Noninvasive Medical Examination and Optimal Physical Activity Prescription Based on Stress Test

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Abstract: Exercise testing offers the investigator the possibility of simultaneously studying the cellular, cardiovascular and ventilatory systems responses under conditions of precisely controlled stress. Exercise testing with appropriate gas exchange measurements can also serve to grade the adequacy of cardiorespiratory function. This is of significant practical impact because of the increased number of therapeutic options now available for conditions that cause exercise limitation. Moreover, an individual patient may have mixed defects (e.g., cardiac and respiratory), and consequently, it is often necessary to determine the relative contribution of each to the patient's symptoms. Exercise testing can also provide vital information regarding the limits of systemic function before surgery or other therapy. Heart rate, pulmonary ventilation, breathing frequency and blood pressure are automatically measured during the examination. Also amount of oxygen and carbon dioxide are measured in patient breath and load is also set by computer. From these data, many of other standard parameters are calculated by means of personal computer. In this paper, the system for automatic cardiopulmonary examination measuring and evaluating is described. Application of this system is possible in work medicine, sport medicine and rehabilitation. Furthermore it allows for the analysis of training or rehabilitation effects, of drug effects as well as of technical applications (for example setting of cardiac pacemakers). The aim of our project was to create suitable applications of physical activities to the individual subjects, handicapped or healthy according to their level of fitness and exercise test results with the help of a computer program.

Key-Words: Exercise test, heart rate, ventilation, volume, expired gas, training level.

1 Introduction

Physical exercise testing requires the interaction of physiologic mechanism that enable the cardiovascular and respiratory systems to support the increased energy demands of contracting muscles. Both systems are consequently stressed during exercise. Their ability to respond adequately to this stress is a measure of their physiologic competence (or "health"). An appreciation of the normal response profiles of the gas transport systems that support cell respiration is essential to recognize the abnormal response patterns that characterize the many disease states that affect them. The increased metabolic rate during exercise requires an appropriate increase in O₂ flow into the muscles. Simultaneously, the CO₂ produced by the muscles must be removed to avoid severe tissue acidosis with its adverse effects on cellular function. To satisfy the increased gas exchange needs of the muscle cell during exercise, precise coupling of the supporting physiologic mechanism is required. This involves the lungs, the pulmonary circulation, the heart, and the peripheral circulation. A treadmill or bicycle ergometer permits a controlled and reproducible exercise stress. Because the subject is relatively stationary, blood pressure and heart rate may be obtained repeatedly, and a continuously monitored electrocardiogram (ECG) incorporating 1, 3 or 12 leads may be used.Expired minute ventilation is determined using a pneumotachograph or other type of in-line flow or volume measurement device. The breath by breath measuring system is used for expired gas, which is sampled and analyzed for O₂ and CO₂ concentrations. Differences in O₂ and CO₂ concentrations from the beginning to the end of each breath are smoothed, and the resultant O₂ and CO₂ concentrations are equal to the volume-weighted average concentrations or "mixed expired" O₂ and CO₂ concentrations [1, 2, 3, 4].

For noninvasively physical load response investigation, measuring systems was developed. The measuring system is connected to personal computer (PC) which shows the information on the display, evaluates, memorizes and prints data.

The turbine with digital output is used for ventilation measuring. For the heart rate measuring the SPORTTESTER is used and information is wireless transmitted. The following devices are used for the exercise system:
a) Flow - turbine flow meter, 26 mm, VE range 10 - 250 l/min.
b) %O₂ Expiratory - Zirconia oxygen sensor, range 0 to 100%.
c) %CO₂ Expiratory - Infrared carbon dioxide sensor, 0 - 10 % CO₂, dual detector technology.
d) Heart pulse - heart rate meter SPORTTESTER is used.
e) Pressure sensor - differential dual ports integrated silicon pressure sensor on chip signal conditioned, temperature compensated and calibrated is used.
f) Pump - micro diaphragm gas sampling pump is connected to a gas analyzer.

**Table 1**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VE</td>
<td>Ventilation</td>
<td>l/min, BTPS</td>
</tr>
<tr>
<td>RF</td>
<td>Respiratory frequency</td>
<td>1/min</td>
</tr>
<tr>
<td>Vt</td>
<td>Tidal volume</td>
<td>l, BTPS</td>
</tr>
<tr>
<td>VO₂</td>
<td>Oxygen uptake</td>
<td>l/min, STPD</td>
</tr>
<tr>
<td>VCO₂</td>
<td>Production of CO₂</td>
<td>l/min, STPD</td>
</tr>
<tr>
<td>FeO₂</td>
<td>mixed expired O₂</td>
<td>%, dry</td>
</tr>
<tr>
<td>FeCO₂</td>
<td>mixed expired CO₂</td>
<td>%, dry</td>
</tr>
<tr>
<td>HR</td>
<td>Heart rate frequency</td>
<td>bpm</td>
</tr>
<tr>
<td>RQ</td>
<td>Respiratory quotient</td>
<td>---</td>
</tr>
<tr>
<td>VE/VO₂</td>
<td>Ventilatory Equiv. for O₂</td>
<td>---</td>
</tr>
<tr>
<td>VE/VCO₂</td>
<td>Ventilatory Equiv. for CO₂</td>
<td>---</td>
</tr>
<tr>
<td>VO₂/HR</td>
<td>Oxygen pulse</td>
<td>ml/bpm</td>
</tr>
<tr>
<td>VO₂/Kg</td>
<td>VO₂ per Kg</td>
<td>ml/min-Kg</td>
</tr>
<tr>
<td>VO₂peak</td>
<td>Maximum value VO₂</td>
<td>ml/min-Kg</td>
</tr>
<tr>
<td>VEmax</td>
<td>Maximum value VE</td>
<td>l/min, BTPS</td>
</tr>
<tr>
<td>HRmax</td>
<td>Maximum value HR</td>
<td>bpm</td>
</tr>
<tr>
<td>VO₂/HRmax</td>
<td>Max. value VO₂/Max. HR</td>
<td>ml/bpm</td>
</tr>
<tr>
<td>RFmax</td>
<td>Maximum value RF</td>
<td>l/min</td>
</tr>
</tbody>
</table>

2 Data measuring and evaluating

During the exercise testing the system acquires the following main signals: Heart frequency, Flow, %O₂ Expiratory, %CO₂ Expiratory. These signals are processed in PC software [5, 6, 7, 8]. The standard parameters calculated by the program are shown in Table 1. Also a continuously monitored 12 leads ECG is separately used. Expired gas is passed into mixing chamber from which gas is sampled and analyzed for O₂ and CO₂ concentrations. Differences in O₂ and CO₂ concentrations from the beginning to the end of each breath are smoothed, and resultant O₂ and CO₂ concentrations are equal to the volume-weighted average concentrations or "mixed expired" O₂ and CO₂ concentrations [9, 10, 11, 12, 13].

The user can edit the data acquired during the test, or after the test. All measured data and personal data of the patient are stored in Microsoft database. The program can display and print many types of protocols and graphs. The curves can be filtered by least-squares data smoothing. Our program enables to find automatically some important values from the data measured. In some cases, the models of different functional dependencies are needed. In most of the graphs the functional dependencies based on polynomial least-squares are used and coefficients are displayed (Fig. 2). This function is useful mainly for testing of athletes (comparing different types of load).

Maximal oxygen consumption (VO₂ max) is the highest amount of oxygen a person can use from inspired air while performing dynamic exercise involving a large part of total muscle mass. VO₂max kg⁻¹ is considered the most predictive value of cardiovascular fitness and exercise capacity. It is convenient to express oxygen uptake in multiples of sitting/resting requirements [14, 15, 16]. One metabolic equivalent (MET) is a unit of sitting/resting oxygen uptake = 3.5 ml of O₂ per kilogram of body weight per minute [ml.kg⁻¹.min⁻¹].
Another important value is an anaerobic threshold (lactate threshold - LT). The anaerobic threshold is defined as the level of exercise above which aerobic energy production is supplemented by anaerobic mechanisms and is reflected by increase in lactate concentration in a blood [17, 18]. The program has a possibility to detect LT based on V-slope method. Above LT, the increase in lactic acid production results in an increase \( VCO_2 \) to \( VO_2 \) ratio (respiratory exchange ratio). When these variables are plotted against each other, the relationship is composed of two apparently linear components, the lower of which has slope of slightly less than 1.0, whereas the upper component has a slope steeper than 1.0, [19]. The intercept of these two slopes is lactate threshold (LT), shown in Fig. 3 (V-slope method). More exact method for LT estimation used in program is based on lactate samples taken during the examination and lactate curve construction. From 3 or 4 samples of lactate, the LT is determined by the exponential approximation (Fig. 4).

During the examination, immediately values of some important parameters are displayed and also graph of HR and RQ are shown (Fig. 5).

### 3 Results

Directly from the results of the exercise test the program takes over \( VO_2 \) max. \( kg^{-1} \), \( HR \) max and LT values (with corresponding values of \( HR, VO_2 \) \( kg^{-1}, VO_2 \) max.\( HR^{-1} \) on the level of LT). The program is able to display also the values from each steps of the exercise test, which are marked by the physician. Calculation of corresponding MET and \( kJ \) values follows. Under mentioned equations are used following already published studies [15, 16, 17]. In the next step the user chooses between the healthy or handicapped subject.

#### Healthy persons

In case of the healthy person there is necessary to insert the type of his/her present physical activity (no, or minimal activities, recreational or sports activities). It is followed by the question:

*Do you want to improve your physical performance?*

In case of the positive answer, the program calculates the recommended training value \( VO_2 \) \( kg^{-1} \) train and \( HR \) train according to the formula (1) and (2):

\[
VO_2 \text{ \( kg^{-1} \) train} = \left( VO_2 \text{ \( max. \) \( kg^{-1} \) /350} \right) + 0.6/100 \% \text{ (1)}
\]

\[
HR \text{ \( train \)} = \left( VO_2 \text{ \( max. \) \( kg^{-1} \) /350} \right) + 0.6^* \left( HR \text{ \( max \) - \( HR \text{ \( rest \) } \right) } + HR \text{ \( rest \) } \left( \text{pulse/min} \right) \text{ (2)}
\]

When no expired gas was analyzed during exercise test, \( HR \text{ \( train \}) \) is calculated according to this simple formula (3):

\[
HR \text{ \( train \} = (HR \text{ \( max \) - \( HR \text{ \( rest \) )/0.6 + HR \text{ \( rest \) \} [pulse/min] \text{ (3)}
\]

The program permits values corrections by a user (e.g. physician). Obtained or corrected values are introduced in formulas [20, 21, 22] for running and walking velocities (v) according equations (4) and (5):


In the next step the program offers suitable activities according to corresponding MET values. Upper and lower MET values are estimated as the training MET value ± 10%. Also these values can be corrected by the physician. The program offers possible kinds of activities in the rated MET range. From these the user can choose suitable activities for a concrete person. Example of possible screen display is shown in Fig. 6. For improvement of physical performance in recreational activities the program recommends the training frequency 3 times 30 minutes per week as a minimum. The program sets no special procedures for high-trained sportsmen because it cannot involve different practices in many sports branches. Nevertheless VO₂ max kg⁻¹, HRmax and LT value with corresponding values of HR, VO₂ max kg⁻¹, VO₂ max HR⁻¹ on LT level are determined too.

**Handicapped persons**

Procedures mentioned above are not quite valid for handicapped persons. Nevertheless, many forms and stadiums of some diseases are compatible with definite types and levels of physical activities too. Coronary heart disease (CHD) and hypertension (HD) are the most frequent diseases that come in to question. In these patients there is mostly necessary to interrupt the exercise test prior to VO₂ max is reached. The interruption must be made for the warning symptoms like dyspnoea, stenocardia, dangerous BP values, arrhythmias and ischemic signs in ECG. The last step of the exercise test without warning symptoms is usually called symptoms limited load. This level must be determined by a physician. Thus, he/she orders VO₂ max kg⁻¹, VO₂ max HR⁻¹, MET and HRmax - each of them symptoms limited values. According to MET value, the program includes the CHD patient in a corresponding stadium of NYHA classification [16] and sets him/her the physical activity level that can be corrected by the physician too. From the recommended range of MET intensity (MET train ± 10%) the program proposes mainly dynamic, cyclic and mild endurance activities for CHD and HD patients. Besides, there is a safety precaution in form of LT in patients. It is generally accepted, that the physical activity in patients with CHD and HD should be realized in the aerobic zone. Hence, if the recommended activity would be set above LT, the program asks:

_Do you really wish to set the physical activity above LT?_

Each patient obtains 2 HR values: HR for training should be reached for the optimal level of physical activity and maximal HR should not be exceeded.

5 Conclusions

The demonstrated system and program could be used by physicians as a support for the physical activity prescription both in healthy and handicapped persons.

**Practice points**

- The computer programme takes over results from the exercise test directly
- Programme can be applied both in healthy and in handicapped persons.
- Practical activities, HR train and HRmax suggested by the programme can be changed by the user (physician) in each level.
- Physicians can compare their own proposals with the results of the program.

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Fig. 6. Example of screen offers different possibility of activities based on test result.