

Maximum Oxygen Consumption Measurement: Valuable Biological Marker in Health and in Sickness

Claudio Gil Soares de Araújo^{1,2}, Artur Haddad Herdy^{3,4,5}, Ricardo Stein^{6,7}

Programa de Pós-Graduação em Ciências do Exercício e do Esporte – Universidade Gama Filho¹; Clínica de Medicina do Exercício (Clinimex)², Rio de Janeiro, RJ; Instituto de Cardiologia de Santa Catarina³; Clínica Cardiosport⁴; Universidade do Sul de Santa Catarina (Unisul)⁵, Florianópolis, SC; Departamento de Medicina Interna da Faculdade de Medicina – Universidade Federal do Rio Grande do Sul⁶, Porto Alegre, RS; Vitta Exercício & Clínica de Saúde⁷, Porto Alegre, RS – Brazil

Human beings depend on atmospheric oxygen (O₂) for survival. To perform physical work, it is necessary to increase the volume of air into the lungs, increase blood flow and activate specific metabolic in the skeletal muscles, resulting in an increased O₂ uptake and utilization. Integrated responses of the respiratory, cardiovascular and muscular systems in exercises involving large muscle groups increase up to a limit that defines the maximum oxygen consumption (VO₂max) or aerobic fitness of the individual.

Considering that the human body is a machine capable of transforming chemical energy into mechanical work, VO₂max corresponds to physical performance, which is defined as Maximum Functional Capacity (MFC) and can be estimated with good accuracy. With the exception of extreme cases of greater or lower mechanical efficiency, such as athletes that are extremely technical regarding motor gestures or disabled individuals with greatly reduced functional capacity, there is usually a significant association between VO₂max and MFC for virtually all other individuals¹. This point of view briefly discusses the major historical and methodological aspects and the physiological, clinical and epidemiological significance of VO₂max, as well as demonstrating its role as a marker of health status and physical performance.

During exercise situations, the physiological mechanisms can increase alveolar ventilation 10 to 30 times; heart rate 3 to 4 times; cardiac output 5 to 6 times, and the arteriovenous peripheral extraction of O₂ at some times. Thus, VO₂ increases in direct proportion to the intensity of the effort. While VO₂max tends to be higher in men and decrease with age, VO₂max measurements eventually differ in humans. In resting conditions, an adult tends to consume slightly more than 200 mL of O₂ (approximately 1 kcal) per minute or something like 3.5 mL O₂.kg⁻¹.min⁻¹. In order to simplify it, it was decided that this resting energy

expenditure would be called 1 metabolic equivalent (MET).

While some individuals with heart disease, lung disease and the elderly may be limited to only 3 or 4 METs or VO₂max between 10 and 14 mL O₂.kg⁻¹.min⁻¹, active middle-aged men tend to have a VO₂max ranging between 25 and 35 mL O₂.kg⁻¹.min⁻¹, adolescents and young adults between 35 and 55, and elite athletes in predominantly aerobic modalities may even exceed 70 mL O₂.kg⁻¹.min⁻¹. Despite the fact that a young and healthy individual can reach VO₂max in just over a minute during a sudden and very high-intensity effort, as it indeed occurs in several sports competitions, in the clinical practice exercise testing protocols are used with small increments or on a slow ramp, aiming to achieve a VO₂max after approximately ten minutes and favoring the interpretation of different cardiorespiratory and ECG variables.

Historically, it is known that the early studies of VO₂max measurements were published more than a hundred years ago, which in fact contributed for physiologist Archibald V. Hill, one of the tested subjects and the author of these studies, to be awarded the Nobel Prize in Physiology and Medicine in 1922². In Brazil, this measurement started to be performed primarily in exercise physiology labs in the early 70's. In a not so distant past, the assessment of VO₂max was restricted to a few specialized centers. However, currently the number of sites able to effectively measure VO₂max during a cardiopulmonary exercise test (CPET) has increased very rapidly. For instance, when considering all authors of this point of view, more than 20,000 procedures have been performed in the last 40 years.

VO₂max may be directly measured by analysis of expired gases during a CPET or estimated using equations based on distance traveled during a time period - for example, Cooper's test - or duration of an exercise test with a specific protocol (Bruce or Ellestad, for instance). Even if under some circumstances the use of these prediction equations may result in good association with the values obtained from direct measurements, the error for a given individual can be quite high, of around 15% to 20% and, in rare cases, up to or more than 30%, a margin of error that is not found in other measurements in the biological area. Thus, whenever possible and consistent with the current trend, it is preferable to perform a truly maximum CPET³ and obtain more accurate and direct measures of VO₂max.

In situations where a limitation in VO₂max is observed or when very low values are attained, much lower than those predicted for age and sex, a diagnostic meaning may ensue, especially when such results are to be compared with previous tests that showed normal results. However, the greatest relevance of determining the VO₂max and MFC is in its

Keywords

Cardiopulmonar exercise testing; Ergospirometry; Exercise testing; Aerobic fitness; Physical fitness; Functional evaluation.

Mailing Address: Dr. Claudio Gil S. Araújo •

CLINIMEX – Clínica de Medicina do Exercício
Rua Siqueira Campos, 93/101 – Postal code 22031-070 – Rio de Janeiro, RJ – Brazil

E-mail: cgaraujo@iis.com.br

Manuscript received November 29, 2012; revised manuscript January 01, 2013; accepted January 10, 2013.

DOI: 10.5935/abc.20130085

prognostic use. Classic studies with large samples of middle-aged and elderly individuals from different parts of the world have repeatedly found that the risk of mortality from all causes in follow-ups between 5 and 20 years can vary from one to five times for individuals located in the most extreme quartiles or quintiles of VO₂max or MFC^{4,6}. For adult, middle-aged men, an increment of 3.5 mL O₂.kg⁻¹.min⁻¹ corresponds to a 12% gain in life expectancy⁶. Putting this information into the clinical perspective of individual risk stratification, one can compare the annual mortality rate of middle-aged men in different clinical conditions and VO₂max (Table 1). Based on these epidemiological data, it is clear that having a proportionally high VO₂max (or MFC) is a strong sign of health and longevity. Men that at the age of 50 complete a 10 km race in less than 50 minutes will show an excellent prognosis regarding life expectancy in the following 5 to 10 years⁷. On the other hand, "healthy" individuals (with normal cardiac assessment) and VO₂max < 17 mL O₂.kg⁻¹.min⁻¹ (approximately 50%-60% of predicted for age and gender) have an annual mortality rate of around 5%⁶, not very different from that observed after the diagnosis of colon cancer, which, according to the latest data from the U.S. CDC, is around 7%/year¹³.

It is interesting to note that a high VO₂max attenuates the negative impact of the presence of other known coronary risk factors⁸. In parallel, other studies with quantification of regular physical activity pattern, a variable also clearly associated with VO₂max and MFC, showed similar results, corroborating the clinical impression⁹. In this sense, there has been a recent study involving several population cohorts comprising a total of 650,000 individuals, aged 21 to 90 years old, which found a strong positive association between regular physical activity and life expectancy¹⁰.

Considering that VO₂max is a valuable indicator of health and physical performance, it is worth considering the effect of regular aerobic exercise at different stages of life upon this variable. Recent data indicate that VO₂max values of older elite professional soccer players (27-36 years old) remain similar to those of younger ones (17-22 years old), suggesting that it is possible to maintain very high levels of VO₂max when one has appropriate training¹¹.

In fact, these data only confirm the empirical observation that most of the excellent results observed in marathoners, triathletes and elite road cyclists occur when they are in their 4th or 5th decade of life. In this sense, it is noteworthy that

recent evidence point to a reduction in mortality when aging is accompanied by a more active lifestyle and a proportionally smaller decrease in VO₂max with age¹². One can assume that with the increasing participation of middle-aged and elderly individuals in mass sporting events (e.g., half-marathons and marathons), in the near future, scientific data will identify with greater precision the effects of declining reduction of VO₂max with age on survival and health-related quality of life.

In short, having a reduced VO₂max, or aerobic fitness, both in absolute terms and relative to age and sex, not only decreases the MFC and impairs physical performance, but also, what is more important, has an enormous negative impact on the mortality rate in subsequent years. Probably, no other biological variable has as much relevance to health as VO₂max. Thus, it is about time for clinical cardiologists to have VO₂max measurement of their patients at the top of their priorities and decisions, with CPET being the best propaedeutic tool for its measurement.

Author contributions

Conception and design of the research, Acquisition of data, Analysis and interpretation of the data, Writing of the manuscript and Critical revision of the manuscript for intellectual content: Araújo CGS, Herdy AH, Stein R; Obtaining funding: Araújo CGS.

Potential Conflict of Interest

Dr. Claudio Gil Soares de Araújo - Potential Conflict: Financial aid from manufacturers and lecture honoraria - Inbrasport e Micromed.

Dr. Ricardo Stein - Potential Conflict: Financial aid from manufacturer and lecture honoraria - Inbrasport.

Sources of Funding

Dr. Claudio Gil Soares de Araújo is recipient of CNPq and FAPERJ research grants.

Dr. Ricardo Stein is recipient of CNPq and FAPERGS research grants.

Study Association

This study is not part of a dissertation or thesis

Table 1 - Annual mortality rate regarding clinical status and aerobic fitness in middle-aged individuals (based on data from references^{6,7,13})

Clinical status	Aerobic fitness	Mortality rate
Apparently healthy	Excellent (>120%)	< 0.1%/year
Apparently healthy	Good or Very good (100%-120%)	1%/year
Heart disease	Good or Very good (100%-120%)	2.5%/year
Apparently healthy	Very low (50%-60%)	4.5%/year
Colon cancer (all stages) ¹³	Not informed	7%/year
Heart disease	Very low (50%-60%)	8%/year

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