EDITORIAL

ACCEPTED: September 2022
PUBLISHED ONLINE: October 2022
Schmidt-Trucksäss A. Cardiorespiratory fitness – properly measured, interpreted and applied? Dtsch Z Sportmed. 2022; 73: 199-202. doi:10.5960/dzsm.2022.543

Cardiorespiratory Fitness – Properly Measured, Interpreted and Applied?

Kardiorespiratorische Fitness – richtig erfasst, interpretiert und verwendet?

Prof. Dr. med. Arno Schmidt-Trucksäss
Vice Director, Department of Sport, Exercise and Health (DSBG), University of Basel, Switzerland

Cardiorespiratory fitness is one of the most important health markers. It is determined by the interaction of lungs, heart, vessels and musculature, as demonstrated by Wasserman (16) in the form of a gear model. This model makes clear that numerous organs are involved in the transport of O_2 and CO_2 and thereby in the function of elements of the model which determine the degree of cardiorespiratory fitness. It is not without reason that cardiorespiratory fitness plays a central role in the assessment of health, which is often still underestimated.

Considering the importance of an ergometric exercise testing in internal medicine, especially cardiology, the poor negative or positive predictive value of the stress ECG for the detection of an obstructive coronary-arterial disease written in a Guideline of the European Cardiological Society (ESC) on the «Diagnosis and Management of the chronic Coronary Syndrome» immediately catches the eye (7). With only moderate sensitivity of 58% and specificity of 62%, ischemia diagnostics and the recognition of complex arrhythmias still remain the main area of the use of ergometry in clinical practice (7). This could be because on the one hand even with a recommended pretest probability of a coronary obstruction of at least 15% in performing a stress-ECG, the number of patients who meet this criterion is still very high. On the other hand, perhaps assessing cardiorespiratory fitness was recognized as important to health, which should be the case without question in sport and exercise medicine.

At the latest, when the American Heart Association several years ago termed cardiorespiratory fitness as the fifth vital sign (12), it should have become clear to everyone that measuring the maximum ergometric exercise capacity has a special value in assessing the state of health and the risk of mortality. In an observational study on 22878 participants (age at baseline 47.4 years, follow-up 9.2 years) Israel et al. (5) were able to clearly improve the prediction of deaths (N=505); the relative risk of death in persons with a high Euro Risk Score and low cardiorespiratory fitness (<11 MET (metabolic equivalent of task)) was 35.6 times that of persons who were fit and not affected by risk factors. If the cardiorespiratory fitness was good (>11MET) with equally unfavorable Euro Risk Score, the risk could be reduced to 8.5 times, or to nearly 25%. The net-reclassification over all risk groups from low to high risk of death showed an improvement of 56.8% when cardiorespiratory fitness was combined with the Euro Risk Score. A meta-analysis by Kodama et al. (8) showed that a decrease in total mortality and cardiovascular mortality of 15% and 13%, respectively, is coupled with an increase in cardiorespiratory fitness of 1 MET. Comparing the relative risk of total mortality in manifest diseases like diabetes type 2 (HR 1.40), coronary heart disease (HR 1.29) or also risk factors like smoking (HR 1.41) or an existing arterial hypertension (HR 1.21) with that of a below-average maximum endurance exercise capacity (HR 1.95), it can be interpreted as comparable in the sense of prediction (10). It must be emphasized that the reduction of the risk occurs not only in people who are already fit, but the improvement is already substantial if the least fit person is compared to the next unfit person (10).

These observations were, however, not only made in healthy persons, but also in patients with various chronic diseases. Thus, patients with heart failure, mental and neurological diseases, metabolic diseases like diabetes type 2 or even patients with cancer benefit from improvement of cardiorespiratory fitness. Apparently the endurance activity associated with the improvement in fitness acts via various mechanisms like chronic inflammation, autophagy or mitochondrial metabolism. The effects of improved fitness measured in intervention studies and observable in clinical routine on blood pressure regulation, glucose metabolism and the cholesterol subfractions, as well as directly on vascular structure and function in the micro- and macrovasculature must be mentioned here (12).

Selection of the Proper Exercise Method

Despite these numerous positive effects in healthy people and patients with chronic diseases, one sometimes has the impression that the assessment of cardiorespiratory fitness as a health marker is still not well established in the preventive thinking in medical practice. What could be behind that?

First, assessing cardiorespiratory fitness is coupled with a certain degree of apparative costs. To obtain valid and well-reproducible measurements, one needs at least an ergometer. For this, the bicycle ergometer typically plays a domi- ›

Article incorporates the Creative Commons Attribution – Non Commercial License.
https://creativecommons.org/licenses/by-nc-sa/4.0/

QR-Code scannen und Artikel online lesen.

CORRESPONDING ADDRESS:
Prof. Dr. med. Arno Schmidt-Trucksäss
Vice Director, Department of Sport, Exercise and Health (DSBG), University of Basel,
Grosse Allee 6, 4052 Basel, Schweiz
: arno.schmidt-trucksaess@unibas.ch

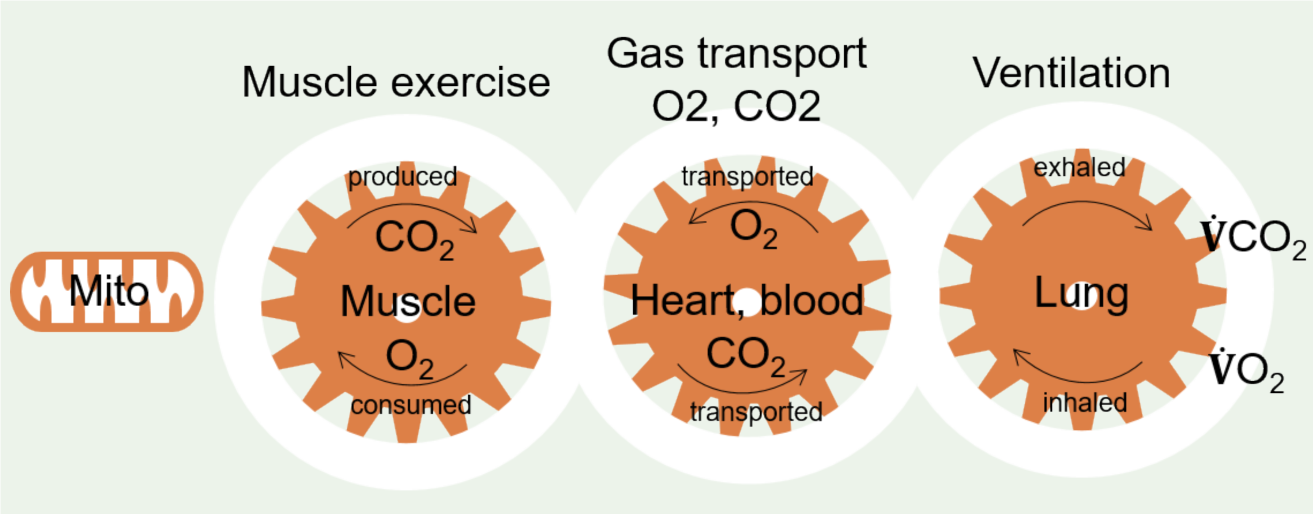

Figure 1

Wasserman gear model of cardiovascular system function that reflects the complexity of the interplay of different organs in gas transport (adapted from (16)).

nant role in the German-speaking region. But treadmill ergometers and, to an even lesser extent, rowing ergometers are alternatives for the measurement. In favor of the bicycle ergometer are its broad use and the ability of most people to ride a bicycle, although this can no longer be considered self-evident due to increasing migration and inactivity of the population. Nonetheless it can be assumed that most people can reach nearly maximum exercise on the bicycle ergometer. In sport and exercise medicine, exercise in a sitting position on the bicycle ergometer is preferred to exercise in semi-recumbent position (30-45°) due to the higher exertion. The peak oxygen uptake, about 10% lower by comparison, and thus the exercise capacity on the bicycle ergometer compared to the treadmill ergometer is offset by the lower demands on coordination capacity, a largely artefact-free recording of the parallel exercise ECG and blood pressure measurement during exercise. Especially among elderly people (more than 70 years of age), exercise on the treadmill ergometer is more likely coupled with a greater coordinative demand, since the exercise is very unusual for many (1).

Estimating Cardiorespiratory Fitness Is not Sufficient

Submaximal tests like the Astrand-Rhyming Test appear rather unsuitable to assess the maximum endurance exercise capacity by ergometry (4). Based on this test, the maximum aerobic exercise capacity can only be estimated using nomograms. These values can deviate by 10-20% from the real maximum attainable values. However, submaximal tests appear to be acceptable if the presence of a physician, which is required for safety reasons, cannot be provided. A submaximal test is then clearly superior to pure estimation based on population-based equations, like that in the FRIEND Registry (11). In the latter, the deviation from the actually measured maximum exercise capacity (maximum oxygen uptake, $\dot{V}O_2$) can be 20-25%, so that the application of equations in estimating the maximum aerobic exercise capacity can be used only for orientation, but not in the sense of an individual valid value.

The correct maximum exertion of the patient is also among the quality aspects in performing spiroergometry. It must be emphasized that spiroergometry has a clear advantage over normal ergometry without gas exchange measurement in the objective determination of maximum exertion based on the RER (respiratory exchange ratio). Several studies (9, 15) show that the RER is dependent on both age and weight and therefore a uniform limit value of, for example, 1.10 signalizes sufficient exertion on average, but not the individual maximum value to be achieved. Thus, maximum exertion can be expected in people aged 20-39 years with an RER of 1.3, aged 40-59 years of 1.10 and aged 60-69 years of 1.06. The age-predicted maximal heart rate, correctly estimated by the equation 210 minus age or 208-0.7 x age is another criterion (15). If both factors are achieved, near maximum exertion can be assumed even without attaining a plateau in oxygen uptake. An oxygen plateau, also recognizable as a levelling-off of oxygen uptake, is only achieved by 30-50% of all maximum exercise spiroergometries (2). The other 50-70% show either a continuous increase to cessation of exercise or an excessive increase shortly before the end of exercise. For this reason, secondary maximum exertion criteria appear to be meaningful alternatives/supplements in estimating maximal exertion.

Pay Attention to Diurnal Variability

To guarantee reproducible values, it must also be noted that the variability within a day can on average be 8.5% of the maximal oxygen uptake. In this, contrary to various statements in the literature, there is no particular time of day at which the maximal exercise capacity is attained. Compared to the intra-day variability, the variability at the same time of day on different days is lower by about a factor of 2.5 (6). For this reason, care must be taken that spiroergometric examinations over time are always performed at the same time of day. This is particularly of interest since improvements in cardiorespiratory fitness after endurance training interventions in untrained persons are typically in the range of 10-30%. For this reason, the time of day can certainly have significant influence on the achieved or measured oxygen uptake. In addition, it is noted that verification tests, that is tests with exercise until exertion repeated after a few minutes, do not improve the reliability of determination of cardiorespiratory fitness and can thus be omitted (14).

Reference Values Are Important in Risk Stratification

Finally, reference values for healthy persons are required for the proper assignment of cardiorespiratory fitness for use in risk stratification. It is seen that considerable differences may exist between cohorts. The maximal absolute oxygen uptake attained by healthy persons of both genders in the COmPLETE-cohort study (13) is 22% higher than for people of the same age who are considered healthy in the SHIP-cohort (3) examined at the University of Greifswald. With comparable quality criteria in the calibration of the equipment, this difference can most likely be explained by the still better health of the COmPLETE participants (BMI $\geq 30 kg/m^2$, diabetes, and current smoking are among the exclusion criteria) and a higher maximum exertion (inclusion in SHIP already at RER >1.0). It is therefore certainly necessary for valid assessment of cardiorespiratory fitness as a health marker that consensus be reached concerning the criteria for a healthy normal cohort and the maximum exertion criteria. If this is achieved, cardiorespiratory fitness will probably take an even higher clinical relevance as a health marker in risk stratification and in clinical practice.

References

(1) **AMERICAN THORACIC SOCIETY; AMERICAN COLLEGE OF CHEST PHYSICIANS.** ATS/ACCP Statement on cardiopulmonary exercise testing. Am J Respir Crit Care Med. 2003; 167: 211-277. doi:10.1164/rccm.167.2.211

(2) **DAY JR, ROSSITER HB, COATS EM, SKASICK A, WHIPP BJ.** The maximally attainable VO2 during exercise in humans: the peak vs. maximum issue. J Appl Physiol (1985). 2003; 95: 1901-1907. doi:10.1152/japplphysiol.00024.2003

(3) **GLÄSER S, ITTERMANN T, SCHÄPER C, OBST A, DÖRR M, SPIELHAGEN T, FELIX SB, VÖLZKE H, BOLLMANN T, OPITZ CF, WARNKE C, KOCH B, EWERT R.** [The Study of Health in Pomerania (SHIP) reference values for cardiopulmonary exercise testing]. Pneumologie. 2013; 67: 58-63. doi:10.1055/s-0032-1325951

(4) **GRANT S, CORBETT K, AMJAD AM, WILSON J, AITCHISON T.** A comparison of methods of predicting maximum oxygen uptake. Br J Sports Med. 1995; 29: 147-152. doi:10.1136/bjsm.29.3.147

(5) **ISRAEL A, KIVITY S, SIDI Y, SEGEV S, BERKOVITCH A, KLEMPFNER R, LAVI B, GOLDENBERG I, MAOR E.** Use of exercise capacity to improve SCORE risk prediction model in asymptomatic adults. Eur Heart J. 2016; 37: 2300-2306. doi:10.1093/eurheartj/ehw053

(6) **KNAIER R, INFANGER D, NIEMEYER M, CAJOCHEN C, SCHMIDT-TRUCKSASS A.** In Athletes, the Diurnal Variations in Maximum Oxygen Uptake Are More Than Twice as Large as the Day-to-Day Variations. Front Physiol. 2019; 10: 219. doi:10.3389/fphys.2019.00219

(7) **KNUUTI J, WIJNS W, SARASTE A, CAPODANNO D, BARBATO E, FUNCK-BRENTANO C, PRESCOTT E, STOREY RF, DEATON C, CUISSET T, AGEWALL S, DICKSTEIN K, EDVARDSEN T, ESCANED J, GERSH BJ, SVITIL P, GILARD M, HASDAI D, HATALA R, MAHFOUD F, MASIP J, MUNERETTO C, VALGIMIGLI M, ACHENBACH S, BAX JJ; ESC SCIENTIFIC DOCUMENT GROUP.** 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. Eur Heart J. 2020; 41: 407-477. doi:10.1093/eurheartj/ehz425

(8) **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. doi:10.1001/jama.2009.681

(9) **LOE H, STEINSHAMN S, WISLOFF U.** Cardio-respiratory reference data in 4631 healthy men and women 20-90 years: the HUNT 3 fitness study. PLoS One. 2014; 9: e113884. doi:10.1371/journal.pone.0113884

(10) **MANDSAGER K, HARB S, CREMER P, PHELAN D, NISSEN SE, JABER W.** Association of Cardiorespiratory Fitness With Long-term Mortality Among Adults Undergoing Exercise Treadmill Testing. JAMA Netw Open. 2018; 1: e183605. doi:10.1001/jamanetworkopen.2018.3605

(11) **MYERS J, KAMINSKY LA, LIMA R, CHRISTLE JW, ASHLEY E, ARENA R.** A Reference Equation for Normal Standards for VO2 Max: Analysis from the Fitness Registry and the Importance of Exercise National Database (FRIEND Registry). Prog Cardiovasc Dis. 2017; 60: 21-29. doi:10.1016/j.pcad.2017.03.002

(12) **ROSS R, BLAIR SN, ARENA R, CHURCH TS, DESPRÉS JP, FRANKLIN BA, HASKELL WL, KAMINSKY LA, LEVINE BD, LAVIE CJ, MYERS J, NIEBAUER J, SALLIS R, SAWADA SS, SUI X, WISLØFF U; AMERICAN HEART ASSOCIATION PHYSICAL ACTIVITY COMMITTEE OF THE COUNCIL ON LIFESTYLE AND CARDIOMETABOLIC HEALTH; COUNCIL ON CLINICAL CARDIOLOGY; COUNCIL ON EPIDEMIOLOGY AND PREVENTION; COUNCIL ON CARDIOVASCULAR AND STROKE NURSING; COUNCIL ON FUNCTIONAL GENOMICS AND TRANSLATIONAL BIOLOGY; STROKE COUNCIL.** Importance of Assessing Cardiorespiratory Fitness in Clinical Practice: A Case for Fitness as a Clinical Vital Sign: A Scientific Statement From the American Heart Association. Circulation. 2016; 134: e653-e699. doi:10.1161/CIR.0000000000000461

(13) **WAGNER J, KNAIER R, INFANGER D, KÖNIGSTEIN K, KLENK C, CARRARD J, HANSSEN H, HINRICHS T, SEALS D, SCHMIDT-TRUCKSÄSS A.** Novel CPET Reference Values in Healthy Adults: Associations with Physical Activity. Med Sci Sports Exerc. 2021; 53: 26-37. doi:10.1249/MSS.0000000000002454

(14) **WAGNER J, NIEMEYER M, INFANGER D, HINRICHS T, GUERRA C, KLENK C, KÖNIGSTEIN K, CAJOCHEN C, SCHMIDT-TRUCKSÄSS A, KNAIER R.** Verification-phase tests show low reliability and add little value in determining [Formula: see text]O2max in young trained adults. PLoS One. 2021; 16: e0245306. doi:10.1371/journal.pone.0245306

(15) **WAGNER J, NIEMEYER M, INFANGER D, HINRICHS T, STREESE L, HANSSEN H, MYERS J, SCHMIDT-TRUCKSÄSS A, KNAIER R.** New Data-based Cutoffs for Maximal Exercise Criteria across the Lifespan. Med Sci Sports Exerc. 2020; 52: 1915-1923. doi:10.1249/MSS.0000000000002344

(16) **WASSERMAN K.** The Dickinson W. Richards lecture. New concepts in assessing cardiovascular function. Circulation. 1988; 78: 1060-1071. doi:10.1161/01.CIR.78.4.1060