Chapter 13

FOLLOW-UP MEDICAL CARE OF SERVICE MEMBERS AND VETERANS—CARDIOPULMONARY EXERCISE TESTING

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INTRODUCTION

Individuals who present with respiratory symptoms will have standard screening medical tests performed, including spirometry and chest X-ray radiographs. If further testing is indicated based on history, symptoms, and results of screening studies, this may include more complete lung function testing: lung volumes, diffusing capacity measurement, and response to the one-time use of a bronchodilator. For some individuals, even more advanced testing may be needed for complete evaluation of possible causes of respiratory symptoms, which may include bronchoprovocation challenge testing and cardiopulmonary exercise testing (CPET). CPET is the evaluation of the lungs, the heart, the circulation, and certain muscle groups under the conditions of exercise.

When a person exercises, the muscles involved in the type of exercise (eg, lower extremity musculature for running or cycling) require increased amounts of energy production by mitochondria in the muscle cells. This increased energy production depends on increased metabolism that, in turn, requires oxygen and substrates for the generation of that energy.

AEROBIC METABOLISM

If oxygen is available, this energy production is accomplished by the utilization of substrates, such as pyruvate (from glucose) through metabolic pathways of the tricarboxylic acid or Krebs cycle. For this to occur, the lungs need to take in increased quantities of oxygen from the atmosphere and transfer the oxygen to the hemoglobin of red blood cells in the circulation. The heart will then need to increase its output of blood to deliver the oxygen to the exercising muscles. As oxygen is utilized by the mitochondria within the exercising muscles, carbon dioxide is produced as a byproduct of this aerobic (with oxygen) metabolism. This extra carbon dioxide must then be transported by the heart and the circulation to the lungs where it is exhaled.

ANAEROBIC METABOLISM

In a situation where the pattern of exercise includes steadily increasing workloads for the individual, the amount of oxygen delivered to the exercising muscles may become limited or inadequate for the usual metabolic pathways for energy production (ATP [or adenosine triphosphate] formation by the Krebs cycle). At that time, energy production is shifted to a pathway that results in lactic acid production. This is known as a shift from aerobic (with oxygen) to anaerobic metabolism (without oxygen).

THE BODY'S RESPONSE TO EXERCISE

There are changes that occur within the body with exercise to supply the exercising muscles with adequate oxygen for energy production. As previously described, the lungs must be able to move more air to take in oxygen from the atmosphere and transfer that oxygen to the blood. This movement of air is measured as minute ventilation (V_E) : liters of air moved per minute. The heart then has to pump more blood to carry the oxygen to the muscles. This increased pumping ability is referred to as cardiac output in liters per minute of blood pumped by the heart to the arterial circulation. Finally, the oxygen delivered to the exercising muscles must be extracted from the blood to be used by mitochondria in the muscles. Those changes with exercise are shown in Figure 13-1.

V_E can increase from a resting value of 7 to 10 L/min to upwards of 70 to 140 L/min. Cardiac output can increase from 4 to 5 L/min at rest to 20 to 25 L/min with exercise. Extraction of oxygen in the periphery by the exercising muscles (the difference between the oxygen-carrying capacity of arterial blood and the venous blood) can increase from 5 mL of oxygen for every 100 mL of blood to 15 to 16 mL of oxygen for every 100 mL of blood. As a result of these changes, the uptake or consumption of oxygen by the body (primarily the exercising muscles) can increase from 4 mL/kg/min to 40 to 50 mL/kg/min (or even higher for some well-trained athletes). This maximal oxygen consumption (VO_{2max}) for the individual is an overall measure of the work performance or exercise capacity for that individual.

INDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING

The adequate supply of oxygen to exercising muscles requires close coordination among

- the lungs (to take in oxygen),
- the heart (to pump the blood with oxygen),
- the circulation (to move oxygenated blood to the muscles), and
- the muscles themselves (to extract and use oxygen efficiently).

When a portion of this system breaks down, the delivery and utilization of oxygen by the exercising muscles are limited, and exercise or work performance for the individual is lower or worse than expected. The individual may experience this reduced or limited performance as excessive dyspnea or shortness of breath. Dyspnea with exercise that is out of proportion to what is expected for the individual may indicate decreased exercise performance and require further evaluation beyond the usual testing of the lungs and heart: pulmonary function tests, echocardiography, etc. In those instances, a CPET can be performed to help in determining the cause of dyspnea. The following are common indications for performing a CPET:

- evaluating unexplained activity-related dyspnea or exercise intolerance;
- differentiating the causes for dyspnea among the lungs, the heart, the circulation, or the exercising muscles;

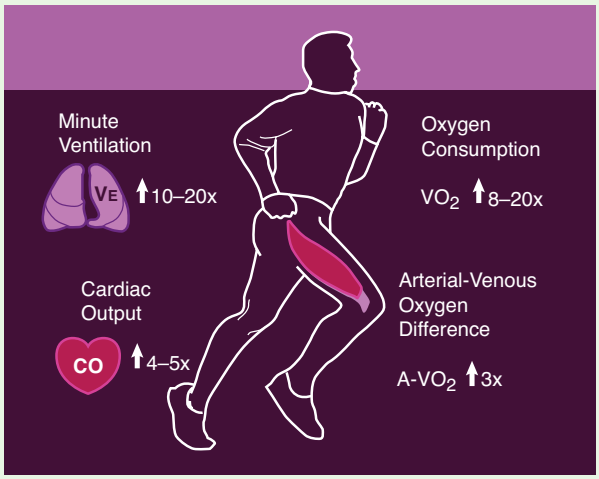

Figure 13-1. Typical changes from rest to maximal exercise.
A-VO_2: arterial-venous oxygen difference; CO: cardiac output; V_E: minute ventilation; VO_2: oxygen consumption (or oxygen uptake)

- determining the impairment rating for disability; and
- monitoring the response to an intervention for a known disease or determining progression of a known disease.

In most cases, testing is done to determine what might limit exercise performance.

TECHNICAL ASPECTS OF CARDIOPULMONARY EXERCISE TESTING: WHAT IS BEING MEASURED?

To assess contributions of the lungs, the heart, and the circulation to the delivery of oxygen to the exercising muscles, the following parameters are measured:

- V_E (tidal volume × respiratory rate) in L/min,
- oxygen uptake (VO_2) in mL/min,
- carbon dioxide production (VCO_2) in mL/min,
- heart rate in beats/min, and
- oxyhemoglobin saturation in percent.

There may also be electrocardiographic tracings obtained for heart rate and any electrocardiogram changes that may occur with exercise. Ideally, for the evaluation of the heart as the limiting factor, actual measurement of the pumping function of the heart or cardiac output itself would be important. However, this is usually not technically possible with most CPET equipment.

Other parameters that are used for interpretation of the test results are mathematical interactions of the previously described parameters:

- ventilatory equivalents: V_E/VO_2 and V_E/VCO_2; and
- lactate threshold: in a progressive test, it is the determination when there is a shift from aerobic metabolism to anaerobic metabolism.

APPLICATION OF WORKLOAD

An exercise test requires the use of an apparatus for generating a workload for the individual to perform. This is usually in the form of a treadmill or stationary bicycle.

Advantages of a treadmill include

- a more familiar form of exercise for most individuals (walking or running), and
- exercise protocols that have been designed for cardiac stress testing for the evaluation of possible cardiac ischemia.

Disadvantages of a treadmill include

- more difficult for overweight individuals;
- more motion artifact for monitoring equipment, such as oxygen saturation and electrocardiographic measurements; and
- workload achieved is not as precise from individual to individual, but in turn depends on the weight of the individual and speed/incline of the treadmill.

Cycle ergometers or stationary bicycles have the following advantages:

- more reproducible workloads from individual to individual,
- measuring devices that may work more reliably, and
- overweight individuals may be able to perform exercise more efficiently.

The disadvantage of a stationary bicycle is that many individuals may have difficulty pedaling it.

For progressive exercise testing, protocols for treadmills exist (eg, Bruce or Naughton protocols). However, these protocols may increase the workload too quickly to get a complete evaluation of work performance. For the stationary bicycle, the increase in workload can be adjusted, depending on the individual with gradual or progressive increases in wattage (work output or power), from 10 W/min to 50 W/min.

INTERPRETATION OF CARDIOPULMONARY EXERCISE TESTING RESULTS

The results of progressive CPET are interpreted by comparing the individual's performance in terms of the parameters previously described, with predicted or expected values based on normal reference values that have been established and identified in the literature.[1] As previously described, the goal of interpretation is to determine if the person appears limited (usually identified by a lower than expected VO_{2max}), wherein the limitation may be the lungs, the heart, the circulation, or the exercising muscles.

TYPICAL PATTERNS OF INTERPRETATION

Different approaches to interpretation of CPETs have been proposed in the past. These include simple algorithms based on decision points for certain measurement parameters[2] to complete textbooks that discuss the subject and propose interpretation strategies.[3] The statement by the American Thoracic Society/American College of Chest Physicians contains the following regarding interpretation approaches:

- There is no consensus on any one approach.
- Algorithms based on a single key measurement and conceptual framework may be helpful in differential diagnosis, but are limited by excessive reliance on that single measurement.
- An integrative approach that emphasizes the interrelationships, trending phenomena, and patterns of key variable responses in a clinical setting framework is recommended.
- Typical patterns of interpretation results include the following:
  - normal response to CPET,
  - deconditioning or obesity,
  - ventilatory or pulmonary limitation,
  - cardiac limitation.
  - persistent hyperventilation, and
  - chronotropic incompetence (including use of a medication such as a beta-blocker).

Because this test is similar to other testing done in the clinical setting where maximal effort is required for most representative results for that individual, there may be times when suboptimal efforts may make interpretation difficult.

SUMMARY

Evaluation of an individual who presents with respiratory symptoms can involve lung function testing to determine the presence of a respiratory illness or disease. In some instances, the results of this testing (spirometry, lung volumes, and diffusing capacity) may not reveal the cause for the symptoms endorsed by the individual, including the symptom of activity-related dyspnea. Also, if the individual appears to have a reduced exercise performance based on a standard exercise protocol (eg, the Army standard 2-mile run that must be completed in a certain time based on age of the individual), then further testing may be indicated, including performance of CPET. Results of such a test can indicate reduced exercise performance and, in many instances, the cause or causes for that reduced exercise performance.

REFERENCES

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