Rate (bpm)	220- age or 210 – (0.65 X age)	90% predicted $\pm$ 15 bpm
Oxygen pulse (ml/beat)	(Predicted $VO_{2,max}$)÷ (predicted max HR)	80% predicted (~ 15 ml/beat in men; ~ 10 ml/beat in women)
Minute Ventilation (L/min)		Peak Exercise: 70-80% of MVV
Maximum Tidal Volume	60% of the FVC	
V_E/VCO_2 (early exercise)		25-35
V_E/VO_2 (early exercise)		25-35
V_D/V_T		0.25-0.35 at rest Should decrease with exercise
$P_{ET}CO_2$ (mm Hg)		38-42 (Should decline after ventilatory threshold)
$P_{ET}O_2$ (mm Hg)		95-100 (Should rise after ventilatory threshold)
A-a O_2 Difference (mm Hg)		Rest: 10-20 Peak Exercise: 15-30
S_aO_2 (%)		> 95% (Should remain constant with exercise)
Respiratory Exchange Ratio	Rest: 0.8 Peak Exercise: > 1.15	Rest: 0.6-1.0 Peak Exercise: 1.1-1.3

Note: Normal values based on data from Gold WM. “Clinical Exercise Testing” in Murray and Nadel’s Textbook of Respiratory Medicine. Elsevier Saunders. Philadelphia

Example of a Report from a Cardiopulmonary Exercise Test

PULMONARY STRESS TEST, COMPLEX / INTERPRETATION

[redacted]

University of Washington Medical Center
Pulmonary Diagnostic Service
1959 NE Pacific St., Seattle, WA 98195

Date of Test: October 20, 2005

Age: 38 **Sex**: Male **Height**: 175 cm **Weight**: 84.1 kg

Referring Physician: [redacted].

Indications for Testing: The patient is a 38-year-old male who developed pulmonary edema in July 2005 while participating in a bicycle race across America. The patient is an elite endurance athlete whose primary activity is cycling. He is formerly a competitive cross-country skier. He performed cardiopulmonary exercise testing at an outside facility in 2004 showing a VO2 max of roughly 60 ml/kg/min. In July of 2005, after the episode of pulmonary edema during the bicycle race, the patient repeated the exercise test at the same facility and it showed a VO2 max of 40 ml/kg/min. Today's exercise testing is being performed here to confirm the previously-noted decreased exercise capacity, as well as help determine the etiology of his exercise limitation. We will also collect additional data, including dead-space calculations, which were not done on his July 2005 exercise test.

PULMONARY FUNCTION TESTING (10/20/05)

Spirometry: FEV1 4.07 liters (99% of predicted); FVC 5.70 liters (113% of predicted); FEV1/FVC ratio 71%.

Maximum Voluntary Ventilation: 186 liters/minute.

IMPRESSION: Normal spirometry.

PULMONARY STRESS TEST, COMPLEX

Exercise Protocol: The risks and benefits of progressive maximal cardiopulmonary exercise testing were explained to the patient. Informed, written consent was obtained prior to the start of the procedure and placed in the chart. The patient was exercised on the cycle ergometer to a symptom-limited maximum with a progressively increasing workload at 30-watt/minute increments. Continuous oxygen saturation, EKG, and expired gas analysis were performed. Serial blood pressures were obtained and he had an arterial line was placed for the procedure. The patient reached a maximum workload of 500 watts and appeared to give a good effort. He stopped due to leg fatigue.

Continued…

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Example of a Report from a Cardiopulmonary Exercise Test (cont.)

Measurement	Rest	Max	Pred Max	% Predicted
Work (watts)	0	500	214	234%
VO2 (ml/min)	640	5373	2872	187%
VO2/kg (ml/kg/min)	7.6	63.9	40.9	[redacted]
VO2/kg (ideal weight)	9.1	76.5	40.9	
Heart Rate	73	179	182	
O2 pulse	8.8	30.0	15.8	190%
Blood Pressure	120/72	180/68		
Ventilation (liters/minute)	17	186	186	100% MVV
			163	114% FEV1 x 40
Respiratory Rate	14	57		
Tidal Volume (liters)	1.21	3.26		
O2 saturation	100	96		
EtCO2 (mmHg)	38	37		

RESULTS:

Maximum Oxygen Consumption: The patient's VO2 max was 5373 ml/min, which represents 187% of his predicted maximum. When normalized for his body weight, his VO2 max was 63.8 ml/kg/min, which is 156% of his predicted maximum. When normalized for his ideal body weight, his VO2 max was 76.5 ml/kg/min, which is 187% of his predicted maximum.

Cardiac Response: The resting EKG showed a question of a mild enlargement of the P-wave in lead II and an RSR prime complex in lead V1 with a normal QRS duration. No ST changes, Q-waves, or T-wave inversions were noted. Axis and intervals were normal. At maximal exercise no ischemic changes were noted. The heart rate was 73 beats/minute at rest and rose to 179 beats/minute at maximal exercise, which is 98% of his age-predicted maximum. The O2 pulse was 8.8 ml/beat at rest and rose to 30 ml/beat at maximal exercise, which is 190% of his age-predicted maximum. The blood pressure at rest was 120/72 at rest and increased to 180/68 at maximal exercise. A ventilatory threshold was noted at 4397 ml/min, which represents 82% of the patient's VO2 max.

Ventilatory Response: The patient's resting ventilation was 17 liters/minute and increased to 186 liters/minute at maximal exercise, representing 100% of his maximum voluntary ventilation and 114% of his FEV1 x 40. The respiratory rate was 14 breaths/minute at rest and rose to 57 breaths/minute at maximal exercise. Tidal volume increased from 1.21 liters at rest on the bicycle to 3.26 liters at maximal exercise.

Gas Exchange: The patient's oxygen saturation was 100% at rest and 96% at maximal exercise. End-tidal CO2 was 38 at rest and fell to 25.9 at maximal exercise. Arterial blood gases:

At rest: PO2 - 101.6 mmHg / PCO2 - 38.9 mmHg / dead space - 0.29.

At peak exercise: PaO2 – 84.6 mmHg / PCO2 – 32.7 mmHg / dead space 0.21. This dead space calculation was obtained 30 seconds after the end of maximal exercise. Through the duration of the patient's exercise, the dead space fluctuated between 0.21 and 0.17.

The (A-a)O2 difference reached a peak of 40.2 at maximal exercise.

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Example of a Report from a Cardiopulmonary Exercise Test (cont.)

IMPRESSION / SUMMARY: This cardiopulmonary exercise test demonstrates an excellent performance. The patient reached a VO2 max of 63.9 ml/kg/min, which represents 156% of his age-predicted maximum, reaching a total work rate of 500 watts on the bicycle, representing 234% of his predicted maximum. The pattern demonstrated on today's test is consistent with a cardiac limitation to exercise. While the patient did reach 100% of his maximum voluntary ventilation and did desaturate mildly during the test with an increased (A-a)O2 difference, we believe that these latter two findings are consistent with changes that are often seen in elite athletes on cardiopulmonary exercise testing. Because the patient's dead spaced decreased appropriately during the test and did not increase during the course of exercise, we do not believe that the desaturation is consistent with a pulmonary vascular problem.

The patient had a cardiopulmonary exercise test in July 2005 in which his reported VO2 max was only 40 ml/kg/min. When compared to his test from April 2004, in which he had a VO2 max of 60 ml/kg/min, his July 2005 test raised concern about possible new cardiac or pulmonary pathology contributing to exercise limitation. However, at the start of today's test, the patient indicated that when he did his July 2005 test, he was not exercised to his maximum capacity. Instead, he reported that the test was stopped before he felt that he had reached exhaustion. Today's performance, in which he reached a maximum of 500 watts on the bicycle and a VO2 max of 63.9 ml/kg/min, indicates that he has not had a decrement in his exercise capacity when compared to his prior study from April 2004. In the absence of any evidence on this test of a ventilatory limitation or pulmonary vascular problem, and given his excellent exercise performance, we do not feel that further workup is warranted for possible cardiac or pulmonary pathology, as the evidence for such a process is not present at this time.

I hereby certify that I have personally evaluated all of the measurements recorded above, and agree with the interpretation of the data.

H. Thomas Robertson, M.D., Professor

Report dictated by [redacted], Pulmonary Fellow

cc: [redacted], [redacted]. Box 356522

AL: 10/20/05 cv: 10/28/05

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