CARDIOPULMONARY EXERCISE TESTING FOR VO_2MAX DETERMINING IN SUBJECTS OF DIFFERENT PHYSICAL ACTIVITY

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Abstract

Cardiopulmonary exercise testing (CPET) provides assessment of the integrative exercise responses involving the pulmonary, cardiovascular, haematopoietic, neuropsychological, and skeletal muscle systems, which are not adequately reflected through the measurement of individual organ system function. This non-invasive, dynamic physiological overview permits the evaluation of both submaximal and peak exercise responses, providing the doctor with relevant information for clinical decision making. CPET is increasingly being used in a wide spectrum of clinical applications for the evaluation of undiagnosed exercise intolerance and for the objective determination of functional capacity and impairment. Its use in patient management is increasing with the understanding that resting pulmonary and cardiac function testing cannot reliably predict exercise performance and functional capacity and that overall health status correlates better with exercise tolerance than with resting measurements. CPET involves measurements of respiratory oxygen uptake, carbon dioxide expenditure and pulmonary ventilation during a step-vice increased physical workload up to the maximum (or symptom-limited level in patients) on ergometer. In this paper the principle of CPET is described and results for VO_{2max} *and* $VO_{2max/kg}$ *of almost 3000 measurements in subjects of different physical activity are presented. These values characterizing cardiorespiratory capacity of the subjects were compared to the values of maximal performance achieved during stress test on bicycle ergometer (Wmax and Wmax/kg) and regression equations for* $VO_{2max} – W_{max}$ *and* $VO_{2max/kg} – W_{max/kg}$ *were calculated.*

Keywords

cardiopulmonary exercise testing, VO_{2max}*, bicycle ergometer, regression equations, measuring system*

Introduction

Cardiopulmonary exercise testing (CPET) provides assessment of the integrative exercise responses involving the pulmonary, cardiovascular, haematopoietic, neuropsychological, and skeletal muscle systems, which are not adequately reflected through the measurement of individual organ system function. This non-invasive, dynamic physiological overview permits the evaluation of both submaximal and peak exercise responses, providing the doctor with relevant information for clinical decision making. CPET is increasingly being used in a wide spectrum of clinical applications for the evaluation of undiagnosed exercise intolerance and for the objective determination of functional capacity and impairment. Its use in patient management is increasing with the understanding that resting pulmonary and cardiac function testing cannot reliably predict exercise performance and functional capacity and that overall health status correlates better with exercise tolerance than with resting measurements. CPET involves measurements of respiratory oxygen uptake (VO_2), carbon dioxide expenditure (VCO_2), and pulmonary ventilation during a step-vice increased physical workload up to the maximum (or symptom-limited level in patients) on ergometer. In this paper the principle of CPET is described and results for VO_{2max} and $VO_{2max/kg}$ of 2777 measurements in subjects of different physical activity are presented. These values characterizing cardiorespiratory capacity of the subjects were compared to the values of maximal performance achieved during stress test on bicycle ergometer (W_{max} and $W_{max/kg}$) and regression equations for VO_{2max} – W_{max} and $VO_{2max/kg}$ – $W_{max/kg}$ were calculated.

VO_{2max} and $VO_{2max/kg}$ values were directly obtained during 2777 measurements in competitive athletes and active but not competing subjects. W170 and W170/kg characterize physical working capacity. W170 is the estimated performance in watts, corresponding to the heart rate 170 beats/min [74, 75].

The normatives of cardiorespiratory capacity for different age groups of male and female endurance athletes (Group A), team sport players (Group B) and

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other sports (group C) were established, and compared to normatives for Czech population based on the International Biological Program (IBP) results [62]. Group D in our study included subjects performing sport and physical activity in their leisure time, however, did not participated in any competitive sport (so called "hobby" athletes).

The most favorable values of cardiorespiratory capacity (both VO_{2max}; $VO_{2max/kg}$ and W170; W170/kg) were found in the group A athletes (endurance trained) – both males and females. Their level highly exceeded the values of untrained Czech IBP population and also those obtained in control group D in this study.

The highest correlation was found between VO_{2max} and W_{max} and between $VO_{2max/kg}$ and $W_{max/kg}$. This high correlation was very similarly high in the whole sample of 2777 examinations, in the sample of men (n=2015) and sample of women (n=762) and also in all age-groups in different athletic groups A to D.

It was proved that VO_{2max} and $VO_{2max/kg}$ values could be calculated according to the maximal performance attained on bicycle ergometer [73].

During spiroergometric examination the values of stroke volume and cardiac output can also be calculated [52, 64]. These values represent additional data closely correlating with the adaptive changes of circulatory system.

Regular aerobic endurance exercise could reduce biological age of active individuals by 10 to 20 years with a correspondingly decreased likelihood of becoming dependent when a senior and an expressive improvement in the quality of the final years of life [7, 57, 71]. VO_{2max} and $VO_{2max/kg}$ values represent important health quality marker. They also offer feedback information, positive and/or negative, about the effectiveness of physical activity influencing its development. Thus, aerobic fitness level has been strongly and positively associated with reduced disease and mortality rates, good quality of life, performance level, and functional ability.

Exercise capacity and oxygen uptake measuring

Peak exercise capacity is defined as "the maximum ability of the cardiovascular system to deliver oxygen to exercising skeletal muscle and of the exercising muscle to extract oxygen from the blood". Consequently, exercise tolerance is determined by three factors: pulmonary gas exchange; cardiovascular performance, including the peripheral vascular tree; and skeletal muscle metabolism.

Understanding the Fick equation is of paramount importance for appreciating the utility of functional exercise testing. At rest, the Fick equation states that oxygen uptake (VO_2) equals cardiac output times the arterial minus mixed venous oxygen content:

$$VO_2 = SV \cdot HR \cdot \left(C_aO_2 - C\bar{v}O_2\right) \qquad (1)$$

where SV is the stroke volume, HR is the heart rate, CaO_2 is the arterial oxygen content, and CvO_2 is the mixed venous oxygen content. Oxygen uptake is often normalised for body weight and expressed in units of ml $O_2 \cdot min^{-1} \cdot kg^{-1}$. One metabolic equivalent (MET) is the resting oxygen uptake in a sitting position and equals 3.5 $ml \cdot min^{-1} \cdot kg^{-1}$.

This reflects the maximal ability of a person to take in, transport and use oxygen. It defines that person's functional aerobic capacity. VO_2max has become the preferred laboratory measure of cardiorespiratory fitness and is the most important measurement during functional exercise testing. In healthy people, a VO_2 plateau occurs at near maximal exercise. This plateau in VO_2 has traditionally been used as the best evidence of VO_{2max}. It represents the maximal achievable level of oxidative metabolism involving large muscle groups.

Cardiopulmonary exercise testing measuring principles

Several different methods exist for measuring ventilation and respiratory gas parameters during exercise. Some clinical systems rely on breath-by-breath analysis techniques because they provide the best measures of the metabolic response to exercise.

The block diagram of measuring system is shown in Fig. 1. The exercise tests were performed on an electronically braked cycle ergometer (or treadmill) controlled by computer. Subjects were familiarized with the apparatus and performed a continuous incremental symptom-limited maximal test for determination of VO_{2max} and lactic acidosis threshold (LAT).

A non-rebreathing valve is connected to a mouthpiece to prevent mixing of inspired and expired air. Oxygen and carbon dioxide gas analysers are usually incorporated in a "metabolic cart" designed specifically for functional testing. Respiratory volumes are computed by integrating the air flow signals over the time of inspiration and expiration. Average minute volumes are derived from the breath-by-breath data multiplied by the respiratory rate [65].

Many different protocols are used for functional testing. The purpose of the test and the functional capabilities of the patient determine the choice of protocol. In evaluating patients with congestive heart failure (CHF), both bicycle and treadmill protocols have been used. The rate of workload progression is somewhat arbitrary, although it has been suggested that optimal exercise duration for functional assessment on the bicycle is between 8 and 17 minutes. Bicycle work is quantified in watts (W) or in kilopondmetres/min (kpm/min; 1 W = ~ 6 $kpm \cdot min^{-1}$). The initial workload for patients with CHF is usually 20–25 W and in-

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creased by 15–25 W every 2 minutes until maximal exertion (symptom limited maximum) is reached. Alternatively, the workload can be computer controlled for electronically braked bicycle ergometers, and a ramp protocol (eg. 10 $W \cdot min^{-1}$) is often used.

Testing protocol in our laboratory was based on the testing protocol used in the IBP [42, 62]. In healthy and average fit subjects three submaximal workloads of 3-min duration were used. The first workload corresponded approximately to 1 $W \cdot kg^{-1}$ body weight of the subject, the second workload to 1.5 $W \cdot kg^{-1}$ body weight and the third workload to 2 $W \cdot kg^{-1}$ body weight respectively. After 9 minutes warming up the workload was consecutively increased every half minute by 20 to 30 W (dependant on body weight and age of the subjects) until exhaustion. In highly fit subjects the initial warming up submaximal workloads were 1.5 $W \cdot kg^{-1}$, 2 $W \cdot kg^{-1}$ and 2.5 $W \cdot kg^{-1}$ of body weight respectively.

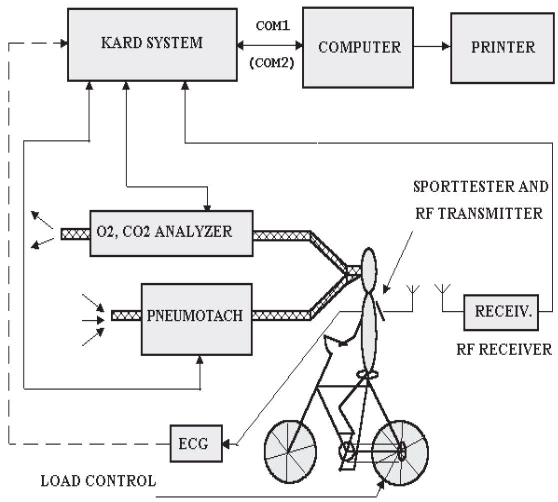

Fig. 1: Block diagram of measuring system for non-invasive CEPT. The cycle or treadmill ergometer can be used.

Equipment for cardiorespiratory capacity evaluation is shown on Fig. 2. The electrical signals from sensors were connected to microcontroller systems (KARD SYSTEM). The expired gas samples were connected to respiratory gas analyzer (O_2-CO_2 analyzer). All electrical signals from sensors and from gas analyzer were processed in personal computer. Both patients with heart disease and healthy subjects require continuous ECG monitoring and frequent blood pressure measurements during exercise testing. Since verbal communication is usually not possible with the mouthpiece apparatus, hand signals are usually used during exercise.

Oxygen uptake (VO_2) is determined by cellular O_2 demand up to some level that equates to maximal rate of O_2 transport, which then is determined by that maximal rate of transport. As VO_2 increases with increasing external work, one or more of the determinants of VO_2 approach limitations (eg, stroke volume, heart rate, or tissue extraction), and VO_2 versus work rate may begin to plateau. This plateau in VO_2 has traditionally been used as the best evidence of VO_{2max}. The main determinants of a normal VO_{2max} are genetic factors [10, 11], quantity of exercising muscle, age, gender and body size [5]. Other important factors are previous training and patient motivation. VO_{2max} should be expressed in absolute values ($l \cdot min^{-1}$) and as a percentage of the predicted value. VO_2 can increase from a resting value of about 3.5 $ml \cdot min^{-1} \cdot kg^{-1}$ (about 250 $ml \cdot min^{-1}$ in an average person) to VO_{2max} values about 15 times the resting value (30–50 $ml \cdot min^{-1} \cdot kg^{-1}$). Athletes may attain values over 20 times their resting values (up to 90 $ml \cdot min^{-1} \cdot kg^{-1}$).

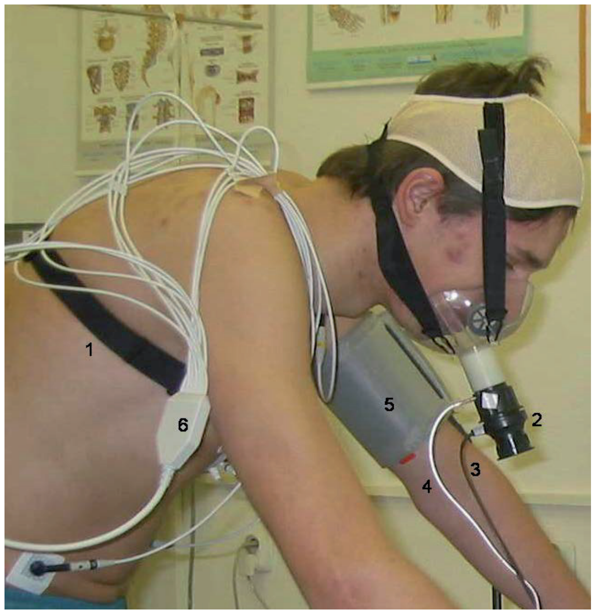

Fig. 2: Equipment for cardiorespiratory values measuring: 1-HR belt (Sporttester), 2-turbine for pulmonary ventilation measuring, 3-cable for ventilation pulses, 4-tube for expired gas samples, 5-cuff for blood pressure monitoring, 6-cable for ECG monitoring.

The ratio of carbon dioxide output/oxygen uptake (VCO_2/VO_2) is called the respiratory exchange ratio (RER). Under steady state conditions, the RER equals the respiratory quotient (RQ). The RQ value is determined by the fuels used for metabolic processes. RQ of 1.0 indicates covering the metabolic demands exclusively by carbohydrates, while RQ 0.7 indicates metabolism only by free fatty acids. Normal resting values of RQ~0.8 indicates that metabolic demands are by third covered by carbohydrates and by two thirds by free fatty acids. During step-vice increased workload RQ increases up to 1.0 and more due to higher utilization of carbohydrates in muscle metabolism and buffering processes connected to metabolic acidosis

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evoked by near maximal and/or maximal intensity workload.

Example of HR and VO_2 dependence on workload intensity is shown in Fig. 3 and 4.

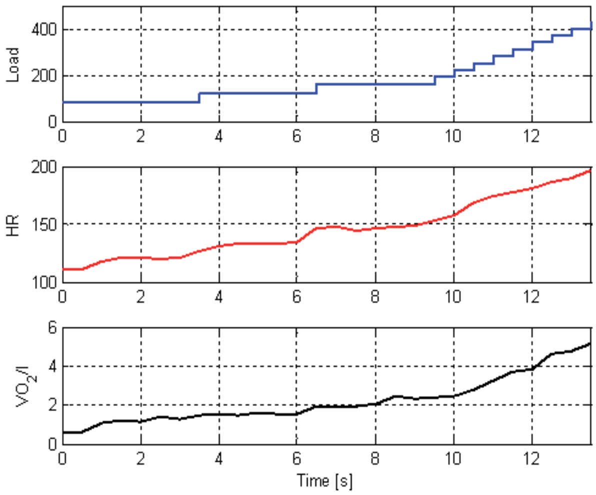

Fig. 3: Workloads [in W] and corresponding HR (heart rate) and VO_2 [l/min] during CPET (male ice hockey player, 18 years).

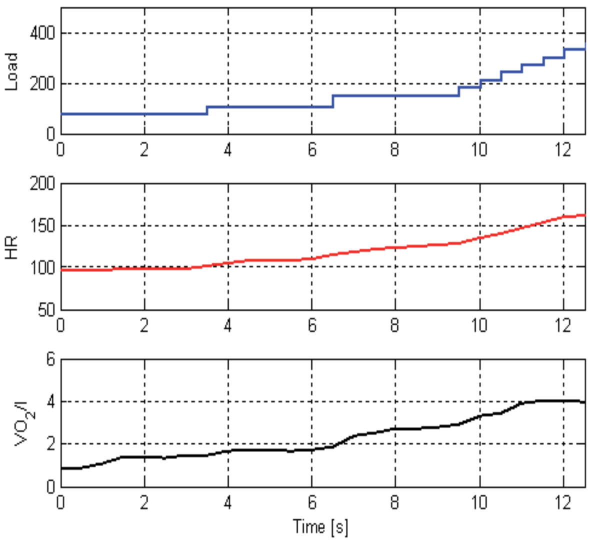

Fig. 4: Workloads [in W] and corresponding HR (heart rate) and VO_2 [l/min] during CPET (male cyclist, 57 years).

Indications for terminating CPET

Symptoms during step-vice increased workload up to the maximum during ergometer stress test can rarely result in premature test termination. There are several absolute indications for termination of an exercise test, such as: suspicion of a heart attack, onset of moderate-to-severe angina (chest pain), drop in systolic blood pressure below standing resting pressure, signs of poor perfusion, including pallor, cyanosis, or cold and clammy skin, severe or unusual shortness of breath, CNS symptoms e.g. ataxia, vertigo, visual or gait problems, or confusion, serious arrhythmias e.g. second/third degree AV block, atrial fibrillation with fast ventricular response, increasing premature ventricular contractions or sustained ventricular tachycardia, and also technical inability to monitor the ECG. Cardiac arrhythmias are usually not an indication to stop the test unless sustained tachyarrhythmias develop. Other indications for CPET terminating might be any chest pain that is increasing, physical or verbal manifestations of shortness of breath or severe fatigue, wheezing, leg cramps or intermittent claudication, hypertensive response (SBP>260 mm Hg; DBP>115 mm Hg) and others.

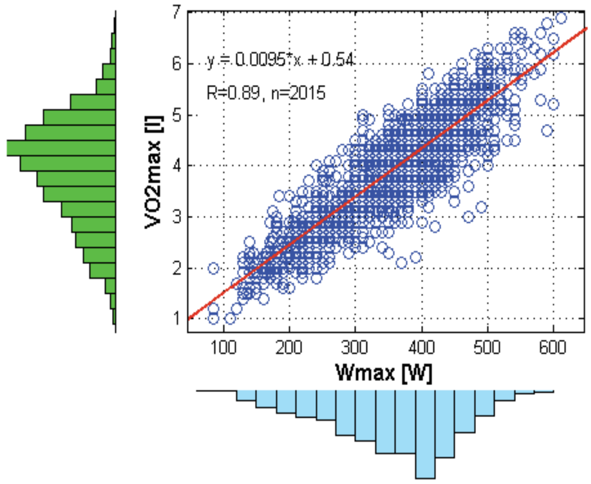

Fig. 5: Group MEN-all (n=2015). Relation between VO_{2max} and W_{max}, R=0.89.

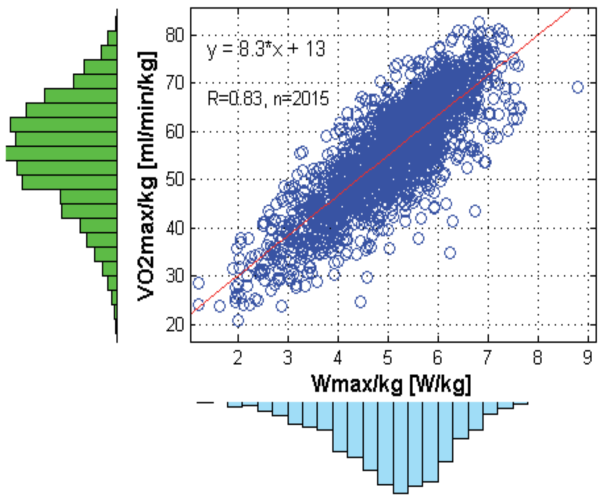

Fig. 6: Group MEN-all (n=2015). Relation between $VO_{2max/kg}$ and $W_{max/kg}$, R=0.89.

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Oxygen uptake estimation

Bicycle ergometer is nowadays a very common device for testing fitness level of the subject. However, accurate estimation of the VO_{2max} is exclusively dependent on direct availability to analyze O_2 and CO_2 content in the expired air. Equipment for O_2-CO_2 analysis is relatively expensive and mostly only in specialized stress test laboratories available. It was the purpose of this study to find the posibility for accurate indirect determination cardiorespiratory capacity without need for the O_2-CO_2 anylysis. Hence, the values of direct VO_{2max} and $VO_{2max/kg}$ were compared with other fitness values, obtained without the need need for the O_2-CO_2 anylysis: W170 and W170/kg, and W_{max} and $W_{max/kg}$.

The highest correlation was found between the values of VO_{2max} and W_{max}, and between $VO_{2max/kg}$ and $W_{max/kg}$. Fig. 5 and Fig. 6 illustrate this correlation in the group of 2015 healthy men. Regession equations were calculated to obtain approximate values of VO_2 and VO_{2max} indirectly without any need for additional equipment. Similarly, the regression equation could be calculated for individual age subgroups in each group of different level of physical aktivity (for example see Table 1 and 2).

There are other approaches for VO_2 estimation [27]. According to the Fick principle, eq. (1), VO_{2max} may be expressed as the product of cardiac output (Q) and the arterio-venous O_2 difference

$$VO_2 = Q \cdot \left(C_aO_2 - C\overline{v}O_2\right) \tag{2}$$

Thus, since Q is the product of HR and stroke volume (SV), VO_{2max} can be expressed as

$$VO_2 = HR \cdot SV \cdot \left(C_aO_2 - C\overline{v}O_2\right) \tag{3}$$

When applied to rest VO_{2max} can be expressed as:

$$VO_{2rest} = HR_{rest} \cdot SV_{rest} \cdot \left(C_aO_2 - C\overline{v}O_2\right)_{rest} \tag{4}$$

implying that

$$\frac{VO_{2rest}}{HR_{rest} \cdot SV_{rest} \cdot \left(C_aO_2 - C\overline{v}O_2\right)_{rest}} = 1 \tag{5}$$

During maximal exercise the Fick equation reads:

$$VO_{2\max} = HR_{\max} \cdot SV_{\max} \cdot \left(C_aO_2 - C\overline{v}O_2\right)_{\max} \tag{6}$$

By multiplying the right side of eq. 6 with 1 in the form of eq. 5 it follows that:

$$\frac{VO_{2\max}}{VO_{2rest}} = \frac{HR_{\max} \cdot SV_{\max} \cdot \left(C_aO_2 - C\overline{v}O_2\right)_{\max}}{HR_{rest} \cdot SV_{rest} \cdot \left(C_aO_2 - C\overline{v}O_2\right)_{rest}} \tag{7}$$

therefore

$$VO_{2\max} = \left(\frac{HR_{\max}}{HR_{rest}}\right)\left(\frac{SV_{\max}}{SV_{rest}}\right)\frac{\left(C_aO_2 - C\overline{v}O_2\right)_{\max}}{\left(C_aO_2 - C\overline{v}O_2\right)_{rest}} VO_{2rest} \tag{8}$$

VO_{2rest} is dependent on and increases with the individual's body mass. Relative to body mass (BM), resting VO_{2rest} equals about 3.5 $ml \cdot min^{-1} \cdot kg^{-1}$ (one MET), but slightly lower values were reported by other researchers (e.g. 3.3 for men and 3.1 for women, respectively [27]). As a compromise is possible take 3.4 $ml \cdot min^{-1} \cdot kg^{-1}$ to represent the mass-specific resting VO_{2max}. Accordingly, VO_{2rest} may be expressed as 3.4 $ml \cdot min^{-1} \cdot kg^{-1}$ times BM in kg.

$$VO_{2\max} = \left(\frac{HR_{\max}}{HR_{rest}}\right)\left(\frac{SV_{\max}}{SV_{rest}}\right)\frac{\left(C_aO_2 - C\overline{v}O_2\right)_{\max}}{\left(C_aO_2 - C\overline{v}O_2\right)_{rest}} 3.4 \cdot BM \tag{9}$$

From a simplified test only the HR_{max} to HR_{rest} ratio is readily obtainable. The other two ratios in the equation involve complicated measurements, in fact more complicated than the measurement of VO_2 itself.

The average SV_{max}/SV_{rest} is approximately 1.29 when measured in the supine position. Thus, according the SV_{max}/SV_{rest} may be replaced by a dimensionless value of approximately 1.3. The arterio-venous oxygen difference increases from rest to maximal exercise. It was found the average ratio between maximal and resting $\left(C_aO_2 - C\overline{v}O_2\right)_{\max} / \left(C_aO_2 - C\overline{v}O_2\right)_{rest}$ to be approx. 3.4. Therefore $\left(C_aO_2 - C\overline{v}O_2\right)_{\max} / \left(C_aO_2 - C\overline{v}O_2\right)_{rest}$ can be replaced with 3.4.

Altogether, based on previous derivation suggest that eq. 9 may be simplified to final approximations

$$\begin{aligned} VO_{2\max} &= 1.3 \cdot 3{,}4 \cdot 3.4 \cdot BM \cdot \frac{HR_{\max}}{HR_{rest}} \\ &= 15.0 \cdot BM \cdot \frac{HR_{\max}}{HR_{rest}} \quad \left(\text{l.min}^{-1}\right) \end{aligned} \tag{10}$$

or for $VO_{2max/kg}$ is

$$VO_{2\max/kg} = 15.0 \cdot \frac{HR_{\max}}{HR_{rest}} \quad \left(\text{ml.min}^{-1}.\text{kg}^{-1}\right) \tag{11}$$

Estimation VO_{2max} according another approach [68] can be calculated according:

$$\begin{aligned} VO_{2\max} &= 125.7 - (0.476 \cdot age) + (7.686 \cdot sex) \\ &- (0.451 \cdot BM) + (0.179 \cdot W_{\max}) - (0.415 \cdot HR_{\max}) \end{aligned} \tag{12}$$

where sex is 1 for male and 0 for female, BM weight (kg), W_{max} is maximal workload (W) and HR_{max} is maximal heart rate (beats per minute).

Lékař a technika 2016, Vol. 46(4), pp. 91–101
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Several other attempts with different accuracy were used for indirect calculation of VO_{2max} [16, 40, 43].

Tab. 1: Examples of regression equations for group A – well trained men, for individual age subgroups (R = correlation coefficient; N = number of subjects).

Group: age <16 year	R	N
VO2max =0.013· Wmax -0.54	0.87	189
VO2max/kg =16.13· Wmax/kg -26.8	0.60	189
Group: 17< age <25 year	R	N
VO2max =0.016· Wmax -2.23	0.71	218
VO2max/kg =16.39* Wmax/kg -32.6	0.66	218
Group: 26< age <40 year	R	N
VO2max =0.014· Wmax -1.55	0.72	191
VO2max /kg=12.2* Wmax/kg -6.83	0.79	191
Group: 41<age <55 year	R	N
VO2max =0.015· Wmax -1.63	0.72	125
VO2max /kg=11.9· Wmax /kg-4.28	0.82	125
Group: age >55 year	R	N
VO2max =0.014· Wmax -0.8	0.85	36
VO2max /kg=15.15· Wmax /kg-15.3	0.84	36

Tab. 2: Examples of regression equations for group A – well trained women, for individual age subgroups (R = correlation coefficient; N = number of subjects).

Group: age <16 year	R	N
VO2max =0.012· Wmax -0.20	0.82	200
VO2max/kg =15.4· Wmax/kg -19.1	0.64	200
Group: 17< age <25 year	R	N
VO2max =0.014· Wmax -0.69	0.80	62
VO2max/kg =12.5· Wmax/kg -10.4	0.81	62
Group: 26< age <40 year	R	N
VO2max =0.014· Wmax -0.88	0.81	31
VO2max /kg=11.7· Wmax/kg -8.6	0.84	31
Group: 41<age <55 year	R	N
VO2max =0.011· Wmax +0.28	0.95	13
VO2max /kg=10.5· Wmax /kg+5.47	0.94	13

Example:
Male triathlete, age 20 years, body weight = 64.7 kg
Measured values:

W_{max} =440 (W), VO_{2max} =4.98 ($l \cdot min^{-1}$)

$$W_{max/kg} = \frac{440}{64.7} = 6.80 \quad \left(W \cdot kg^{-1}\right)$$

$$VO_{2max/kg} = 1000 \cdot \frac{4.98}{64.7} = 76.97 \quad \left(ml.min^{-1}.kg^{-1}, beats.min^{-1}\right)$$

Estimated values (calculated only from W_{max} and $W_{max/kg}$):

$$VO_{2max} = 0.016 \cdot W_{max} - 2.23 =$$
$$0.016 \cdot 440 - 2.23 = 4.81 \quad \left(l \cdot min^{-1}\right)$$
$$VO_{2max/kg} = 16.39 \cdot W_{max/kg} - 32.6 =$$
$$16.39 \cdot 6.80 - 32.6 = 78.85 \quad \left(ml \cdot min^{-1} \cdot kg^{-1}\right)$$

VO_2max and age

Edvardsen et al. [20] demonstrated that the VO_{2max} relative to body mass ($VO_{2max/kg}$) decreased 8% per decade. The decline had already started after the first age cohort (20–29 years) and was linear throughout all age cohorts until the last one (70–85 years). VO_{2max} was about 25% higher in men than in women. Rogers et al. [58] found that the sedentary subjects' VO_{2max} declined by an average of 12% per decade. The master athletes' VO_{2max} decreased by 5.5% decline per decade. These findings provided evidence that the age-related decrease in VO_{2max} of master athletes who continue to engage in regular vigorous endurance exercise training is approximately one-half the rate of decline seen in age-matched sedentary subjects.

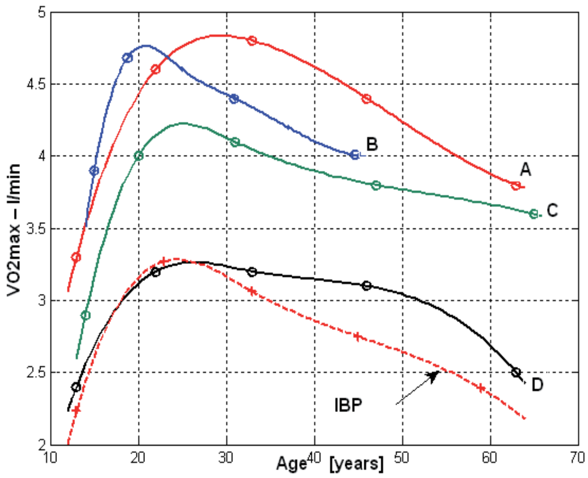

Fig. 7: VO_{2max} (l/min) in different age groups in men (A-red – endurance athletes, B-blue – game sports, C-green – other athletes, D-black – non-competitive athletes, dash line – IBP values).

The decline of VO_{2max} and $VO_{2max/kg}$ was observed also in all age groups in our study. The highest values in both men and women were achieved by endurance trained athletes, followed by game sport athletes and other athletes. VO_{2max} and $VO_{2max/kg}$ in the groups of

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non-competitive sportsmen (and sportswomen) was significantly lower that in all athletic groups and the age-related decline was faster. Compared to the values, valid like normatives for Czecho-slovak population [62], the data of the „non-competitive" groups both men and women are almost identical (see Fig. 7 to Fig. 10). They prove that non-competitive sporting activity is effective for maintaning the average level of fitness, however, does not evoke higher level of cardirespiratory capacity.

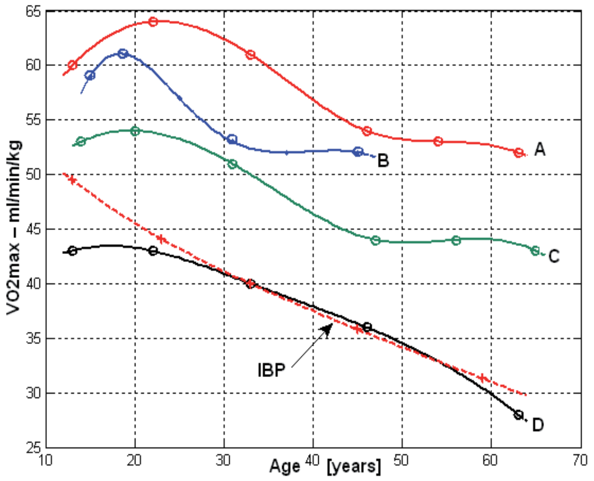

Fig. 8: $VO2_{max/kg}$ ($ml \cdot min^{-1} \cdot kg^{-1}$) in different age groups in men (A-red – endurance athletes, B-blue – game sports, C-green – other athletes, D-black – non-competitive athletes, dash line – IBP values).

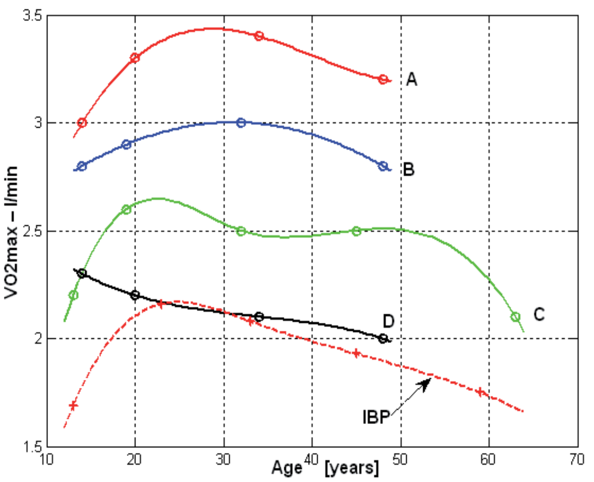

Fig. 9: $VO2_{max}$ (l/min) in different age groups in women (A-red – endurance athletes, B-blue – game sports, C-green – aother athletes, D-black – non-competitive athletes, dash line – IBP values).

The example of different values obtained from the whole cohort of all 2777 examinations (men and women) is presented in Table 3 {in Appendix}.

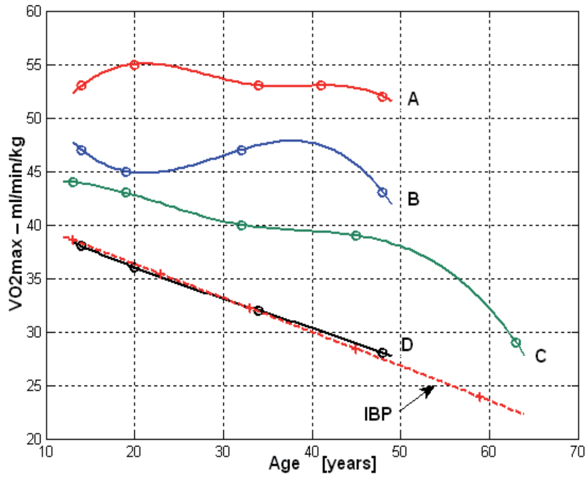

Fig. 10: $VO2_{max/kg}$ ($ml \cdot min^{-1} \cdot kg^{-1}$) in different age groups in women (A-red – endurance athletes, B-blue – game sports, C-green – other athletes, D-black – non-competitive athletes, dash line – IBP values).

Discussion

Oxygen consumption (VO_2) is considered the most accurate variable to measure the intensity of physical activity, and it can be measured directly in the laboratory with metabolic carts or respiratory gas analysers. Portable devices are available for field measurements, but they can be used only for limited periods of time and for limited number of subjects. Therefore, many efforts have been made to find more feasible ways to estimate VO_2 in field studies.

Maximal oxygen uptake or consumption (VO_{2max}) means the maximal capacity of an individual to perform aerobic work. It is the product of cardiac outputand arteriovenous oxygen difference at exhaustion, and represents the golden standard measure for a person's aerobic fitness [63].

Aerobic fitness is related to a person's ability to perform dynamic, moderate-to-high intensity physical activity with large muscle groups for prolonged periods. Thus, it expresses the abilities of both cardiorespiratory and muscular systems to transport and utilize oxygen. It is one of the most fundamental measures of human physiology with remarkable health, wellbeing, life quality, work ability, and performance-related associations.

In addition to oxygen consumption (VO_2), the energy cost of physical activities can be expressed as metabolic equivalents (MET; Metabolic Equivalent of Task). MET is defined as the ratio of metabolic rate (and therefore, the rate of energy consumption) during a specific physical activity to a resting metabolic rate. One MET is defined as 1 $kcal \cdot kg^{-1} \cdot hour^{-1}$ or VO2 equal to 3.5 $ml \cdot min^{-1} \cdot kg^{-1}$, and it is roughly equivalent to the energy cost of sitting quietly.

Individual VO_{2max} values can range from about 10 $ml \cdot min^{-1} \cdot kg^{-1}$ in cardiac patients to over

Lékař a technika 2016, Vol. 46(4), pp. 91–101
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90 ml·min^{-1}·kg^{-1} among world-class endurance athletes. Average values for men and women in different age groups have been used to establish reference fitness categories, as aerobic fitness generally declines with age.

There are numerous reports that higher level of cardiorespiratory fitness is associated not only with maintaining a healthy weight, but also with increased muscle tone and increased basal metabolic rate. Participating in cardiovascular exercise and maintaining and/or even increasing cardiorespiratory capacity leads to reduced risk of several chronic and life-threatening diseases, such as coronary heart disease [4, 9, 12, 18, 19, 30, 34, 35, 39, 46, 48, 54, 61, 69, 72], type 2 diabetes [1, 2, 3, 13, 45], cardio-metabolic syndrome [6, 36, 37, 67], hypertension [15, 17, 21, 23, 24, 31, 32, 33, 41, 70], respiratory diseases [29, 44] and some cancers, such as colon cancer, breast cancer, lung cancer and multiple myeloma cancers [22, 38, 49, 64]. The American College of Sports Medicine states that higher levels of cardiovascular fitness are associated with a 50 percent reduction in cardiovascular disease risk [25, 27]. Regular cardiovascular exercise increases insulin sensitivity and glucose metabolism, reducing chances for developing type 2 diabetes [53, 55] and plays important role in treating obesity [14, 59].

Being active is an effective way to combat anxiety, stress and even depression [47, 50, 60]. Exercise triggers the release of endorphins, which can elevate mood. Finding time to exercise several times per week can also lead to an increase in self-esteem.

It would be extremely beneficial to measure VO_{2max} accurately in real-life. VO_{2max} is a marker of optimal health. If it's critical decrease is diagnosed in time, numerous later health problems could be efficiently prevented. While laboratory tests require expensive equipment and trained personnel, and are thus difficult and expensive to perform, simple estimation of maximal performance on the treadmill ergometer could predict VO_{2max} with sufficient accuracy.

Conclusion

The most important marker of cardiorespiratory capacity is VO_{2max}. Also the concept of so called “fitness age” is based on the knowledge of personal VO_{2max}. If somebody's VO_{2max} is below average compared to age normative, his fitness age is actually *greater* than his chronological age.

On the other hand, a better-than-average VO_{2max} could mean that fitness age is younger than subject's age in years. It's possible to improve VO_{2max} by proper training, which means that the fitness age can actually get younger.

The primary problem with using VO_{2max} to gauge longevity is that very few people know what theirs is, and finding out typically requires high-tech testing on a bicycle and/or treadmill ergometers and analyzing expired air for O_2 and CO_2 content. Our results on large cohorts of subjects demonstrate that simple bicycle ergometer with accurate measurement of performance reached by step-vice increased workload can offer reliable data (W_{max} and $W_{max/kg}$), which can be used for calculation VO_{2max} and $VO_{2max/kg}$ with sufficient enough exactness. Regression equations for men and women and also for different age groups can be used for this purpose.

Fitness age may predict premature death better than risk factors like overweight, high blood pressure, or smoking [51]. If the subject is not satisfied with his fitness age, he is motivated to improve it by regular training program. The recommendation regarding physical activity are available from principle guidelines [8, 25, 26, 27, 56, 63], however, general practitioner and/or sports medical doctor should give personalized advice about the optimal volume, form and intensity.

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Lékař a technika 2016, Vol. 46(4), pp. 91–101
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Appendix

Tab. 3: Example of different values obtained from the whole cohort of all 2777 examinations (men and women) (HR = heart rate; BPs = systolic blood pressure; BPd = diastolic blood pressure; VC = vital capacity; FEV1 = forced exripatory volume per second; METs-max = maximal metabolic equivalent; W_{max} *= maximal performance;* VO_{2max} *= maximal* O_2 *consumption;* VCO_{2max} *= maximal* CO_2 *expenditure; W170 = physical working capacity;* VE_{max} *= maximal pulmonary ventilation;* BF_{max} *= maximal breathing frequency;* RER_{max} *= maximal respiratory exchange ratio).*

	Mean	Median	Max	Min	Std	N
Height (cm)	173.6	175.5	202.0	125.5	10.9	2777
Weight (kg)	68.1	69.5	145.6	20.6	15.2	2777
Age(years)	23.6	19.0	95.0	7.0	12.3	2777
Fat (%)	14.4	13.9	53.0	1.5	6.0	2547
HRrest (beats/min)	66.6	66.0	122.0	34.0	13.2	2777
BPs (torr)	120.6	120.0	200.0	75.0	14.8	2770
BPd (torr)	73.0	71.0	115.0	30.0	10.8	2770
VC (ml)	4528	4575	8270	1370	1064	1958
FEV1 (ml)	3800	3820	6250	1340	799	1846
METs-max	15.0	15.0	29.8	5.6	3.3	2777
W_{max} (watt)	325.6	330.0	610.0	70.0	104.6	2777
$W_{max/kg}$ (W)	4.79	4.89	8.80	1.23	1.16	2777
VO_{2max} (l/min)	3.60	3.60	6.90	0.80	1.10	2777
VCO_{2max} (l/min)	4.24	4.30	8.80	0.90	1.35	2777
$VO_{2max/kg}$ (ml)	52.9	53.5	82.6	19.5	11.6	2777
$VO_{2max/TFmax}$ (ml/min)	19.53	19.55	41.13	4.22	6.19	2777
W170 (watts)	199.6	193.7	494.5	34.3	76.0	2777
W170/kg (watts)	2.9	2.8	6.7	0.9	0.8	2775
HR_{max} (beats/min)	186.2	187.0	230.0	115.0	11.8	2777
VE_{max} (l/min)	110.2	109.3	219.0	27.7	33.2	2777
BF_{max} (breaths/min)	47.4	48.0	60.0	22.0	8.2	1354
RER_{max}	1.09	1.08	1.19	0.87	0.05	2774

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