Original Research

Cardiorespiratory Parameters of Exercise Capacity in a Healthy Lithuanian Population: The Pilot Study

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Introduction: The normative values of exercise capacity used for the interpretation of exercise testing results are influenced by a variety of internal and external factors specific to certain populations. Therefore, in clinical practice it is recommended that population-specific reference values be employed. Cardiorespiratory fitness norms have not yet been established for a healthy Lithuanian population over a wide age span. The purpose of the present study was to determine the main cardiorespiratory fitness parameters for healthy adults living in Lithuania and to compare these parameters with the reference values established for different foreign populations.

Methods: This was a cross-sectional, community-based study involving 168 healthy adults aged from 20 to 60 years who were randomly selected from the general population. All subjects performed a progressive incremental exercise test on the cycle ergometer. The main cardiorespiratory fitness parameters analysed were peak oxygen consumption (VO_2peak), ventilatory anaerobic threshold, and peak heart rate (HRpeak).

Results: The average estimated VO_2peak was 35.02 ± 7.37 $mL.kg^{-1}.min^{-1}$ for men and 28.27 ± 6.33 $mL.kg^{-1}.min^{-1}$ for women. According to the results presented by other authors, this parameter is approximately 9-22% lower compared to other populations in all age groups, with the exception of the 20-29 year old group who alone satisfied fair aerobic fitness criteria. The average age-related decline in VO_2peak was 0.016 $L.min^{-1}$ per year for men and 0.011 $L.min^{-1}$ per year for women. However, age itself explained only 12-14% of the variance. After VO_2peak was adjusted relative to body mass, the difference in the decline between men and women remained insignificant: VO_2peak decrease was 0.34 $mL.kg^{-1}.min^{-1}$ per year for men (coefficient of determination R^2 0.250) and 0.32 $mL.kg^{-1}.min^{-1}$ per year for women (R^2 0.330). A decline in peak heart rate of approximately 9 beats per minute was observed in each following age decade, which was well explained by the advancing age (R^2 0.512 for men and R^2 0.484 for women).

Conclusions: Cardiorespiratory fitness parameters estimated for healthy adults living in Lithuania appeared to be lower compared to different foreign populations, despite the relatively similar general trends in the age-related decline in exercise capacity. Exercise testing laboratories and rehabilitation clinics in Lithuania may use these results in clinical practice when evaluating patients' exercise capacity, or as a promotional tool for physical activity in the general public.

The interpretation of cardiopulmonary exercise test results in the various exercise testing laboratories is based on previously published standard reference values. In some cases, that may cause considerable inaccuracies because cardiorespiratory fitness in a specific population is determined by characteristic physical activity habits, geographic living area, body composition, genetics, and other factors; thus, reference values may differ significantly among various populations. The maximal exercise test itself is particularly sensitive to gender differences, body size, exercise protocol, or exercise type used; it is therefore important to know how these variables differ from those in the reference populations. For this reason, it is recommended for each exercise testing laboratory to produce their own population-specific reference values and to make comparisons with already known normative values available in the literature.[1]

Cardiorespiratory exercise testing is one of the most widely used objective methods for determining physical capacity. Its application in clinical practice is reasonably extensive and, along with diagnostics of cardiovascular and pulmonary diseases, the test has major prognostic value. As has been demonstrated by large-scale cohort studies worldwide, low physical capacity is a major factor affecting all-cause mortality, comparable to high blood pressure, obesity, and alcohol consumption, and almost matches the mortality that is directly linked to tobacco use.[2,3] Cardiorespiratory fitness is commonly described in terms of the parameters maximal oxygen consumption (VO_2max) and ventilatory anaerobic threshold (V_{AT}). VO_2max is the major parameter used to describe physical capacity: low VO_2max is well correlated with high cardiovascular mortality rates.[4] V_{AT} defines a transition between aerobic and anaerobic metabolism and is closely linked to regular exercise training; it is therefore used as an additional parameter to assess cardiorespiratory fitness.[5] The age-related decline in cardiorespiratory fitness is an inevitable physiological phenomenon, which in turn might be explained by the decline in cardiac output,[6] maximal heart rate,[7] loss of skeletal muscle mass,[8] and other factors, such as decreasing functional activity levels or social status.

The purpose of the present study was: (i) to determine the main cardiorespiratory fitness parameters for healthy adults living in Lithuania; (ii) to compare our results with the reference normative values estimated for other foreign populations; (iii) to describe the dynamics of cardiorespiratory fitness parameters with advancing age.

Methods

Subjects

A total of 168 adults aged from 20 to 60 years were enrolled in the study. Subjects were randomly chosen from the general public living in the city of Vilnius. The population was divided into five main groups according to their age as recorded on the day of exercise testing: 20-29, 30-39, 40-49, and 50-59 years. The demographic characteristics of the study population are given in Tables 1 and 2. The selection of subjects for the study was based on the following criteria: currently healthy, non-smoking, not receiving medical therapy that could possibly affect cardiorespiratory function, without a chronic disease or any orthopaedic problems that would not allow them to complete the exercise testing protocol. Baseline resting blood pressure was required to be below 140/90 mmHg. Professional athletes were not included in the study.

Exercise test

Physical capacity was tested by performing a progressive incremental exercise test on the cycle ergometer. Before the test each subject was familiarised with routine testing instructions[9] and consent forms were signed. The cycle ergometer was set to a ramp mode for individually fitted incremental tests. Each increment varied from 15-30 W per minute, and was chosen according to the anticipated physical capacity, gender, age, body mass, and self-reported physical activity status. After 2 minutes of cycling without resistance, the load was constantly increased until voluntary or symptom-limited exercise termination occurred. The exercise protocol was designed to last approximately 8-12 minutes, thus eliciting the most stress on the cardiorespiratory system. Throughout the test, blood pressure measurements (every 2 minutes) were taken with an automatic sphygmomanometer and constant eletrocardiogarphic monitoring was applied. Mean arterial pressure was calculated using the following equation: MAP $= P_{dias} + 1/3\ (P_{sys} - P_{dias})$. The entire exercise test was supervised by a physician. The generally accepted criteria for premature test termination were used.[10]

Prior to the exercise test, spirometry was performed for each subject using a manually calibrated spirometer (SensorMedics, USA), and the parameters forced vital lung capacity (FVC) and forced expiratory volume in one second (FEV1) were recorded. Expired gases during the test were measured and analyzed using a "breath-by-breath" respiratory mass spectrometry system (Vmax® Encore 229, SensorMedics, USA) that was automatically calibrated before each test. The anaerobic threshold and V_{AT} were determined by the "V-slope" method (VCO_2/VO_2 ratio) – the first curve inflection.[11] Ventilatory equivalents for O_2 (V_E/VO_2, where V_E is maximal minute ventilation) and CO_2 (V_E/VCO_2) were used as additional criteria for the establishment of V_{AT}: the start point of the increase in V_E/VO_2, while V_E/VCO_2 reaches a plateau or is still decreasing, as described by Caiozzo et al.[12] Peak oxygen consumption (VO_2peak) was considered to be achieved if VO_2 reached a plateau in the presence of a growing power output (W). If the subject was exhausted before the attainment of VO_2peak, the VO_2 value was accepted as a reasonable maximum if the heart rate was >85% of the predicted maximum rate and a respiratory quotient (RQ) >1.00 was recorded. The interpretation of all data was carried out by two investigators and the main cardiorespiratory fitness parameters were analysed: VO_2peak, V_{AT}, peak heart rate (HRpeak), RQ, V_E, FVC, and FEV1.

Statistical analysis

Statistical analysis was performed using the SPSS 17.0 statistical software. Anthropometric and main cardiorespiratory fitness parameters were grouped in 10-year age cohorts and presented as mean ± standard deviation. Student's t-test was used to make comparisons between physical characteristics for each age group. Linear regression analysis was applied to identify correlations between age and different physical capacity parameters, supplemented by the coefficient of determination (R^2), standard error (SE) and regression statistical significance (p). The level of significance was set at $p<0.05$.

Results

Subjects

The initial study sample included 181 adults. The exercise test results of 13 subjects were excluded from the study analysis because of medical reasons revealed during the test (systolic blood pressure >250 mmHg and manifestation of previously undiagnosed coronary insufficiency) or if the subjects were not physically fit enough to fulfil the V_{AT} or VO_2peak criteria. The final study sample included 91 men and 77 women, making a total of 168 adults analysed. The anthropometric characteristics and cardiorespiratory fitness parameters of the study subjects are presented in Tables 1 and 2. The average peak oxygen consumption adjusted for body mass for all ages was 35.02 ± 7.37 $mL.kg^{-1}.min^{-1}$ for men and 28.27 ± 6.33 $mL.kg^{-1}.min^{-1}$ for women (Tables 3 and 4). Linear regression equations for the main cardiorespiratory fitness parameters are listed in Table 5. Spirometry records are presented in Table 6.

The regression analysis revealed a positive correlation between body mass index (BMI) and age for men and women: BMI (men) = 0.145 × Age + 20.46 (SE=9.73; R^2=0.187; $p<0.001$) and BMI (women) = 0.175 × Age + 17.09 (SE = 9.90; R^2 = 0.253; $p<0.001$), respectively. However, the difference in BMI was statistically significant only in the 20-29 and 50-59 age groups ($p<0.001$; Figure 1).

Aerobic exercise capacity (VO_2peak)

During maximal exercise RQ was similar for both sexes: 1.12 ± 0.12 in men and 1.18 ± 0.15 in women. There was a significant age-related decline in the parameters of cardiorespiratory function, expressed as VO_2peak ($L.min^{-1}$; $mL.kg^{-1}.min^{-1}$). According to the regression analysis the decline was 0.016 $L.min^{-1}$ per year for men and 0.011 $L.min^{-1}$ per year for women (Figure 2), with no significant disparity between the sexes. However, only 12-14% of the variance could be explained by age (Table 5). The decline in VO_2 peak adjusted for body mass did not produce a significant difference between males and females (0.34 $mL.kg^{-1}.min^{-1}$ per year and 0.32 $mL.kg^{-1}.min^{-1}$ per year, respectively), though in this instance age explained more than 25% of the variance for males and 33% for females (Figure 3). The regression equations for VO_2peak were: VO_2peak = 48.77 - 0.342 × Age (R^2=0.25) for men and VO_2peak = 40.99 - 0.319 × Age (R^2=0.33) for women.

Ventilatory anaerobic threshold

The average VO_2 at the V_{AT} was 21.19 ± 6.46 $mL.kg^{-1}.min^{-1}$ for men and 19.64 ± 6.50 $mL.kg^{-1}.min^{-1}$ for women, corresponding to 57 ± 14.4% and 63 ± 14.2% of VO_2peak; there was no significant change with advancing age (Tables 1 & 2). V_{AT} correlated well with the peak VO_2 values ($p<0.001$): V_{AT} = 0.577 × VO_2peak + 0.965 (SE=5.58; R^2=0.434) for men and V_{AT} = 0.742 × VO_2peak - 1.446 (SE=4.39; R^2=0.542) for women (Figure 4). The age-related decline in V_{AT} was significant for both sexes: V_{AT} = 28.38 - 0.181 × Age; SE=10.36; R^2=0.092 ($p<0.01$) for men and V_{AT} = 29.91 - 0.260 × Age; SE=10.7; R^2=0.201 ($p<0.001$) for women (Figure 5).

Table 1. Anthropometric and physical characteristics of male subjects by 10-year age groups.

Parameters	Total n=91	20-29 n=21	30-39 n=24	40-49 n=30	50-59 n=16
Height (cm)	179.71 ± 5.78	182.0 ± 5.34	180.9 ± 4.25	180.1 ± 5.58	174.1 ± 5.62†
Weight (kg)	84.64 ± 11.40	80.95 ± 12.35	84.08 ± 13.34	85.53 ± 9.96	88.63 ± 8.69*
BMI ($kg.m^{-2}$)	26.25 ± 3.54	24.44 ± 3.54	25.63 ± 3.51	26.43 ± 3.44	29.21 ± 2.29‡
Body surface area (m^2)	2.04 ± 0.15	2.01 ± 0.15	2.04 ± 0.16	2.05 ± 0.12	2.04 ± 0.12
VO_2peak ($L.min^{-1}$)	2.92 ± 0.52	3.23 ± 0.48	3.01 ± 0.48†	2.79 ± 0.47†	2.61 ± 0.51‡
VO_2peak ($mL.kg^{-1}.min^{-1}$)	35.02 ± 7.37	40.35 ± 5.77	36.65 ± 8.16†	32.89 ± 5.75‡	29.54 ± 5.48‡
V_{AT} ($mL.kg^{-1}.min^{-1}$)	21.19 ± 6.46	24.83 ± 7.68	22.48 ± 7.53	20.06 ± 5.29	17.91 ± 4.66*
V_{AT} as % of VO_2peak	57.15 ± 14.48	54.67 ± 16.70	56.91 ± 14.21	59.21 ± 15.29	59.25 ± 13.29
HRpeak ($beats.min^{-1}$)	163.37 ± 14.17	178.0 ± 9.22	166.4 ± 8.40‡	157.4 ± 11.59‡	151.0 ± 13.3‡

Data are presented as mean ± standard deviation plus statistical significance (*p<0.05, †p<0.01, ‡p<0.001) for each age group compared to the 20-29 years group.

BMI – body mass index; VO_2peak – peak oxygen consumption; V_{AT} – ventilatory anaerobic threshold; HRpeak – peak heart rate.

Table 2. Anthropometric and physical characteristics of female subjects by 10-year age groups.

Parameters	Total n=77	20-29 n=21	30-39 n=18	40-49 n=20	50-59 n=18
Height (cm)	166.64 ± 6.05	169.0 ± 6.45	167.22 ± 4.89	165.65 ± 6.82*	164.40 ± 5.04*
Weight (kg)	66.12 ± 9.71	62.14 ± 8.95	64.61 ± 8.74	65.95 ± 10.68	71.44 ± 7.68
BMI ($kg.m^{-2}$)	23.89 ± 3.86	21.78 ± 3.03	23.13 ± 3.28	24.08 ± 3.84	26.91 ± 3.56
Body surface area (m^2)	1.74 ± 0.13	1.70 ± 0.13	1.72 ± 0.12	1.73 ± 0.15	1.81 ± 0.09
VO_2peak ($L.min^{-1}$)	1.84 ± 0.36	2.13 ± 0.42	1.76 ± 0.28‡	1.65 ± 0.24‡	1.79 ± 0.25‡
VO_2peak ($mL.kg^{-1}.min^{-1}$)	28.27 ± 6.33	34.68 ± 6.75	27.37 ± 4.11‡	25.34 ± 3.66‡	24.98 ± 4.52†
V_{AT} ($mL.kg^{-1}.min^{-1}$)	19.63 ± 6.50	24.85 ± 7.60	19.25 ± 5.91*	16.34 ± 3.86†	17.46 ± 4.05†
V_{AT} as % of VO_2peak	63.28 ± 14.22	65.50 ± 16.75	59.82 ± 17.02	59.11 ± 10.24	69.13 ± 9.41
HRpeak ($beats.min^{-1}$)	166.8 ± 15.14	178.4 ± 11.75	171.9 ± 9.46	163.4 ± 13.23†	152.0 ± 11.76‡

Data are presented as mean ± standard deviation plus statistical significance (*p<0.05, †p<0.01, ‡p<0.001) for each age group compared to the 20-29 years group.
Abbreviations as in Table 1.

Table 3. Comparison of mean peak oxygen consumption (VO_2peak; $mL.kg^{-1}.min^{-1}$) values for men in our study and normative values by percentiles reported by the Cooper Institute, Dallas TX, by age groups.

Age	No.	Our study data VO_2peak mean ± SD	95% confidence interval	Cooper Institute data VO_2peak percentile 20th	50th	80th
20-29	21	40.35 ± 5.77	37.88–42.82	38.1	43.9	51.1
30-39	24	36.65 ± 8.16*	33.39–39.91	36.7	42.4	47.5
40-49	30	32.89 ± 5.75†	30.84–34.94	34.6	40.4	46.8
50-59	16	29.54 ± 5.48†	26.86–32.22	31.1	36.7	43.3
60 +				27.4	33.1	39.5

20th and 80th percentile values represent poor and excellent cardiorespiratory fitness categories, respectively, as published by American College of Sports Medicine (ACSM).[14] Statistical significance (*p<0.01, †p<0.001) for each age group compared to the 20-29 years group.

Table 4. Comparison of mean peak oxygen consumption (VO_2peak; $mL.kg^{-1}.min^{-1}$) values for women in our study and normative values by percentiles reported by the Cooper Institute, Dallas TX, by age groups.

Our study data				Cooper Institute data VO_2peak percentile		
Age	No.	VO_2peak mean ± SD	95% confidence interval	20th	50th	80th
20-29	21	34.68 ± 6.75	31.80–37.56	31.6	37.4	44.0
30-39	18	27.37 ± 4.11†	25.47–29.27	29.9	35.2	41.0
40-49	20	25.34 ± 3.66†	23.74–26.94	28.0	33.3	38.9
50-59	18	24.98 ± 4.52*	22.90–27.06	25.5	30.2	35.2
60 +				23.7	27.5	32.2

20th and 80th percentile values represent poor and excellent cardiorespiratory fitness categories, respectively, as published by American College of Sports Medicine (ACSM).[14] Statistical significance (*p<0.01, †p<0.001) for each age group compared to the 20-29 years group.

Table 5. Linear regression equations for the cardiorespiratory fitness parameters in men and women.

	Coefficient of determination R^2	p
Men:		
VO_2peak ($L.min^{-1}$) = 3.599 - 0.016 × Age	0.127	<0.001
VO_2peak ($mL.kg^{-1}.min^{-1}$) = 48.77 - 0.342 × Age	0.250	<0.001
BMI ($kg.m^{-2}$) = 0.145 × Age + 20.46	0.187	<0.001
V_{AT} ($mL.kg^{-1}.min^{-1}$) = 0.577 × VO_2peak + 0.965	0.434	<0.001
V_{AT} ($mL.kg^{-1}.min^{-1}$) = 28.38 - 0.181 × Age	0.092	<0.01
Peak HR ($beats.min^{-1}$) = 200.9 - 0.945 × Age	0.512	<0.001
Women:		
VO_2peak ($L.min^{-1}$) = 2.310 - 0.011 × Age	0.147	<0.001
VO_2peak ($mL.kg^{-1}.min^{-1}$) = 40.99 - 0.319 × Age	0.330	<0.001
BMI ($kg.m^{-2}$) = 0.175 × Age + 17.09	0.253	<0.001
V_{AT} ($mL.kg^{-1}.min^{-1}$) = 0.742 × VO_2peak - 1.446	0.542	<0.001
V_{AT} ($mL.kg^{-1}.min^{-1}$) = 29.91 - 0.260 × Age	0.201	<0.001
Peak HR (beats. min^{-1}) = 203.6 - 0.925 × Age	0.484	<0.001

Table 6. Main spirometry parameters for men and women (mean values ± SD) and comparison with spirometry reference values published by the European Respiratory Society (ERS).[13]

Parameters	Under 40	Over 40	Regression equation (coefficient of determination)	Reference equation (ERS)
Men:	n=45	n=46		
FVC (L)	5.94±0.63	5.40±0.63	FVC = 4.38 × Ht - 0.019 × Age -1.45 (R^2 0.32)	FVC = 5.76 × Ht - 0.026 × Age - 4.34
FEV1 (L)	4.82±0.59	4.05±0.53	FEV1 = 4.18 × Ht - 0.03 × Age - 1.78 (R^2 0.55)	FEV1 = 4.30 × Ht - 0.03 × Age - 2.49
FEV1/FVC (%)	80.74±7.11	75.20±7.09	FEV1/FVC = 90.1 - 0.30 × Age (R^2 0.20)	FEV1/FVC = 87.21 - 0.19 × Age
VE_{max} ($L.min^{-1}$)	92.43±17.98	87.57±18.57		
VTpeak (L)	3.00±0.63	3.08±0.48		
Women:	n=39	n=38		
FVC (L)	4.33±0.50	3.89±0.72	FVC = 5.48 × Ht - 0.01 × Age - 4.42 (R^2 0.41)	FVC = 4.43 × Ht - 0.026 × Age - 2.89
FEV1 (L)	3.73±0.44	3.01±0.49	FEV1 = 4.40 × Ht - 0.03 × Age - 2.80 (R^2 0.67)	FEV1 = 3.95 × Ht - 0.025 × Age - 2.60
FEV1/FVC (%)	87.48±6.81	78.21±5.74	FEV1/FVC = 99.98 - 0.43 × Age (R^2 0.35)	FEV1/FVC = 89.10 - 0.19 × Age
VE_{max} ($L.min^{-1}$)	67.51±13.69	63.28±11.80		
VTpeak (L)	2.00±0.32	1.96±0.28		

FVC – forced vital capacity; FEV1 – forced expiratory volume in one second; VTpeak – peak tidal volume; VE_{max} – maximal minute ventilation; Ht – height.

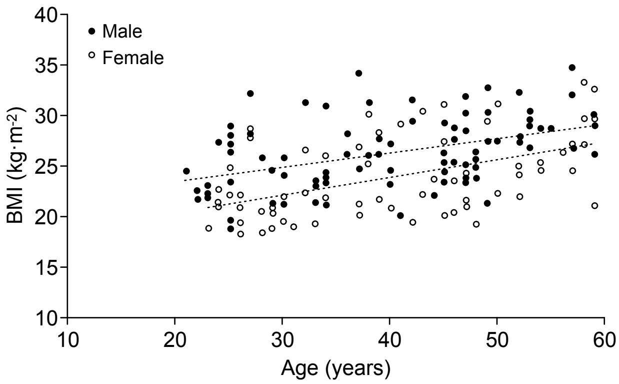

Figure 1. The linear relationship between body mass index (BMI) and age. A significant increase in BMI was observed in both groups: BMI (men) = 0.145 × Age + 20.46 (SE=9.73; R^2=0.187; $p<0.001$) and BMI (women) = 0.175 × Age + 17.09 (SE=9.90; R^2=0.253; $p<0.001$).

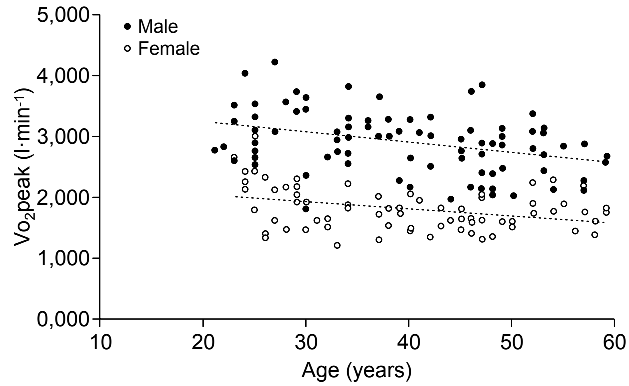

Figure 2. Relationship between age and peak oxygen consumption (VO_2peak). A significant age-related decline in VO_2peak was observed in both men and women: VO_2peak (men) = 3.599 - 0.016 × Age (R^2=0.127) and VO_2peak (women) = 2.310 - 0.011 × Age (R^2=0.147).

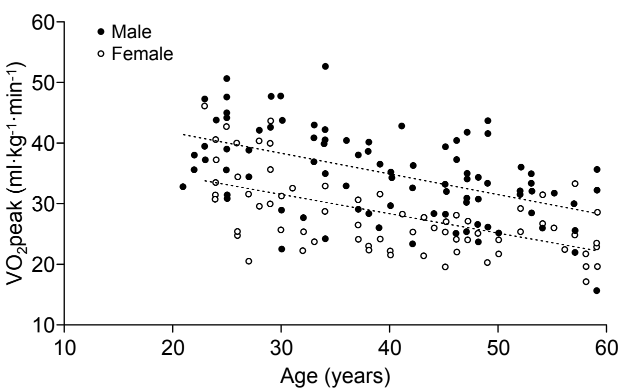

Figure 3. Relationship between age and peak oxygen consumption (VO_2peak) adjusted for body mass. A significant age-related decline in VO_2peak was observed in both men and women: VO_2peak (men) = 48.77 - 0.342 × Age (R^2=0.25) and VO_2peak (women) =40.99 - 0.319 × Age (R^2=0.33).

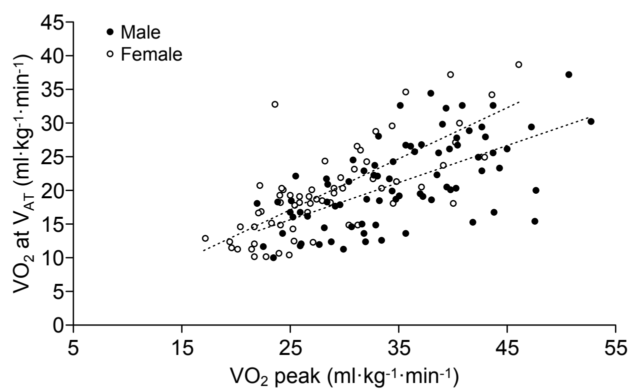

Figure 4. The linear relationship between ventilatory anaerobic threshold (V_{AT}) and peak oxygen consumption (VO_2peak). Higher VO_2peak values produced higher V_{AT} for both sexes: V_{AT} (men) = 0.577 × VO_2peak + 0.965 (SE=5.58; R^2=0.434) and V_{AT} (women) = 0.742 × VO_2peak - 1.446 (SE=4.39; R^2=0.542) for women.

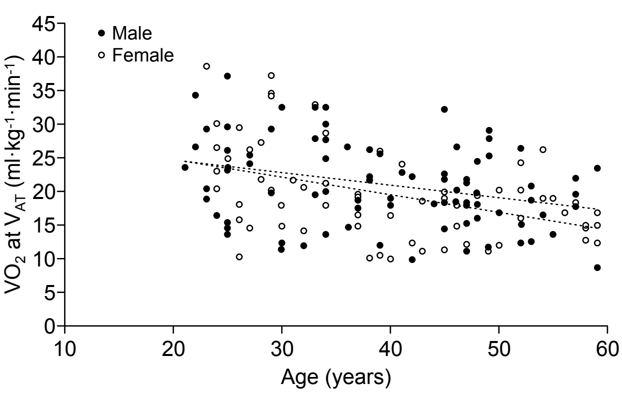

Figure 5. Relationship between ventilatory anaerobic threshold (V_{AT}) and age. A significant age-related decline in V_{AT} was observed in women (V_{AT} = 29.91 - 0.260 × Age; SE=10.7; R^2=0.201; $p<0.001$) and in men (V_{AT} = 28.38 - 0.181 × Age; SE=10.36; R^2=0.092; $p<0.01$).

Peak heart rate

Regression analysis showed a correlation between HRpeak and oxygen consumption (VO_2, $L.min^{-1}$) during maximal exercise: HRpeak = 12.16 × VO_2 + 127.8 (R^2=0.200; $p<0.001$) for men and HRpeak=13.82 × VO_2 + 141.3 (R^2=0.106; $p<0.05$) for women (Figure 6). However, a more solid relationship was observed between HRpeak and age, with a decline of approximately 9 beats per minute in HRpeak for each following age decade: HRpeak = 200.9 - 0.945 × Age (R^2=0.512; p<0,001) for men and HRpeak = 203.6 - 0.925 × Age (R^2=0.484; $p<0.001$) for women (Figure 7). During the maximal exercise test men attained 93.2 ± 5.9% and women 96.4 ± 6.5%

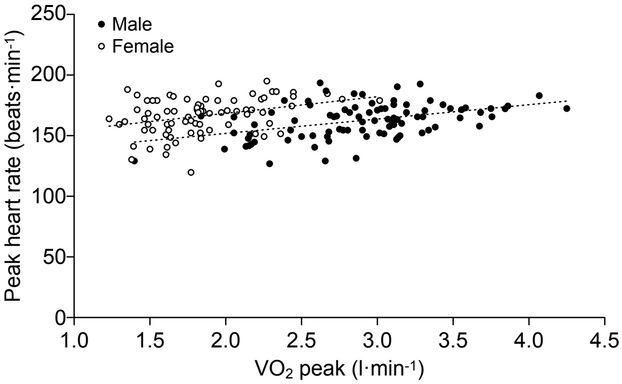

Figure 6. Linear relationship between peak HR and maximal oxygen consumption ($L.min^{-1}$). A significant positive correlation was observed for both sexes.

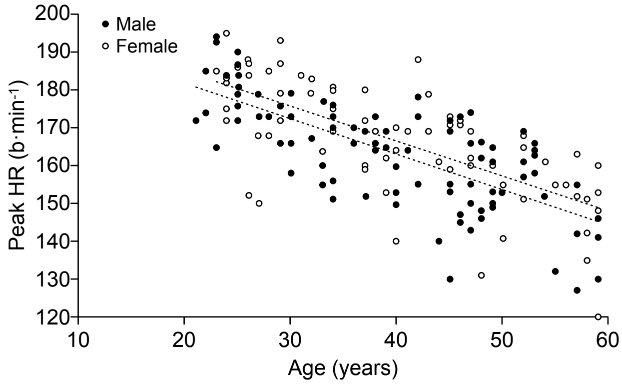

Figure 7. Linear relationship between age and peak heart rate (HRpeak). A significant age-related decline in HRpeak was observed in men (HRpeak = 200.9 - 0.945 × Age; R^2=0.512; p<0,001) and in women (HRpeak = 203.6 - 0.925 × Age; R^2=0.484; p<0.001).

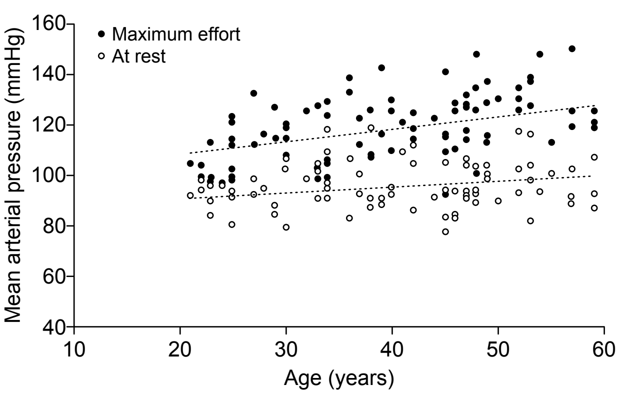

Figure 8. Age-related mean arterial pressure (MAP) prior to the test and during maximal effort in men. The positive correlation was significant only during maximal exercise: MAP=0.495 × Age + 98.31; R^2=0.088; SE 10.3; p<0.05.

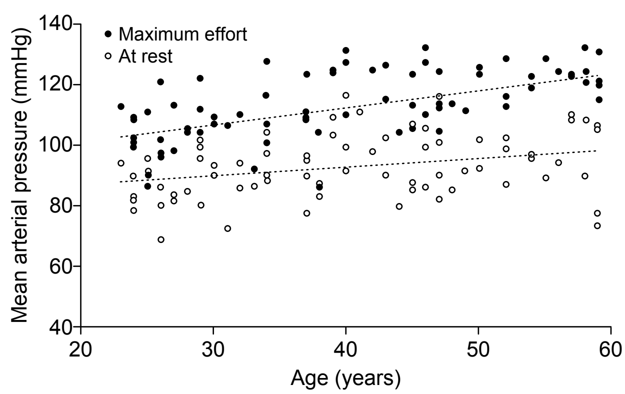

Figure 9. Age-related mean arterial pressure (MAP) prior to the test and during maximal effort in women. The positive correlation was significant only during maximal exercise: MAP = 0.568 × Age + 89.60; R^2=0.370; SE 10.5; p<0.001.

of their predicted age-specific maximal heart rate (HRmax = 220 - age).

Arterial blood pressure

The average arterial blood pressure before the test was 126 ± 12 mmHg / 81 ± 10 mmHg for men and 122 ± 14 mmHg / 78 ± 10 mmHg for women. Mean arterial pressure (MAP) was 96 ± 9 mmHg and 92 ± 10 mmHg before the test, and 118 ± 18 mmHg and 112 ± 17 mmHg during maximal exercise, for men and women, respectively. Age had no effect on resting MAP, though during maximal effort MAP was well explained by age for both sexes: MAP = 0.495 × Age + 98.31; R^2=0.088; SE 10.3; p<0.05 for men and MAP = 0.568 × Age + 89.60; R^2=0.370; SE 10.5; p<0.001 for women (Figures 8 and 9).

A negative correlation was observed between MAP during maximal effort and height in men (R^2=0.066; p<0.05). In addition, in men a higher BMI was associated with higher MAP values at rest and during maximal exercise (MAP = 0.994 × BMI + 70.48; R^2=0.151 and MAP = 2.244 × BMI + 59.07; R^2=0.204, respectively). However, in women neither height nor BMI had an effect on the MAP response (Figure 10).

Ventilatory efficiency

The average V_E/VCO_2 was 26.0 ± 3.2 in men and 27.0 ± 3.1 in women (p<0.05). An age-related decline in ventilatory efficiency measured at the V_{AT} was observed only in men (V_E/VCO_2 = 0.077 × Age + 22.88; R^2=0.066; SE 10.33; p<0.05), and the average V_E/VCO_2 for those below and above 40 years

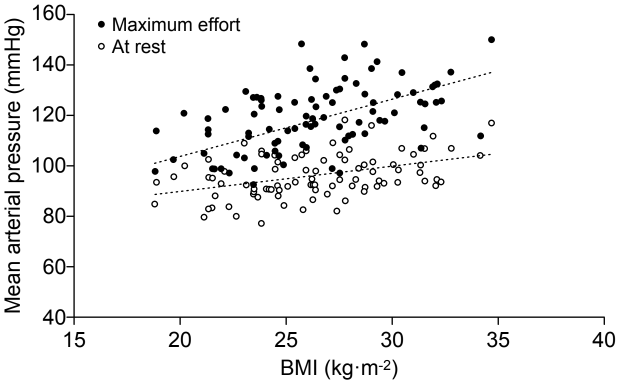

Figure 10. Linear relationship between mean arterial pressure (MAP) and body mass index (BMI) in men. A higher BMI resulted in higher MAP before the test and during maximal effort (MAP = 0.994 × BMI + 70.48; R^2=0.151 and MAP = 2.244 × BMI + 59.07; R^2=0.204, respectively).

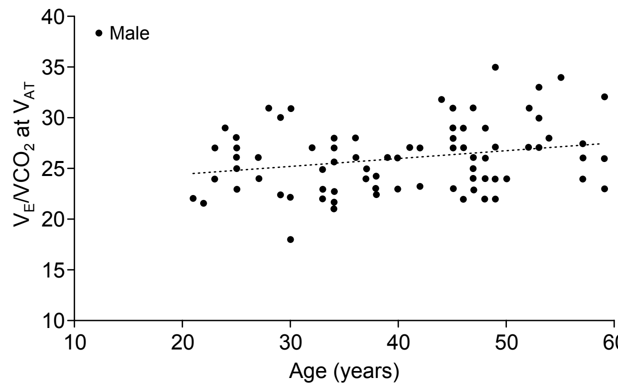

Figure 11. Linear relationship between age and ventilatory efficiency (VE/VCO_2). An age-related decline in VE/VCO_2 was observed in men (VE/VCO_2 = 0.077 × Age + 22.88; R^2=0.066; SE 10.33; p<0.05).

of age was 25.0 ± 2.9 and 26.9 ± 3.2 (p<0.01), respectively (Figure 11). No significant correlation between age and ventilatory efficiency was determined in women.

Discussion

The main purpose of this study was to estimate the cardiorespiratory fitness of a healthy adult Lithuanian population aged from 20 to 60 years. To our knowledge, this is the first study in Lithuania to assess the cardiorespiratory fitness of the general population in the age range 20-60 years and the age-related decline in aerobic fitness parameters. There are no existing solid standards for estimating cardiorespiratory fitness in distinct populations; therefore, many authors recommend that each exercise testing laboratory should establish their own, population-specific, reference values.[1]

The most striking finding of this study was that, in relation to the normative cardiorespiratory fitness values published by the American College of Sports Medicine (ACSM),[14] based on data provided by the Cooper Institute, all the men and women in our study who were aged over 30 years fell below the 20th percentile of VO_2peak, which is considered as poor cardiorespiratory fitness. Only the 20-29 years age group for both sexes satisfied fair aerobic fitness criteria (Tables 3 and 4). The average VO_2peak adjusted for body mass for all ages was 35.02 ± 7.37 $mL.kg^{-1}.min^{-1}$ for men and 28.27 ± 6.33 $mL.kg^{-1}.min^{-1}$ for women. Habedank et al,[15] sampling a healthy European population, demonstrated significantly higher peak VO_2 values: 38.8 ± 7.2 $mL.kg^{-1}.min^{-1}$ for men and 32.2 ± 7.4 $mL.kg^{-1}.min^{-1}$ for women. A study conducted in Japan by Sanada et al,[8] including subjects over 70 years of age, also demonstrated higher VO_2peak parameters: 39.8 ± 7.4 $mL.kg^{-1}.min^{-1}$ for men and 35.4 ± 7.2 $mL.kg^{-1}.min^{-1}$ for women. From a more recent study, the average measured VO_2peak in healthy adults up to 50 years living in the United States was 43.2 ± 0.3 (SE) $mL.kg^{-1}.min^{-1}$ for men and 35.5 ± 0.3 (SE) $mL.kg^{-1}.min^{-1}$ for women.[16] Results reported by other authors indicate that VO_2peak in healthy Lithuanians is approximately 9-22% lower compared to other populations. Another study from the US[17] presented similar results to ours (35.3 ± 8.4 $mL.kg^{-1}.min^{-1}$ for men and 29.4 ± 7.1 $mL.kg^{-1}.min^{-1}$ for women). However, their study population included very old adults (up to 87 years old), which could explain the relatively low reported average VO_2peak values.

The age-related decline in cardiorespiratory fitness is well demonstrated by two parameters: VO_2peak and V_{AT}. The former mainly characterises adaptation to exercise of a central origin, while V_{AT} reflects changes in the periphery related to mitochondrial activity and mitochondria density in muscle fibres.[19,20] In the present study, the age-related decline of VO_2peak adjusted to body mass was 0.34 $mL.kg^{-1}.min^{-1}$ per year in men and 0.32 $mL.kg^{-1}.min^{-1}$ per year in women. The declines in cardiorespiratory fitness were similar to those shown in other studies: Fleg et al,[17] after examining over 800 adults aged 21-87 years, estimated that the average age-related decline in VO_2peak is 0.36 $mL.kg^{-1}.min^{-1}$ per year for men and 0.30 $mL.kg^{-1}.min^{-1}$ per year for women. In a population of healthy women aged 20-64 years the decline was 0.26 mL.kg^{-1}.min^{-1} per year.[20] The rate of decline is also similar in the older population (from 55 to 87 years), as demonstrated by Paterson et al:[21] 0.31 mL.kg^{-1}.min^{-1} per year for men and 0.25 mL.kg^{-1}.min^{-1} per year for women. The similarity between the observations in the above-mentioned studies suggests that the tendency to a decline in cardiorespiratory fitness with advancing age does not depend on the different populations examined, the exercise testing protocols, or the use of somewhat different criteria for establishing the true values of cardiorespiratory fitness.

However, to claim that age is the only parameter responsible for the decline in cardiorespiratory fitness would not be completely accurate. In the present study, age explained only 12% of the variance in the decline of VO_2peak in men and 14% in women. After adjusting for body mass, the age-related decline in VO_2peak accounted for 25% of the variance observed in men and 33% in women; this finding is in agreement with other studies.[21] Physical activity, changes in body composition, and other factors may also determine the rate of decline in cardiorespiratory fitness.[22] Sanada et al[8] examined 1464 adults aged 20-80 years and found that VO_2peak and V_{AT} are well explained by skeletal muscle mass, aside from advancing age. Age-related loss of skeletal muscle mass is a physiological phenomenon, and during each year starting from the fifth decade, the loss approximates 0.18 kg for men and 0.08 kg for women.[23] Loss of skeletal muscle mass can at least partially explain the age-associated decline in aerobic fitness, since muscles are highly metabolically active tissue. Therefore, relating lean body mass parameters to cardiorespiratory fitness is a much better option compared to BMI, as the latter cannot estimate the true body composition and its dynamics. In the present study, we observed an age-related increase of BMI in men and women (R^2=0.187 and R^2=0.253, respectively). Though this does not give the correct values of lean body mass and fat mass and their dynamics over time, we tend to suppose that the increase in BMI is partly explained by an increase in overall adipose tissue.[24]

Some authors state that cycle ergometry is not the most appropriate method for exercise testing, compared to walking or running on the treadmill, mainly because cycling challenges less accustomed muscle groups.[21] It has previously been shown that VO_2max values are 10-15% higher on the treadmill testing than in cycle ergometry.[25,26] However, the point proposed by Paterson et al[21] is more valid for an older population (over 60 years), and we believe that the cycle ergometry used in our study did not require any additional exertion and effort to perform when we compared younger and older study subjects in our population.

Cardiorespiratory fitness and adaptation to exercise stress are in part described by V_{AT}. Commonly V_{AT} is expressed not in absolute values (mL.kg^{-1}.min^{-1}), but as a percentage of maximal oxygen consumption. A number of studies evaluated V_{AT} in adults of different age and fitness. V_{AT} is usually much higher in trained adults, reflecting their better ability to perform more intense work exclusively under aerobic work conditions. The reported VAT for trained triathletes is 75% of VO_2peak,[27] while for most sedentary adults V_{AT} rarely exceeds 60% of VO_2peak.[28] In the present study, V_{AT} was 57% of VO_2peak (SD 14.5) for men and 63% of VO_2peak (SD 14.2) for women, with no significant difference between the sexes. Habedank et al[15] also demonstrated that for sedentary adults V_{AT} is not predetermined by sex.

In our study, V_{AT} remained relatively stable with advancing age. A weak negative correlation was observed in both groups (R^2=0.09 for men and R^2=0.20 for women). The average V_{AT} in our studied population was approximately 20 mL.kg^{-1}.min^{-1}, and this is in agreement with results reported by Habedank et al:[15] sampling 101 healthy persons aged 16-75 years the authors calculated that average V_{AT} was 18.0 mL.kg^{-1}.min^{-1} VO_2 for women and 22.8 mL.kg^{-1}.min^{-1} VO_2 for men. However, there are different data from an older population: Paterson et al,[21] in a study examining adults aged 55-86 years, noticed that the age-related decline in V_{AT} was much faster; this could be attributed to the lower functional activity in elderly persons compared to younger ones. In addition, when interpreting these results it is important to note that the decline in VO_2peak in older individuals is even more rapid, thus explaining the high percentages of V_{AT} relative to VO_2peak at this age: as much as 70-90% of peak oxygen consumption.[21,29] Summarizing, V_{AT} may be considered as an important parameter in defining endurance capacity. In spite of the age-related decline in VO_2peak, the stability of V_{AT} from youth to old age is likely due to maintaining the usual everyday physical activity required for independent living and reflects the preserved metabolic function of skeletal muscles.[18]

We also observed that a higher BMI for men was correlated with the magnitude of the MAP response at rest and during maximal exercise (R^2=0.151 and R^2=0.204, respectively). A high BMI is an established risk factor for the development of hypertension.[30,31] Chen et al[32] conducted a large cohort study (n=35,061) and found that both BMI and cardiorespiratory fitness had an effect on arterial blood pressure at rest: the difference in mean systolic blood pressure between normal-weight and obese individuals was 12 mmHg, while fitter subjects exhibited a 6 mmHg lower mean systolic blood pressure compared to sedentary individuals. It seems that a reduction in BMI is one of the most important measures for hypertension control and prevention, because in the presence of a high BMI other arterial blood pressure modifying tools (diet, physical activity) are not so efficient as in normal-weight subjects.[32,33]

In the present study, the systolic and diastolic blood pressure response during maximal exercise was more exaggerated in older subjects, while age had no effect on resting blood pressure values. This observation was also acknowledged in a study by Miyai et al,[31] investigating 1033 healthy normotensive adults from 20 to 59 years of age. In addition, the authors of the latter study demonstrated that an exaggerated blood pressure response during exercise has important clinical implications, being a good prognostic indicator for the development of future hypertension, increasing the risk by 3 to 4 times. A systolic blood pressure increase during exercise is a normal physiological response determined by increasing cardiac output. Meanwhile diastolic blood pressure remains stable or decreases due to vasodilation of the peripheral blood vessels. Under conditions of abnormal peripheral vascular resistance or low vasodilatory capacity, the diastolic blood pressure response during exercise becomes inadequate. In the present study we used the parameter MAP, which reflects both systolic and diastolic components, when assessing the extent of cardiovascular response to exercise.

The decrease in HRmax in older subjects is the most likely reason for the decline in cardiac output, while according to Fick's equation maximal cardiac output is an essential component of VO_2peak. We observed an average 0.9 beats per year decline in HRmax for both men and women, and this variance was well explained by age (R^2=0.512 and R^2=0.484, respectively). These results are in agreement with other studies of middle-aged populations, which demonstrated an average 0.7-1.0 beats per year reduction in HRmax.[7,20] However, the application of this correlation to a population above middle-age is speculative, because Paterson et al,[21] in their study of adults over 55 years, showed that the widely used equation 220 - age rather underestimates HRmax, while age in that study explained only 20-23% of the variance.

We also evaluated ventilatory efficiency (V_E/VCO_2) calculated at V_{AT} and found that the lower ventilatory efficiency for men was correlated with advancing age (R^2=0.066). Theoretically, ventilatory efficiency is the ratio of ventilation and CO_2 output (V_E/VCO_2), or simply the amount of ventilation required to extract one litre of CO_2 to the atmosphere, and is essentially determined by the ventilation to perfusion match in the lungs.[1] The estimation of this parameter at the V_{AT} is meaningful, because above the anaerobic threshold V_E/VCO_2 stabilizes rapidly, due to the minimal effect of physiological stimuli on ventilation. Subsequently, V_E/VCO_2 is affected by progressive metabolic acidosis and induced hyperventilation.[34] An age-related decline in ventilatory efficiency has been observed in many studies for both sexes.[15,29,34] However, in the present study we did not find any significant change in V_E/VCO_2 for women. Meanwhile, the V_E/VCO_2 values for men under 40 and over 40 years of age (25.4 ± 2.9 and 27.3 ± 3.2, respectively; $p<0.05$) are consistent with currently accepted reference values for ventilatory efficiency.[34]

Professional athletes and those striving for results in sports were not included in the study, because their fitness does not reflect physical activity trends in the general population. For this reason, in terms of cardiorespiratory fitness, our study population was rather homogeneous. However, we did not record accurate everyday physical activity habits for each subject, which could have provided valuable information about the reasons for the relatively low cardiorespiratory fitness noted in our population. We can only speculate that those reasons are closely linked to the insufficient habitual exercise undertaken by Lithuanian people, since approximately 70% of adults living in rural areas in Lithuania are classified as having low leisure-time physical exercise, i.e. less than 30 minutes of exercise 4 times a week,[35] whereas the extent of physical inactivity among 50-year-old persons living in Vilnius is approximately 75%, with an obvious trend towards further reduction in physical activity levels in later life.[36]

In conclusion, this study provides main cardiorespiratory fitness parameters for a healthy Lithuanian population aged from 20 to 60 years, based on the results of cardiopulmonary exercise testing. Referring to the ACSM[14] normative values, our results confirm that aerobic fitness parameters for adults living in Lithuania are below average. Due to the relatively small number of subjects included in this study, it is difficult to draw conclusions concerning the entire Lithuanian population; therefore, it would be advisable to conduct a study on a much larger scale, including a wider range of ages, geographical residence, physical activity, and social factors, all of which may contribute to cardiorespiratory fitness. Exercise testing laboratories in Lithuania may use these results in clinical practice when evaluating patients' exercise capacity, and as a tool for promoting physical activity in the general public.

References

1. Wasserman K, Hansen JE, Sue DY, Stringer W, Whipp B. Normal values. In: Wasserman K, ed. Principles of Exercise Testing and Interpretation. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 161-182.
2. Blair SN, Kohl HW 3rd, Barlow CE, Paffenbarger RS Jr, Gibbons LW, Macera CA. Changes in physical fitness and all cause mortality: a prospective study of healthy and unhealthy men. JAMA. 1995; 273: 1093-1098.
3. Mokdad AH, Marks JS, Stroup DF, Gerberding JL. Actual causes of death in the United States, 2000. JAMA. 2004; 291: 1238-1245.
4. Mora S, Redberg RF, Cui Y, et al. Ability of exercise testing to predict cardiovascular and all-cause death in asymptomatic women: a 20-year follow-up of the lipid research clinics prevalence study. JAMA. 2003; 290: 1600-1607.
5. Meyer T, Lucía A, Earnest CP, Kindermann W. A conceptual framework for performance diagnosis and training prescription from submaximal gas exchange parameters-theory and application. Int J Sports Med. 2005; 26 Suppl 1: S38-48.
6. Ogawa T, Spina RJ, Martin WH 3rd, et al. Effects of aging, sex, and physical training on cardiovascular responses to exercise. Circulation. 1992; 86: 494-503.
7. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001; 37: 153-156.
8. Sanada K, Kuchiki T, Miyachi M, McGrath K, Higuchi M, Ebashi H. Effects of age on ventilatory threshold and peak oxygen uptake normalised for regional skeletal muscle mass in Japanese men and women aged 20-80 years. Eur J Appl Physiol. 2007; 99: 475-483.
9. Wasserman K, Hansen JE, Sue DY, Stringer W, Whipp B. Clinical exercise testing. In: Wasserman K, ed. Principles of Exercise Testing and Interpretation. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 133-159.
10. Fletcher GF, Balady GJ, Amsterdam EA, et al. Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. Circulation. 2001; 104: 1694-1740.
11. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol. 1986; 60: 2020-2027.
12. Caiozzo VJ, Davis JA, Ellis JF, et al. A comparison of gas exchange indices used to detect the anaerobic threshold. J Appl Physiol. 1982; 53: 1184-1189.
13. Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC. Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official Statement of the European Respiratory Society. Eur Respir J Suppl. 1993; 16: 5-40.
14. ACSM Guidelines for Exercise Testing and Prescription. 8th ed. Philadelphia: Lippincott Williams & Wilkins; 2009
15. Habedank D, Reindl I, Vietzke G, et al. Ventilatory efficiency and exercise tolerance in 101 healthy volunteers. Eur J Appl Physiol Occup Physiol. 1998; 77: 421-426.
16. Wang CY, Haskell WL, Farrell SW, et al. Cardiorespiratory fitness levels among US adults 20-49 years of age: findings from the 1999-2004 National Health and Nutrition Examination Survey. Am J Epidemiol. 2010; 171: 426-435.
17. Fleg JL, Morrell CH, Bos AG, et al. Accelerated longitudinal decline of aerobic capacity in healthy older adults. Circulation. 2005; 112: 674-682.
18. Coggan AR, Spina RJ, King DS, et al. Histochemical and enzymatic comparison of the gastrocnemius muscle of young and elderly men and women. J Gerontol. 1992; 47: B71-66.
19. Drexler H, Riede U, Münzel T, König H, Funke E, Just H. Alterations of skeletal muscle in chronic heart failure. Circulation. 1992; 85: 1751-1759.
20. Jackson AS, Wier LT, Ayers GW, Beard EF, Stuteville JE, Blair SN. Changes in aerobic power of women, ages 20-64 yr. Med Sci Sports Exerc. 1996; 28: 884-891.
21. Paterson DH, Cunningham DA, Koval JJ, St Croix CM. Aerobic fitness in a population of independently living men and women aged 55-86 years. Med Sci Sports Exerc. 1999; 31: 1813-1820.
22. Toth MJ, Gardner AW, Ades PA, Poehlman ET. Contribution of body composition and physical activity to age-related decline in peak VO_2 in men and women. J Appl Physiol. 1994; 77: 647-652.
23. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. J Appl Physiol. 2000; 89: 81-88.
24. Atlantis E, Martin SA, Haren MT, Taylor AW, Wittert GA. Lifestyle factors associated with age-related differences in body composition: the Florey Adelaide Male Aging Study. Am J Clin Nutr. 2008; 88: 95-104.
25. Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K, Whipp BJ. Optimizing the exercise protocol for cardiopulmonary assessment. J Appl Physiol. 1983; 55: 1558-1564.
26. Jamison JP, Megarry J, Riley M. Exponential protocols for cardiopulmonary exercise testing on treadmill and cycle ergometer. Eur J Appl Physiol. 2010; 108: 167-175.
27. Schneider DA, Pollack J. Ventilatory threshold and maximal oxygen uptake during cycling and running in female triathletes. Int J Sports Med. 1991; 12: 379-383.
28. Mahon AD, Gay JA, Stolen KQ. Differentiated ratings of perceived exertion at ventilatory threshold in children and adults. Eur J Appl Physiol. 1998; 78: 115-120.
29. Prioux J, Ramonatxo M, Hayot M, Mucci P, Préfaut C. Effect of ageing on the ventilatory response and lactate kinetics during incremental exercise in man. Eur J Appl Physiol. 2000; 81: 100-107.
30. Huang Z, Willett WC, Manson JE, et al. Body weight, weight change, and risk for hypertension in women. Ann Intern Med. 1998; 128: 81-88.
31. Miyai N, Arita M, Miyashita K, Morioka I, Shiraishi T, Nishio

I. Blood pressure response to heart rate during exercise test and risk of future hypertension. Hypertension. 2002; 39: 761-766.
32. Chen J, Das S, Barlow CE, Grundy S, Lakoski SG. Fitness, fatness, and systolic blood pressure: data from the Cooper Center Longitudinal Study. Am Heart J. 2010; 160: 166-170.
33. Forman JP, Stampfer MJ, Curhan GC. Diet and lifestyle risk factors associated with incident hypertension in women. JAMA. 2009; 302: 401-411.
34. Sun XG, Hansen JE, Garatachea N, Storer TW, Wasserman K. Ventilatory efficiency during exercise in healthy subjects. Am J Respir Crit Care Med. 2002; 166: 1443-1448.
35. Grabauskas V, Klumbiene J, Petkeviciene J, et al. Risk factors for noncommunicable diseases in Lithuanian rural population: CINDI survey 2007. Medicina (Kaunas). 2008; 44: 633-639.
36. Petraitis R, Kaminskas A, Abaravičius A, Bagdonaitė L, Olsson A, Kučinskienė Z. Ageing and prevalence changes of coronary heart disease risk factors among Vilnius men: the LiVicordia-V10 study. Acta Medica Lituanica. 2008; 15: 150-155.