CARDIOPULMONARY EXERCISE TESTING – COMPLEXITY AND PERFORMANCE

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Abstract: *Cardiopulmonary exercise testing is a specialized advanced investigation characterizing in a complex manner the exercise capacity of the person who undertakes it. Thus, on effort electrocardiogram, blood pressure and oxygen saturation are monitored, oxygen consumption rate and carbon dioxide consumption are measured, as well as other ventilator parameters. The information obtained allows an evaluation of all organs and systems involved in the effort process: cardiovascular, respiratory, musculoskeletal, hematopoietic and mental. In this article, we present the most important parameters resulted from the cardiopulmonary exercise testing and their interpretation.*

Cuvinte cheie: *testul de efort pulmonary, cardiopatie ischemică, insuficiență cardiacă, gaze respiratorii*

Rezumat: *Testul de efort cardiopulmonar este o investigație avansată, specializată ce caracterizează într-un mod complex capacitatea de efort a persoanei care îl efectuează. Astfel, în momentul efortului se monitorizează electrocardiograma, tensiunea arterială și saturația oxigenului, sunt măsurate rata consumului de oxigen și a consumului de bioxid de carbon, precum și numeroși parametri ventilatori. Informațiile obținute permit o evaluare a tuturor aparatelor și sistemelor implicate în procesul de efort: cardiovascular, respirator, musculoscheletal, hematopoetic și neuropsihic. În acest articol vom prezenta cei mai importanți parametri rezultați în urma efectuării testului de efort cardioplumonar, precum și interpretarea lor.*

Cardiopulmonary exercise testing (CPET) is an exercise test that brings a lot of information on the cardiovascular, respiratory, musculoskeletal, hematopoietic and neuropsychic systems. In addition to tracking symptoms during exercise, ECG and blood pressure monitoring, it benefits from measuring the rate of oxygen consumption (VO_2), CO_2 production rate (VCO_2), the ventilatory parameters and O_2 saturation. The patient breathes in a closed system that allows the analysis of these parameters. The resulting data are numerous and their interpretation is often difficult.

A cycloergometer or a treadmill can be used for performing the CPET. The advantages of the cyclergometer are no arm balance during exercise, a more accurate measurement of the workload, less space and easiness in determining the blood pressure. At the same time, the treadmill involves a more natural effort, often more comfortable for the patient. The maximum oxygen consumption on cicloergometer is of 5-11%, lower than on the treadmill.(1,2)

The protocols used may include either a maximal incremental exercise test with the increase in effort by 5-25 W/min or a test with constant workload lasting for 6-10 minutes, especially useful for monitoring the respiratory and gas exchange kinetics.

Before starting, the effort capacity of patients is clinically estimated to determine the increase rate of the workload. At the beginning of the test, the patient needs to accommodate to the closed breathing system and to the effort, then the effort will increase progressively until exhaustion.

CPET has multiple indications (3), having more varied applications than a simple exercise test. The effort testing is necessary because the evaluation of cardiac and pulmonary function at rest cannot accurately predict the performance during exercise.

For diagnostic purposes, CPET is indicated in case of breathlessness without an apparent cause, low exercise capacity, hypoxemia with exertion or exercise-induced asthma.

In case of heart failure and pulmonary vascular disease, CPET has mainly a prognostic purpose. The characterization of the functional capacity can be achieved by CPET for the preoperative evaluation, decreased exercise tolerance evaluation, selection of patients for cardiac transplant and for the evaluation the treatment response.

A very important indication for the modern management in secondary prevention patients with cardiovascular diseases is the exercise prescription for cardiac and pulmonary rehabilitation.

CPET has contraindications (4,5) that are generally common to that of the classic stress test: acute ischemic ECG changes, unstable angina, decompensated congestive heart failure, uncontrolled arrhythmias, third degree heart block, uncontrolled hypertension (SBP>250mmHg, DBP>120 mmHg), thrombophlebitis, intracardiac thrombi, myocarditis, acute pericarditis, severe aortic stenosis or oxygen saturation < 85%.

The mechanisms involved in limiting the effort can be understood by studying CPET and the heart and lung exercise parameters, thus defining the concept of cardiac and pulmonary reserve.

The reserve is calculated as the difference between the maximum value predicted for a measured parameter and the maximum value obtained during effort.

The heart rate reserve is defined as:

HRR = max predicted HR - HR max measured.(6)

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Ventilatory reserve (VR) can be calculated by using the same formula or by comparing the two values:

VR = MVV - VEmax, or VEmax / MVV (7)

During the CPET, there are analysed different cardiac, pulmonary and metabolic parameters which characterize the effort performance.

The metabolism and its efficiency are studied in terms of many parameters:

1. **VO_2** is the amount of oxygen consumed by the subject. At rest, it is equivalent to 3.5 ml/min/kg (1 metabolic equivalent-1 Met). During exercise, it is increased to 4l/min.(8)

There are different values of VO_2 at different time points of effort.

2. **VO_2 max** is the maximum O_2 consumption during exercise and it is calculated when VO_2 does not increase anymore and reaches a plateau despite the continuing effort. It occurs in healthy people, but it lacks in deconditioned people, in cardiovascular or pulmonary disease. In this case, we can measure peak VO_2, as the amount of oxygen consumed during maximum exercise, when there is no plateau. VCO_2 is the amount of CO_2 produced by the body and is the expression of the metabolic status.
3. **Respiratory exchange ratio (RER)** is the ratio VCO_2/VO_2, both measured by respiratory gases. Is a rough measure to characterize the type of metabolism: when RER = 1 mainly carbohydrate catabolism is used, when it is 0.7 carbohydrates and fats are used, and the value of 0.8 is when carbohydrates and proteins are used. During exercise, values of RER $\geq$ 1.1 to 1.15 mean that a maximum effort was reached.
4. **Anaerobic threshold (AT)** estimates the metabolic acidosis which appears when the inefficient aerobic metabolism in muscle switches to the anaerobic metabolism and lactic acid accumulates during near maximal effort. AT is used as an indicator of fitness and can be used to diagnose a limitation in exercise.

AT usually occurs in about 40-50% VO_2 max (9,10), lower values suggesting impaired release of oxygen or its takeover in muscles and actually reflecting a state of hypoxia in the muscle during exercise. AT appearance is more important than VO_2 value at which it appears, indicating that a near maximal effort was reached. The anaerobic threshold is a parameter that cannot be voluntarily controlled and cannot be affected by psychological factors.

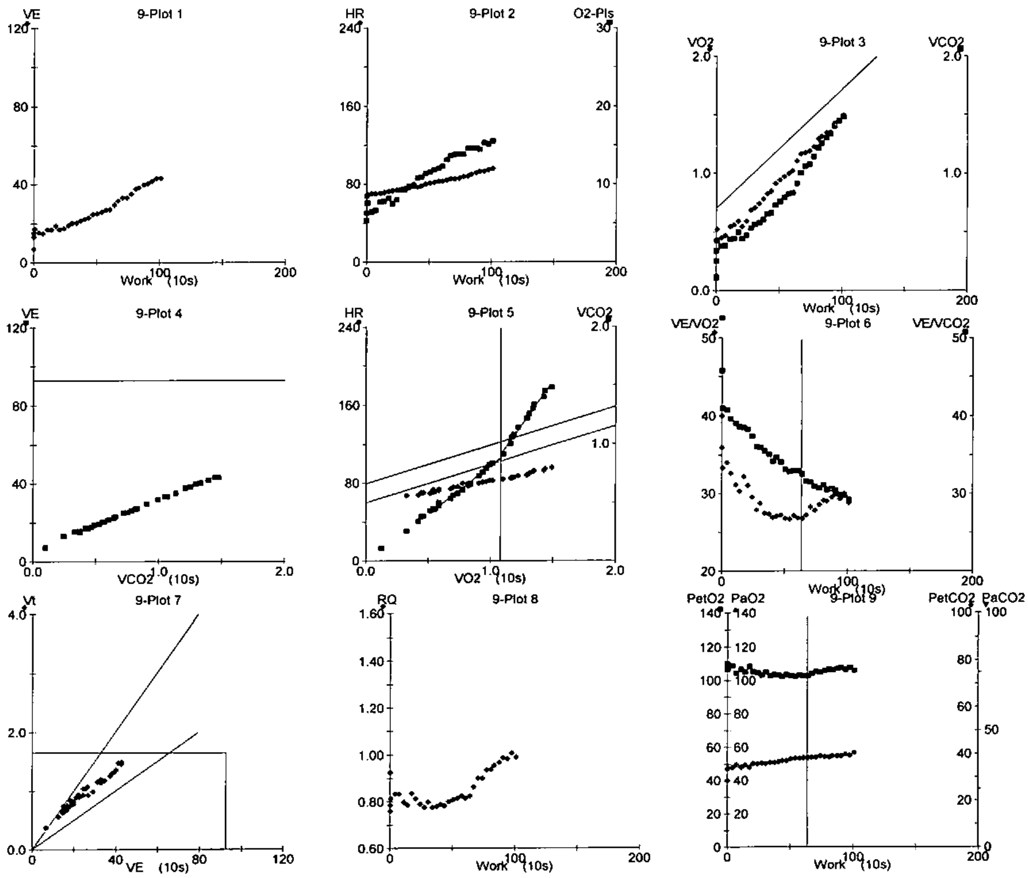
The direct measurement of the AT requires the determination of serum lactate, method which does not have practical applications. In contrast, the noninvasive assessment can be made through CPET, analyzing gas exchange, specifically measuring the oxygen consumption and the CO_2 production.

After the initiation of the anaerobic metabolism, the resulting lactic acid needs to be buffered by bicarbonate, which produces a disproportionate increase in VCO_2 as compared to oxygen consumption.

At this point, the AT can be identified by graphical analysis of the two regression lines of these gases by the V slope method (11), when the two curves have the same slope, equal to 1, during the aerobic metabolism and, when switching to anaerobic metabolism, CO_2 production increases its slope.

When the two graphs will become divergent, the AT is reached, as shown in graphic 5 from figure no. 1.

Figure no. 1. Graphical representation of parameters in cardiopulmonary exercise testing



The parameters characterizing the cardiac function are the classical ones, which are joined by new parameters specific to CPET:

1. **Maximum heart rate (HR)** represents a noninvasive monitoring of cardiac response to exercise. The rest HR and its increase during exercise to the maximum HR are monitored. This is calculated as 220-age and it is reached by the people with a normal exercise capacity, as well as by the deconditioned persons, but not in case of cardiopulmonary diseases that evolves with chronotropic incompetence.
2. **Blood pressure (BP)** is measured at rest and during exercise, with increased values in hypertension. A decrease in BP $\geq$ 10mmHg during exercise implies a negative prognosis.
3. **12 leads ECG** may reveal ST segment changes, arrhythmias and conduction disturbances.
4. **O_2** pulse estimates the quantity of oxygen consumed per heart beat and reflects stroke volume.(12) It is calculated by the ratio of oxygen consumption to HR:
   OP = VO2/HR

Low values are found in the cardiovascular disease, anaemia (low O_2 content), arterial hypoxemia, myopathies or deconditioning.

The graphical representation reflects a linear increase of HR with VO_2 until the maximum HR, afterwards the oxygen pulse reaches a plateau. In cardiovascular disease the HR and VO_2 curve is shifted to the left and O_2 pulse reaches the plateau earlier, because of a low stroke volume and of the need for higher HR for any level of effort.

Ventilatory parameters are:

1. **Spirometry** performed before CPET will provide details on ventilatory performance, mainly measuring the vital capacity (VC), current volume (CV), forced expiratory volume in one second (FEVS1). Thus, it can be calculated by spirometry the predicted maximum voluntary ventilation (MVV), as
   MVV = 40 x FEVS1 (13)
2. **Minute ventilation (VE),** measured in litres of air ventilated per minute, includes the efficient alveolar ventilation and that of the dead space. VE at rest is about 5-10 L / min and during exercise increases 20-25 times.(14)
3. **Ventilatory reserve.** The difference between measured and predicted maximum ventilation represents the respiratory limitation. A respiratory limitation is always abnormal.

At the beginning of the effort, VE increases by increasing the CV, and when it reaches 50-60% of the VC, the ventilation increases by increasing the respiratory rate. Under anaerobic threshold, VE increases linearly with oxygen consumption (VO_2), with a slope VE/VO_2 = 25-30, measured between 25-50% VO_2 max; after reaching the anaerobic threshold, there is a disproportionate increase between ventilation and O_2 consumption. A normal ventilatory response to effort is to achieve 75% of the MVV corresponding to the predicted VO_2 max.(7)

Gas exchange is studied by CPET and the main variables measured were:

1. **Oxygen saturation (SaO_2)** is a simple, noninvasive measurement of the degree of oxygenation by pulse oximetry. Desaturation during exercise of > 4% is considered significant and shows impaired ventilation or reduced pulmonary vascular bed.(15)
2. **CO_2 partial pressure ($PetCO_2$)** is measured at the mouth at the end of each breath. For a normal subject, it can be considered equal to CO_2 mean alveolar partial pressure ($PaCO_2$) and CO_2 mean arterial pressure ($PaCO_2$). $PetCO_2$ is about 40 mmHg before reaching the anaerobic threshold, low values indicating hyperventilation and increased values having significance of alveolar hypoventilation.(16)
3. **O_2 partial pressure ($PetO_2$)** is the oxygen pressure measured at the end of the breathing at mouth level.

TECP interpretation must answer several questions:

1. Is the maximum effort normal? (VO_2 max)
2. Is the cardiovascular response normal? (HR, OP, AT)
3. Is the respiratory response normal? (VE/MVV, VR, $PetCO_2$)
4. Is the gas exchange normal? (VE/VCO_2, PaO_2, P (A-a) O_2, SaO_2)

For a correct interpretation, the parameters must be analyzed as numerical values (normal values shown in table no. 1) and as graphical representation, as shown in figure no. 1.

Table no. 1. Normal cardiopulmonary exercise test parameters (17,18)

Parameters	Normal values
VO_2 max	> 84%
AT	> 40% VO_2 max
FC	> 90%
RFC	< 15 bpm
TA	<220/90 mmHg
PO (VO_2/FC)	>80%
RV (VE/MVVx100)	<85%
FR	<60/min
VE/VCO_2	<34
PaO_2	>80 mmHg

VO_2 max - maximum oxygen consumption, AT - anaerobic threshold, HR - heart rate, HRR - heart rate reserve, BP - blood pressure, OP - oxygen pulse, VR - ventilatory reserve, VE - minute ventilation, MVV - maximum voluntary ventilation, BR - breathing rate, PaO2 - oxygen partial pressure

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