Cardiopulmonary exercise testing – the gold standard in physical performance assesment

Claudiu Avram[1], Mihaela Oraviţan[1], Adrian Nagel[1], Lucian Hoble[1]
1 - Physical Education and Sport Faculty, West University of Timişoara, Romania

Abstract
Background: Cardiopulmonary exercise testing (CPX) is a modern procedure that allows us to evaluate the global performance of a subject. Because CPX devices are expensive and less popular due to a less amount of specialists in this field, many of laboratories uses the more common ECG stress tests for physical performance assessment. *Aim:* to demonstrate the importance and accuracy of cardiopulmonary exercise testing comparing with traditional maximal electrocardiographic (ECG) stress test without gas exchange analysis. *Methods:* 18th elite soccer players (age 22.7±6 years, body mass 74.6±9.5 kg, height 175.4±9.8 cm) participated in the study. The subjects accomplished two treadmill effort tests with and without gas analyses, in 2 consecutive days interval. *Results:* At the end of the study we noticed a highly significant statistical difference ($p<0.0001$) between the investigated testing methods. In gas exchange testing method we found a decreased level of all the parameters evaluated comparing to stress ECG: VO_2 peak ($ml*kg^{-1}*min^{-1}$) = 55.4±5.2 vs. 67.8±5.7; AT ($ml*kg^{-1}*min^{-1}$) = 41.2±7.6 vs. 47.4±6.9; VO_2/HR (ml) = 23.8±2.5 vs. 23.8±2.5. *Conclusions:* Asessment of exercise performance based solely on a maximal stress ECG without gas analyzing is inaccurate. Furthermore, estimation of peak exercise responses based upon calculation of VO_2 peak from peak work rate are inappropriate in sportsman. The study demonstrate once again that CPX remain the most accurate and reliable test for detection of AT and for a comprehensive physical performance assessment and cannot be replace by other surrogate laboratory exercise tests like stress ECG.
Key-words: ergospirometry, physical performance, maximal oxygen uptake.

Cardiopulmonary exercise testing (CPX) evaluate the global performance of a subject through reaching his cardio, ventilatory or muscular limitation. By using gas exchange analysis, CPX testing allows for the simultaneous study of cellular, cardiovascular, and ventilatory responses to exercise. The gold standard in exercise testing is the laboratory-based maximal incremental gas exchange test. Since it spans the entire range of tolerable work-rates, the incremental exercise test is the test of choice for:

- assessment of limited exercise capacity and investigation into the factors limiting exercise performance;
- assessment of risk of participation in exercise programmes;
- prescription of exercise training. (1)

For all of these indications, incremental exercise testing is necessary, as it provides physical trainers with key data that cannot be obtained from other individual measures of pulmonary or

cardiac function, arterial blood gas levels and acid/base status, or other less-comprehensive exercise tests.

However, the test relies on a number of devices, sensors, and assessment which will be valid only if all function correctly, the test can generally be performed within 20 min.

The most commonly selected ergometers for incremental exercise testing are the treadmill and cycle ergometer. Performance of the test on a cycle ergometer or a treadmill is an important choice, as each has advantages and disadvantages. (Table 1).

In sportsmen it is recommended to choose the bicycle or treadmill according to their moving patterns - closed or open kinetic chain (e.g. for runners, soccer player – treadmill, for cyclists, skiers – cycle ergometers).

The maximal incremental exercise test design consists of:

- a resting baseline phase of 2–3 min
- a period of unloaded pedaling (typically of 3 minutes)
- the incremental phase of the exercise test
- a recovery period of unloaded pedaling or a very low work-rate in order to avoid any sudden drop in blood pressure due to pooling of venous blood. (2)

Tabel I. Advantages and disadvantages between bicycle and treadmill effort tests.

	Bicycle	Treadmill
VO_2 max	lower	higher
Leg muscle fatigue	often limits	less limiting
Work rate quantification	yes	estimation
Weight bearing in obese	less	more
Noise and artifacts	less	more
Safety issues	less	more

The choice of the appropriate work rate increment size is of considerable importance in the tailoring of the test to the individual subject. Ideally, peak work-rate should be reached within 8–12 min. (3)

For exercise based rehabilitation purposes, measurements typically include work-rate, 12-lead electrocardiography and heart rate (HR), oxygen uptake (VO_2) and carbon dioxide production (VCO_2), anaerobic threshold (AT), oxygen pulse (VO_2/HR), blood pressure (BP), and symptom scores (e.g. dyspnoea and exertion). (4)

Lactate threshold or anaerobic threshold (AT) is a VO_2 value above which exercise cannot be sustained for a long period of time and which is associated with a continuous accumulation of lactate in the blood. It is most accurately and commonly determined using breath-by-breath analysis of oxygen uptake and carbon dioxide output.

AT determination through CPX is a non-invasive method omparing to blood lactate tests which is more convenient for the tested subjects. For endurance or resistance training purposes, AT is

the most useful parameter in order to tailor training and it has the advantage of being independent to the subject motivation. (Figure 1-3) (2)

The oxygen pulse (VO_2/HR) is given by the ratio of VO_2 to HR, and is determined by stroke volume and the arterio-mixed venous O2 content difference. VO_2/HR will increase with a hyperbolic profile as WR increases. The steeper HR-VO_2 relationship in unfit subjects means that their O2 pulse profile will be relatively shallow. Therefore, the O2 pulse at peak exercise is dependent on fitness, as well as body mass, sex, age and hemoglobin concentration. (Figure. 4)

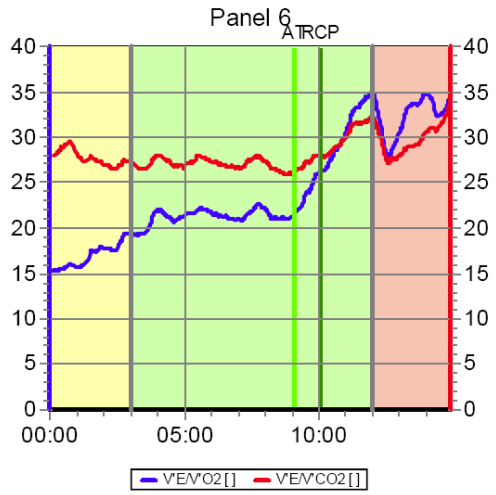

Figure 1. Detection of AT using oxygen and carbon dioxide equivalents; RCP: respiratory conversion point, AT: anaerobic thresholdVE/VO2: oxygen equivalent, VE/VCO2: carbon dioxide equivalent

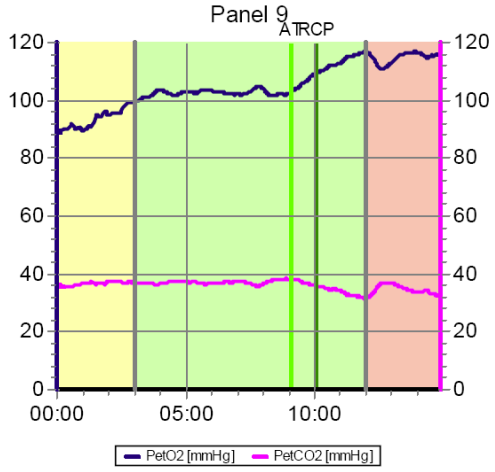

Figure 2. Detection of AT using oxygen and carbon dioxide end tidal pressure; PetO2: oxygen end tidal pressure, PetCO2: carbon dioxide end tidal pressure

All three parameters (VO_2, AT, VO_2/HR) is important indicators for physical fitness assessment both in sportsmen and for exercise based rehabilitation purposes.

Aim

The aim of this study is to demonstrate the importance and accuracy of cardiopulmonary exercise testing comparing with traditional maximal electrocardiographic (ECG) stress test without gas exchange analysis.

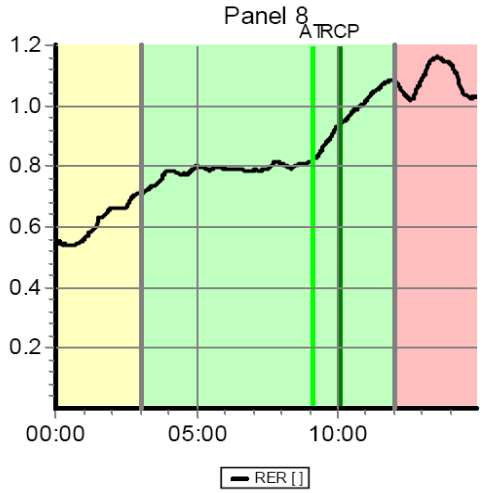

Figure 3. Detection of AT using rate of expiratory ratio – one of the most reliable parameter in detection of AT. RER: rate of expiratory ratio,

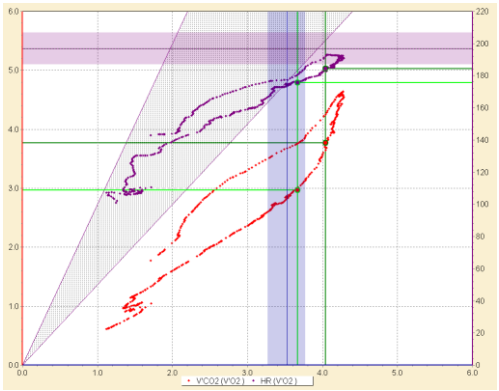

Figure 4. Evaluation of VO_2/HR (oxygen pulse) – the values are in the normal range

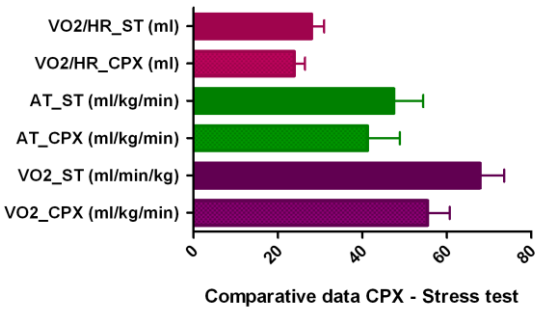

Figure 5. Comparative stress tests evaluation of oxygen uptake, level of anaerobic threshold and pulse oxygen. The data represents mean with standard deviation.

Methods

18th elite soccer players (age 22.7+/-6 years, body mass 74.6+/-9.5 kg, height 175.4±9.8 cm) participated in the study. The subjects accomplished two treadmill effort tests with and without gas analyses, in 2 consecutive days interval.

For CPX testing we used a Metalyzer 3B device (Cortex, Germany) performing a breath by breath measurement of oxygen uptake and carbon dioxide production along with a 12 lead stress electrocardiographic device (GE Medical System, Germany). For the second evaluation we used only stress ECG to test the subjects.

For all the subjects included we used the same treadmill protocol consists of 2 minutes resting period, 3 minutes of 5 km/hour walking followed by up to 12 minutes of velocity incremental phase and 5 minutes of cool down at 5 km/hour.

Maximal oxygen uptake (VO_2 peak), anaerobic threshold (AT) and oxygen pulse (VO_2/HR) measured by both testing methods, were the parameters used to evaluate the physical performance of the soccer players. For the second method (stress ECG evaluation) we estimate the VO_2 peak using the Wasserman formula (VO_2 peak [ml/min] = 151 ml/min + 5.8*body weight[kg]+ 10.5 * work load[Watt]) and AT as the point in which the HR is not increasing despite increasing in work rate.

Statistical analysis was performed using the GraphPad Software (GraphPad v. 3.05, SUA). Data are reported as mean ± standard deviation. Compa-risons between testing results were made by paired t tests.

Table II. Comparison of maximal oxygen uptake, level of anaerobic threshold and pulse oxygen measured by both stress test methods (with and without gas exchange analyses).

	VO_2 peak ($ml*kg^{1}*min^{-1}$)	AT ($ml*kg^{-1}*min^{-1}$)	VO_2/HR (ml)
Stress test without gas exchange analyses	67.8±5.7	47.4±6.9	27.9±2.9
Cardiopulmonary exercise testing	55.4±5.2	41.2±7.6	23.8±2.5
p value	<0.0001	<0.0001	<0.0001

Results

In gas exchange testing method we found a decreased level of all the parameters evaluated comparing to simple stress ECG: VO_2 peak ($ml*kg^{-1}*min^{-1}$) = 55.4±5.2 vs. 67.8±5.7; AT ($ml*kg^{-1}*min^{-1}$) = 41.2±7.6 vs. 47.4±6.9; VO_2/HR (ml) = 23.8±2.5 vs. 23.8±2.5. (Table 2)

At the end of the study we noticed a highly significant statistical difference ($p<0.0001$) between the investigated testing methods.

Conclusions

Asessment of exercise performance based solely on a maximal stress ECG without gas analyzing is inaccurate. Furthermore, estimation of peak exercise responses based upon calculation of VO_2 peak from peak work rate are inappropriate in sportsman.

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