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

Claudio Gil Soares de Araújo1,2, Artur Hadad Herdy3,4,5, Ricardo Stein6,7
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 (VO₂ max) or aerobic fitness of the individual.

Considering that the human body is a machine capable of transforming chemical energy into mechanical work, VO₂ max 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 VO₂ max and MFC for virtually all other individuals. This point of view briefly discusses the major historical and methodological aspects and the physiological, clinical and epidemiological significance of VO₂ max, 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 VO₂ max tends to be higher in men and decrease with age, VO₂ max 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 VO₂ max between 10 and 14 mL O₂.kg⁻¹.min⁻¹, active middle-aged men tend to have a VO₂ max 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 VO₂ max in just over a minute during a sudden and very high-intensity effort, as it indeed occurs in several sports competitions, in the practical exercise testing protocols are used with small increments or on a slow ramp, aiming to achieve a VO₂ max after approximately ten minutes and favoring the interpretation of different cardiorespiratory and ECG variables.

Historically, it is known that the early studies of VO₂ max 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 1922. 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 VO₂ max was restricted to a few specialized centers. However, currently the number of sites able to effectively measure VO₂ max 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.

VO₂ max 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 CPET and obtain more accurate and direct measures of VO₂ max.

In situations where a limitation in VO₂ max 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 VO₂ max and MFC is in its

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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
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Table 1 - Annual mortality rate regarding clinical status and aerobic fitness in middle-aged individuals (based on data from references6,7,13)

<table>
<thead>
<tr>
<th>Clinical status</th>
<th>Aerobic fitness</th>
<th>Mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparently healthy</td>
<td>Excellent (&gt;120%)</td>
<td>&lt; 0.1%/year</td>
</tr>
<tr>
<td>Apparently healthy</td>
<td>Good or Very good (100%-120%)</td>
<td>1%/year</td>
</tr>
<tr>
<td>Heart disease</td>
<td>Good or Very good (100%-120%)</td>
<td>2.5%/year</td>
</tr>
<tr>
<td>Apparently healthy</td>
<td>Very low (50%-60%)</td>
<td>4.5%/year</td>
</tr>
<tr>
<td>Colon cancer (all stages)13</td>
<td>Not informed</td>
<td>7%/year</td>
</tr>
<tr>
<td>Heart disease</td>
<td>Very low (50%-60%)</td>
<td>8%/year</td>
</tr>
</tbody>
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References


