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# High "Fitness Age" as a Risk Factor for Morbidity and Premature Mortality

**Jaroslav NOVÁK**[1], **Milan ŠTORK**[2]

[1]Department of Sports Medicine, Medical Faculty of Charles University, Plzeň, Czech Republic,
[2]Department of Electronics and Information, Technology/RICE, University of West Bohemia, Plzeň, Czech Republic

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**Summary**

The level of cardiorespiratory capacity, as measured by maximum $VO_2$max oxygen consumption, is a significant factor related to the risk of metabolic syndrome, coronary heart disease and other health disorders. A total cohort of 2901 examinations was divided into 5 groups according to the nature of physical activity: group A – endurance athletes, group B – team sports players, group C – other competitive athletes, group D – recreational leisure-time athletes, group E – people with health problems. Cardiorespiratory fitness was assessed according to the $VO_2$max and METmax parameters found in the stress test on a bicycle ergometer. A gradually increased load until exhaustion was used. While in groups A to D cases that would be classified as NYHA 1 (METmax lower than 9) were quite rare (10 cases out of 2777, i.e. 0.3 %), in groups E it was 20 % in men (16 cases out of 82) and 52 % in women (23 cases out of 44) of those examined. Accordingly, fitness age in groups A, B and C generally corresponded to a lower age than the calendar age, in groups E of both men and women, fitness age was significantly higher compared to the calendar age. High fitness age represents a significant risk of morbidity in relation to non-communicable diseases and probably also a significant limitation of their quality of life in later age.

**Key words**

Cardiorespiratory capacity • NYHA classification • $VO_2$max • Fitness age • Physical activity

**Corresponding author**

J. Novák, Department of Sports Medicine, Medical Faculty of Charles University, Alej Svobody 76, 323 00 Plzeň, Czech Republic. E-mail: jaroslav.novak@lfp.cuni.cz

## Introduction

The favorable trend of declining cardiovascular mortality has stopped and appears to have reversed. According to statistics of Czech cardiologists, we have 2,912,942 cardiac patients in the Czech Republic, which is about 364,000 more than 10 years ago (Fig. 1). While deaths from acute heart attacks are decreasing, the number of cases of heart failure is increasing. In 2021, 122,068 people suffered from heart failure, compared to 96,668 in 2011 (Fig. 2). Early diagnosis of impending heart failure is crucial for the fate of these patients.

The NYHA classification divides cardiac patients into 4 categories according to disease severity and functional cardiorespiratory capacity [1]. In NYHA class I cardiac disease is present, but daily physical activity of the patient is not limited. Ordinary physical activity does not cause undue fatigue, palpitation, dyspnea or anginal pain. At NYHA class II patients are comfortable at rest, but ordinary physical activity results in fatigue, palpitation, dyspnea or anginal pain. Patients enrolled in NYHA class III are characterized by marked limitation of physical activity. They are comfortable at rest, bus less than ordinary activity causes fatigue, palpitation, dyspnea or anginal pain. In NYHA class IV patients are unable to carry on any physical activity without discomfort. Already at rest, symptoms of cardiac failure are present. If any physical activity is undertaken, discomfort increases [1]. The problems increase to the "frailty" level, when the patient becomes non-independent. In a healthy adult, cardiorespiratory capacity should be at least 9 METs, i.e. $VO_2$max/kg should be greater than 31.5 ml/min/kg. Comparison with METs and thus possible inclusion in one

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of the NYHA classes is a simple method to distinguish healthy and satisfactorily fit people from those who, due to low cardiorespiratory capacity, can already be classified as cardiacs (Table 1).

Only well-informed clients can correctly interpret what the values of aerobic capacity $VO_2$max or $VO_2$max/kg, or METmax values, express in relation to their physical fitness and thus to their health condition. Therefore, when interpreting the results of the stress test, we usually help ourselves by comparing the achieved values with the norms for the same age population of men or women. It is then quite understandable to compare the achieved results with the theoretical age to which the achieved values correspond.

Such a possibility is provided by the establishment of the so-called fitness age. The fitness age is a reliable interpretation of $VO_2$max estimate. It is calculated by comparing the current $VO_2$max level to the normal values of people within the same gender. As we age, cardiorespiratory fitness typically declines. This loss of performance ability can be slowed and even reversed, to an extent, with regular physical activity. On the contrary, insufficient physical activity has very serious negative impacts on health, one of the features of which is a gradual decrease in cardiorespiratory capacity to below-average values. Notifying the client about his sometimes several decades higher fitness age compared to his calendar age can be a strong argument to think about how to adjust his lifestyle in order to improve his cardiorespiratory capacity and thus positively affect his health.

The aim of this study was to show how insufficient physical activity in people with weakened health status translates into low parameters of cardiorespiratory capacity and thus significantly higher fitness age values.

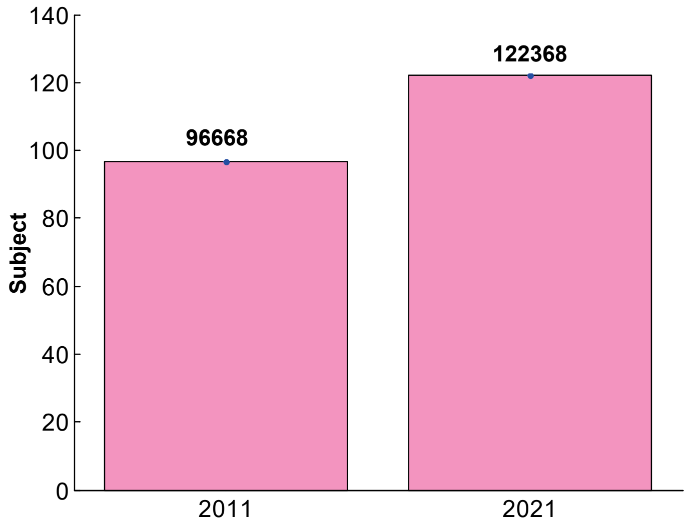

**Fig. 1.** Comparison of the number of registered patients with heart failure in 2011 and in 2021 in the Czech Republic.

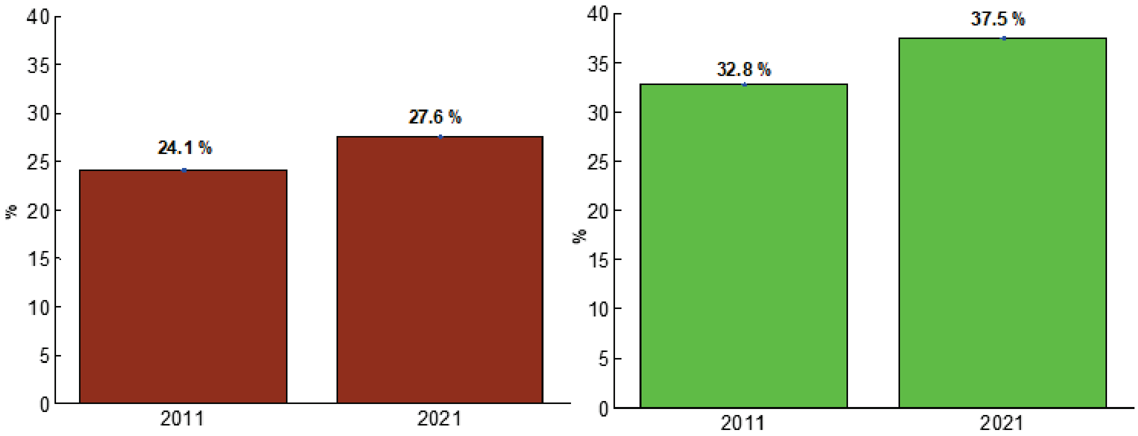

**Fig. 2.** Comparison of the proportion of registered cardiac patients in the total Czech population (brown) and in the group of persons over 25 years of age (green) in 2011 and in 2021 (in %) in the Czech Republic.

**Table 1.** Cardiorespiratory capacity in NYHA patients and in healthy adult population.

| *Fitness level* | **METmax** | **$VO_2$max/kg ml/min** |
|---|---|---|
| *NYHA IV* | 1-3 | 3.4-10.5 |
| *NYHA III* | 3.1-5 | 10.6-17.5 |
| *NYHAII* | 5.1-7.1 | 17.6-24.5 |
| *NYHA I* | 7.1-9 | 24.6-31.5 |
| *Healthy adults* | >9 | >31.5 |
| *World class endurance athletes* | >25 | >85 |

## Methods

*$VO_2$max determination*

The level of cardiorespiratory capacity, as measured by maximum oxygen consumption ($VO_2$max), is a significant factor related to the risk of metabolic syndrome, coronary heart disease and other health disorders. From an extensive database of all persons examined at the Department of Sports Medicine of the University Hospital in Pilsen and at the Department of Sports Medicine of the Medical Faculty of Charles University in Pilsen between 1994 and 2015, the protocols of those examined were selected that provided the necessary data.

During each of these complex sports medical examinations, the examined person underwent a stress test on a bicycle ergometer.

There is general agreement on the methodology of maximal oxygen uptake ($VO_2$max) testing as the gold standard of fitness. $VO_2$max is usually measured by means of graded exercise test on bicycle or tearmill ergometers using indirect calorimetry. The test begins at a relatively easy workload and becomes progressively more demanding due to increasing intensity. If an automated system is being used, then $VO_2$ is measured continuously; it can also be measured manually at the end of each workload by collecting bags of expired air to be analyzed by hand. Total testing should last from 8 to 15 min [2,3]. For top-class athletes, a ramp protocol is sometimes used [4]. The subjects to be tested should be well motivated and carefully prepared [5]. Immediately following exercise and 6-8 min after the stress test ECG in upright position should be monitored [6].

In this study, the procedure consisted of the workload on the bicycle ergometer gradually increased until exhaustion. The procedure was similar to that of the International Biological Program in the 70s of the last century, which was the basis for determining the normatives of physical fitness of the Czechoslovak population.

All subjects completed a maximal graded spiroergometric exercise test according to a standardized protocol established uniformly within the framework of the International Biological Programme (IBP) in 1972 to 1975. This program was used in testing the Czechoslovak population and determining population normatives of fitness for the age range 12-55 years [7]. These normatives are still used in our country, as a similar study has not been carried out since.

For subjects younger than 12 years of age included in our study (2.67 % of examinations for men and 3.34 % of examinations for women), values for 12-year-olds were used as norms. For subjects older than 55 years of age included in our study (2.72 % of examinations for men and 0.67 % of examinations for women), values for 55 year-olds were used as norms.

The stress test consisted of three three-minute loads of light, moderate and sub-maximum intensity (as a warm-up) and subsequent increasing the load every half minute until maximum (exhaustion). The intensity of the load was selected individually according to the expected level of cardiorespiratory capacity of the subject. For most, the initial warm-up workloads were related to the body weight of the subject, so that the first three-minute workload corresponded to 1 W/kg body weight, the second stress level to 1.5 W/kg body weight and the third stress level to 2 W/kg body weight. Further increase of the workload took place every half minute, usually by 30 W (proportionally less due to the lower body weight in children age probands). For the subjects with weakened health status, stress levels were chosen with a lower intensity of workload (Fig. 3). In obese people, it was 0.5 W/kg of body weight for the first stress level, 1 W/kg of body weight for the second stress level and 1.5 W/kg of body weight for the third stress level, and so it was for other subjects with weakened health. At maximum load, at least two of the following criteria must have been met: the age norm for maximal heart rate (HRmax), RER (respiratory exchange ratio) greater than 1.10, maximum ventilatory equivalent for $O_2$ (VEq$O_2$) greater than 30 l and maximum lactate concentration (LAmax) in adults greater than 10 mmol/l.

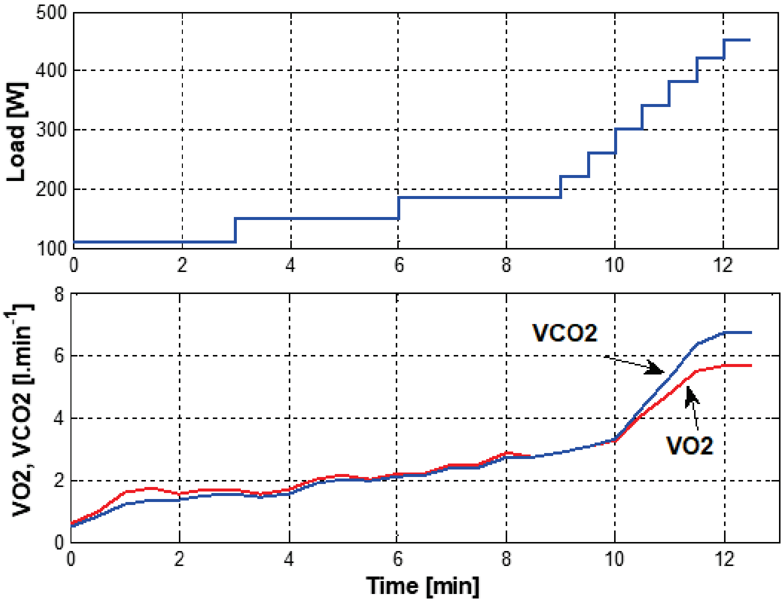

**Fig. 3.** Stress test procedure used for spiroergometric examination: 3 three-minute loads of light, moderate and submaximal intensity and subsequent load increased every half-minute until exhaustion (all-out). The lower part of the figure shows the changes in $O_2$ uptake and $CO_2$ expenditure during the stress test (in l/min).

The instrumentation has undergone some changes over the years. The stress test in the period 1994-1998 was carried out on a bicycle ergometer of the Lode type (Groningen, The Netherlands), in the period 1999-2015 on a bicycle ergometer of the Ergoline.erR900 type Germany). On both types of ergometers, the intensity of the load was guaranteed by the manufacturer. The set load (can be set by entering the load value on the computer keyboard) was pedaling cadence independent with the recommended cadence (pedaling stroke) of about 60/min. The cadence of pedaling was first checked by the ticking of the metronome, later the feedback on the pedaling frequency was provided to the examined person using a digital indicator located on the "handlebars" of the ergometer.

*Heart rate monitoring*

Heart rate (HR) could be measured in two ways. For further computer evaluation, the values captured by the Polar instrument were stored in the computer's memory. The principle of this device was a walkie-talkie that reads heart beat signals from two precordially placed flat electrodes (fixed in the correct position using an elastic band) and a sensing part permanently located on the handlebars of the ergometer, connected to the computer. The correct operation of the system (information about the heart rate value) could be checked on the wristwatch display, which also reads the radio signals. These are also attached to the handlebars of the ergometer. At the same time, heart rate information was received by a personal computer. The real values measured by this sensor could be checked regularly at set intervals by reading the H value from the ECG recording.

Since 1999, the twelve-lead ECG record was continuously monitored throughout the examination and for at least 5 min after the end of the stress test. If no abnormal or pathological changes were present, the record was stored in the computer's memory at the end of each of the three sub-maximum workloads and at each half-minute of the maximum workload. After the end of the stress test, these records were printed out and then archived in the documentation of the examined person. The ECG was monitored in 4-5 min of recovery after the stress test until exhaustion.

*Correction of the ventilatory and respiratory parameters*

Before starting each stress test, the current values of the $f_{STPD}$ and $f_{BTPS}$ correction factors had to be entered into the computer's memory. These factors were determined according to the tables based on the current, usually morning values of barometric pressure and temperature in the examination room. Respiratory values, i.e. oxygen consumption per minute $VO_2$ and carbon dioxide output $VCO_2$, were automatically corrected for standard STPD conditions, i.e. 0 °C, barometric pressure 760 Torr and for dry air. Ventilation values, i.e. pulmonary ventilation per minute, were corrected for BTPS conditions: for body temperature of 37 °C, for current barometric pressure and for air saturated with water vapor.

Breathing gas analyzers have also undergone substantial improvements over the years. In the period 1994-1998 expired air during the stress test was collected for the last half a minute at the end of each workload stage using modified Douglas bags. To determine the content of respiratory gases in expired air, the $O_2$-$CO_2$ analyzer Spirolyt (East Germany) was used. Since 1999 Junkalor analyzer (with gas sensors from a Swiss company Pewatron) performed the determination of respiratory gas content continuously. The values of the $O_2$ consumption and the $CO_2$ expenditure in the expired air could be monitored throughout the whole stress test. The software allowed direct export of data from the program driver of the Kardiospirox breathing gas analyzer [8].

*Cohort of 2901 examinations*

A total of 2901 examinations (2095 examinations in the male population, 806 examinations in the female population) in the age range of 7 to 95 years were included in this study. The whole contingents were divided into 5 groups according to the nature of physical activity: group A – endurance athletes, group B – team sports players, group C – other competitive athletes, group D – recreational leisure-time athletes.

Group E included subjects with health problems, but without significant physical limitations. According to diagnoses, stenocardia and CHD (19 cases), obesity and orthopedic problems (11 cases each) and hypertension (10 cases) were most frequently represented in men in group E, as well as individual cases inadequate dyspnea, accidental heart murmur, valvular defects and palpitations (4 cases each) and individual cases of Marfan syndrome, dyslipidemia, mononucleosis, peptic ulcer, hypothyroiddism, epilepsy and others. In women, there were stenocardia (11 cases), obesity (10 cases), excessive dyspnea (6 cases), frequent viral infections and ischemic heart disease (4 cases each) involved, and further individual cases of hypothyroidism, ventricular extrasystole, hypertension, mononucleosis, smoking, paroxysmal vertigo and polymorbid disease. The physical activity of this group was irregular in most people. Their health allowed them to live independently without depending on their surroundings. Lack of physical activity in most of them was one of the causes of health problems, on the other hand, health problems were the cause of their low physical activity in some of them.

$VO_2$max values were converted to METmax and compared to NYHA criteria (Fig. 3).

2450 subjects from this cohort were mostly competitive athletes (groups A, B and C), for whom regular sports medical check-ups are a condition for participation in sports competitions. These athletes underwent a sports medical examination completely voluntarily, before the examination they were explained the procedure of the examination and at the end they received a written report with conclusions for their further sports activities. Groups D of this cohort (327 subjects) included leisure time athletes who included regular physical activity as part of their lifestyle. They themselves were interested in how their lifestyle is reflected in the parameters of physical fitness. Groups E included 126 subjects who came to the sports medical examination either out of their own interest in advice on what form of physical activity to choose to achieve the optimal effect, or were sent by their doctor to receive expert recommendations on what physical activity to choose within a comprehensive treatment program.

Out of a total database of 5892 examinations, our contingents account for 47 % of the total. For unclassified examinations, these are those examinations where either the stress test on the ergometer was not performed at all (e.g. it was only a control sports medical examination) or the stress test on a bicycle ergometer contained only an ergometric examination without respiratory gas analysis or the examination was performed on a treadmill ergometer (a total of 421 examinations) and therefore, the results could not be compared with those obtained by examination on a bicycle ergometer.

The Konsil program was used to process the measured data during the examination and store it in the database. This program, including instrumentation was first introduced at the Congress of Sports Medicine in 1992 and introduced at the University Hospital in Pilsen in 1995. In the following years, the instrumentation and software were gradually improved. Currently, Konsil W-1 program was used, where all manipulations have been transferred from the DOS operating system to the Windows operating system [9,10] allowing to automatically determine and evaluate most of the monitored parameters.

All statistical calculations were performed using the statistical toolbox that is part of the MATLAB program.

## Results

As expected, METmax values reached the highest levels in both male and female A groups. In both men and women, the METmax values in groups A, B and C were significantly higher than in group E. The main factor of these differences was the regular long-term training load in competitive athletes, regardless of the type of sport they were engaged in (Table 2 and Figs 3 and 4). In group E, due to long-term lack of physical activity, the parameters of cardiorespiratory capacity, assessed according to METmax values, were significantly below the average age norms for this group. While in groups A to D cases that would be classified as NYHA 1 (METmax lower than 9) were quite rare (10 cases out of 2777, i.e. 0.3 %), in groups E it was 20 % in men (16 cases out of 82) and 52 % in women (23 cases out of 44) of those examined (Fig. 4). Most of these subjects have either never competed in any sports or, in some cases, stopped sports activity at a very young age.

**Table 2.** Mean values (± standard deviation) of age, body height (cm), body weight (kg), fat content (% of body weight) and body mass index (BMI).

| *Group* | | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|---|
| *Men* | *N* | 759 | 446 | 618 | 192 | 82 |
| | *age* | 28.0±14 | 18.7±6.1 | 24.0±12.7 | 27.9±13.2 | 27.6±17.8 |
| | *BH* | 176.6±9.9 | 178.3±8.5 | 175.4±11.4 | 176.7±10.8 | 169.1±14.7 |
| | *BW* | 71.3±14.2 | 73.8±11.9 | 70.9±11.2 | 74.5±16.2 | 72.6±27.2 |
| | *fat* | 13.1±5.4 | 12.9±4.2 | 12.48±5.9 | 15.1±6.9 | 24.0±6.2 |
| | *BMI* | 22.9±3.1 | 23.2±2.5 | 23.0±3.5 | 23.9±4.0 | 25.4±6.4 |
| *Woman* | *N* | 307 | 161 | 159 | 135 | 44 |
| | *age* | 18.1±9 | 18.7±6.7 | 20.6±11.3 | 28.3±13 | 26.3±15.8 |
| | *BH* | 163.6±8.7 | 169.9±6.6 | 164.8±7.7 | 165.6± | 165.6±8.7 |
| | *BW* | 53.5±10.7 | 63.1±8.2 | 56.8±11 | 62.3±8 | 68.6±24.3 |
| | *fat* | 16.9±4.4 | 20.1±6 | 17.7±6.4 | 21.9±7 | 33.1±11.7 |
| | *BMI* | 20.0±2.6 | 21.8±2.5 | 20.9±3.2 | 22.7±3.9 | 25.0±7.8 |

Group A (endurance athletes), group B (team sports), group C (other competitive athletes), group D (leisure sport activities) and group E (subjects with health problems). Fat content was measured using the skinfold thickness method.

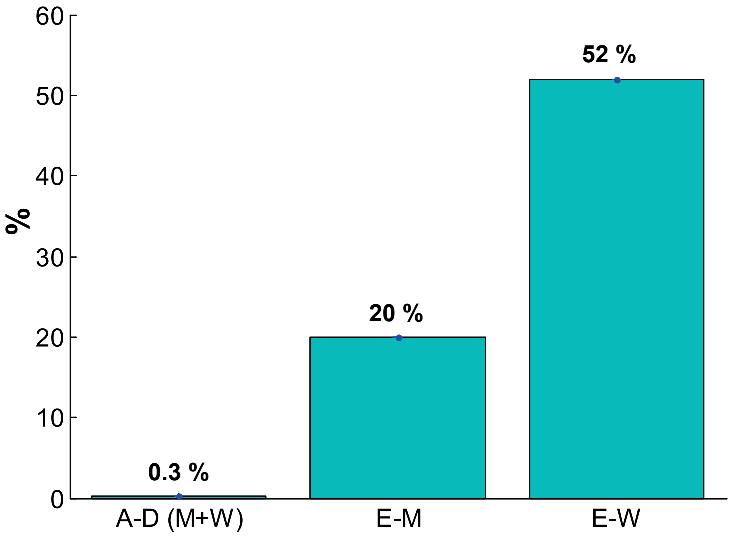

**Fig. 4.** Prevalence of subjects with METmax lower than 9. A-D (M+W) = all physically active subjects – men and women (n=2777); E-M = men with health problems (n=82); E-W = women with health problems (n=44).

**Table 3.** METmax values in differently trained groups.

| *Group* | | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|---|
| *Men* | x̄ | 17.2 | 16.6 | 14.5 | 11.7 | 10.2 |
| | SD | 3.0 | 2.3 | 2.8 | 2.1 | 2.1 |
| *Woman* | x̄ | 14.3 | 13.6 | 11.9 | 10.1 | 8.5 |
| | SD | 2.2 | 2.0 | 1.8 | 1.9 | 1.5 |

Groups: A – endurance athletes, B – team sports, C – other sports. D – leisure sports activities, E – subjects with health problems; mean and standard deviation.

Table 3 illustrates METmax values in differently trained groups. The average values of METmax, achieved in individual groups, were compared with the age norms given for the Czech population by Seliger and Bartůněk [7]. While significantly above-average values of METmax in groups A, B and C, i.e. in all three competitive sports groups, corresponded to the norms for persons under 20 years of age, both in men and women, it was different in groups D and E.

For male group D (average age 27.9 years), their METmax corresponded to the age of 35 years, i.e. their fitness age was 7.1 years higher compared to their calendar age. For female group D (average age 28.3±13.2 years), their METmax corresponded to the age of 25 years, i.e. their fitness age was 3.3 years lower compared to their calendar age.

For both groups E, men and women, the difference between fitness age and calendar age was similar. For male group E (average age 27.2±17.8 years), their METmax corresponded to the age of 54 years, i.e. their fitness age was 26.8 years higher compared to their calendar age.

For female group E (average age 26.3±15.8 years), their METmax corresponded to the age of 52 years, i.e. their fitness age was 25.7 years higher compared to their calendar age.

If the level of $VO_2$max and/or METmax is below average of the corresponding age group, the subjects´s fitness age is older than actual calendar age and vice versa. Unlike actual age – fitness age can be lowered with the optimal physical activity according to the recommendations of the World Health Organization. All subjects, classified in group E, received recommendations related to optimal physical activity at the end of the examination.

## Discussion

Maximal oxygen consumption ($VO_2$max) is the gold-standard measure of cardiorespiratory fitness (CRF) and a powerful predictor of all-cause and cause-specific mortality and morbidity. The level of cardiorespiratory capacity, assessed by maximum oxygen consumption $VO_2$max or by the METmax, is a significant factor related to the risk of metabolic syndrome, CAD and other major risk factors for noncommunicable diseases [8,11,12,13]. The cardioprotective importance of a high cardiorespiratory capacity, expressed by the $VO_2$max level, has been demonstrated by a number of experimental studies and extensive meta-analyses.

Endurance exercise training has displayed the ability to positively impact the heart through beneficial hypertrophy, angiogenesis, and improved contractility [14]. Additionally, individuals who exercise tend to experience relative bradycardia due to autonomic modulation, allowing for longer diastolic periods and elevated myocardial perfusion at submaximal workloads. These effects combine to improve vascular, endothelial, and myocardial health.

Cross-sectional findings showed that a large cohort of middle-aged men and women demonstrated inverse associations between fitness and CHD risk factors, regardless of CHD status [15]. Recent data suggest that CRF has an important role in reducing not only cardiovascular and all-cause mortality, but also incident myocardial infarction, hypertension, diabetes, atrial fibrillation, heart failure, and stroke [16].

At the Cooper Institute in Dallas 11049 men underwent clinical examination before 1990 until the occurrence of CVD death, non-CVD death, or attainment of age 90 years. A single measurement of low fitness in mid-life was associated with higher lifetime risk for CVD death, particularly among persons with a high burden of CVD risk factors [17].

Exercise training program can help restore physiological function in order to increase aerobic capacity and improve the quality of life even in patients at risk of heart failure [18].

Gupta *et al.* [19] concluded, that a single measurement of fitness significantly improves classification of both short-term (10-year) and long-term (25-year) risk for CVD mortality when added to traditional risk factors. Physical activity and cardiorespiratory fitness are known to be associated with enhanced health and quality of life, and even small improvements in fitness have been associated with reduced cardiovascular and all-cause mortality.

These sources show how important it is to maintain adequate cardiorespiratory capacity from youth to old age. Below-average $VO_2$max and/or METmax is one of the diagnostic signs of impending heart failure. For untrained individuals, numerical physiological parameters are difficult to understand. Expressing them through fitness age and alerting the client how much higher their level is compared to calendar age could be a motivation for some to adjust their lifestyle in a desirable direction.

## Conclusions

Exercises volumes corresponding to current physical activity (PA) recommendations are still associated with substantial risk reductions. Because larger PA volumes yield additional health benefits, adults are advised to limit sedentary behaviors and engage in ≥150 to 300 min of moderate-intensity aerobic PA or 75 to 150 min of vigorous-intensity PA, or equivalent combinations thereof, throughout the week [20]. Physical activity affects health such as cardiovascular disease, diabetes, cancer, and obesity as well as aging and mental health. Sedentary living habits and poor fitness are among major public health problems. Even small increases of PA can bring huge health benefits [21]. Cardiorespiratory fitness is favorably associated with most modifiable coronary heart disease (CHD) risk factors, risk factors, especially physical activity [22].

Our data show that, in contrast to all groups of regularly training athletes, the cardiorespiratory capacity of untrained people (their “fitness age”), assessed by their METmax or $VO_2$max, corresponds to the norms of older age groups for both men and women. This represents a significant risk of their morbidity in relation to non-communicable diseases and probably also a significant limitation of their quality of life in later life.

People without regular, satisfactory physical activity expose themselves to the risk of the entire complex of non-communicable diseases, today referred to as “sedentary death syndrome” [22].

## Conflict of Interest

There is no conflict of interest.

## Acknowledgements

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## References

1. Raphael C, Briscoe C, Davies J, Whinnett ZI, Manisty C, Sutton R, Mayet J, Francis DP. Limitations of the New York Heart Association functional classification system and self-reported walking distances in chronic heart failure. Heart 2007;93:476-482. https://doi.org/10.1136/hrt.2006.089656
2. Haff G, Dumke C. *Laboratory Manual for Exercise Physiology*. Human Kinetics, Champaign, Illinois, USA, 2012, 464 p.
3. Wasserman K, Hansen JE, Sue DY, Stringer WW, Sietsema KE, Sun X-G, Whipp BJ. *Principles of Exercise Testing and Interpretation, Including Pathophysiology and Clinical Applications. Fifth Edition.* Wolters Kluwer/Lippincott Williams & Wilkins, Philadelphia, Pennsylvania, USA, 2012, 572 p.
4. Tanner RK, Gore CJ. *Physiological Tests for Elite Athletes*. Human Kitetics, Champaign, Illinois, USA, 2013, 560 p.
5. Shephard RJ. *Frontiers of Fitness*. Charles CT, Springfield, Illinois, USA, 1971.
6. Heyward VH. *Advanced Fitness Assessment Exercise Prescription. Third Edition*. Human Kinetics, Champaign, Illinois, USA, 1998, 322 p.

7. Seliger V, Bartůněk Z. *Mean Values of Various Indices of Physical Fitness of Czechoslovak Population Aged 12-55 Years*. ČSTV, Praha, 1976, 117 p.
8. Štork M. Hardware and software for spiroergometric examination. Med Sport Bohem Slov 2001;10:98-103.
9. Štork M, Novák J, Zeman V. Noninvasive medical examination and optimal physical activity prescription based on stress test. 14th WSEAS International Conference on Systems, Greece 2010:580-584.
10. Zeman V, Novák J, Štork M. Medical teaching innovation - creation of the computer program and electronic system for optimal physical activity prescription. In: *Applied Electronics 2007*. ZČU Plzeň, Plzeň 2007, pp 245-248.
11. Earnest CP, Artero EG, Sui X, Lee D, Church TS, Blair SN. Maximal Estimated Cardiorespiratory Fitness, Cardiometabolic Risk Factors, and Metabolic Syndrome in the Aerobics Center Longitudinal Study. Mayo Clinic Proc 2013;88:259-270. https://doi.org/10.1016/j.mayocp.2012.11.006
12. Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, Sugawara A, Totsuka K, Shimano H, Ohashi Y, Yamada N, Sone H. Cardiorespiratory Fitness as a Quantitative Predictor of All-Cause Mortality and Cardiovascular Events in Healthy Men and Women. A Meta-analysis. JAMA 2009;301:2024-2035. https://doi.org/10.1001/jama.2009.681
13. Reynolds K, Galassi A, He J. Metabolic Syndrome and Risk of Cardiovascular Disease. A Meta-Analysis. Amer J Med 2006;119:812-819. https://doi.org/10.1016/j.amjmed.2006.02.031
14. Chowdhury MA, Sholl HK, Sharrett MS, Haller ST, Cooper CC, Gupta RJ, Liu LC. Exercise and Cardioprotection: A Natural Defense Against Lethal Myocardial Ischemia-Reperfusion Injury and Potential Guide to Cardiovascular Prophylaxis. J Cardiovasc Pharmacol Ther 2019;24:18-30. https://doi.org/10.1177/1074248418788575
15. LaMonte MJ, Eisenman PA, Adams TD, Shultz BB, Ainsworth BE, Yanowitz FG. Cardiorespiratory fitness and coronary heart disease risk factors: the LDS Hospital Fitness Institute cohort. Circulation 2000;102:1623-1628. https://doi.org/10.1161/01.CIR.102.14.1623
16. Al-Mallah MH, Sakr S, Al-Qunaibet A. Cardiorespiratory Fitness and Cardiovascular Disease Prevention: an Update. Curr Atheroscler Rep 2018;20:1. https://doi.org/10.1007/s11883-018-0711-4
17. Berry JD, Dyer A, Cai X, Garside DB, Ning H, Thomas A, Greenland P, Van Horn L, Tracy RP, Lloyd-Jones DM. Lifetime risks for cardiovascular disease mortality by cardiorespiratory fitness levels measured at ages 45, 55, and 65 years in men. The Cooper Center Longitudinal Study. J Am Coll Cardiol 2011;57:1604-1610. https://doi.org/10.1016/j.jacc.2010.10.056
18. do Prado DML, Rocco EA. The Benefits of Exercise Training on Aerobic Capacity in Patients with Heart Failure and Preserved Ejection Fraction. Adv Exp Med Biol. 2017;1000:51-64. https://doi.org/10.1007/978-981-10-4304-8_4
19. Gupta S, Rohatgi A, Ayers CR, Willis BL, Haskell WL, Khera A, Drazner MH, ET AL. Cardiorespiratory Fitness and Classification of Risk of Cardiovascular Disease Mortality. Circulation 2011;123:1377-1383. https://doi.org/10.1161/CIRCULATIONAHA.110.003236
20. Franklin BA, Eijsvogels TMH, Pandey A, Quindry J, Toth PP. Physical activity, cardiorespiratory fitness, and cardiovascular health: A clinical practice statement of the ASPC Part I: Bioenergetics, contemporary physical activity recommendations, benefits, risks, extreme exercise regimens, potential maladaptations. Am J Prev Cardiol 2022:12:100424. https://doi.org/10.1016/j.ajpc.2022.100424
21. Bouchard C, Blair SN, Haskell WL. *Physical Activity and Health. Second edition.* Human Kinetics, Champaign, Illinois, USA, 2012, 456 p. https://doi.org/10.5040/9781492595717
22. Booth FW, Kruppa DJ. Sedentary death syndrome is what reasearchers now call American second largest threat to public health. MOspace. http://hdl.handle.net/10355/10361.