VO_2 max / maximum O_2 consumption / maximum O_2 uptake capacity / maximum aerobic power

Manoj Nath, Post Graduate Teacher
Department of Human Physiology, Women's College
Agartala, Tripura (West), India, PIN-799001

VO_2 max or maximum O_2 consumption or maximum O_2 uptake capacity or maximum aerobic power is the maximum capacity of an individual's body to transport and use oxygen during incremental exercise, which reflects the physical fitness of the individual. The name is derived from V - volume, O_2 - oxygen, max - maximum. The VO_2 max is defined as the highest O_2 uptake, the individual can attain, during exercise engaging large muscle groups, while breathing air at sea level (Exercise time 2-6 minutes, depending on the type of exercise). The value of VO_2 max depends on various physiological & psychological factors and is the important basis of physical fitness of an individual.

VO_2 max is expressed either as an absolute rate in litres of oxygen per minute (L/min) or as a relative rate in millilitres of oxygen per kilogram of bodyweight per minute (i.e., mL/(kg·min)).

Normal value

- The average untrained healthy male have a VO_2 max of approximately 35–40 mL/(kg·min).
- The average untrained healthy female shows a VO_2 max of approximately 27–31 mL/(kg·min).

Determination:

[For determination of VO_2 max, there are two main criteria:-

1. There is no further increase in O_2 uptake despite further increase in the rate of exercise and
2. The blood lactate conc. exceeds 8-9 ml (mainly in the young individual)

The assumptions for the determination are that large muscle groups are involved & the exercise time exceeds 3 minutes.

Most suitably, the VO_2 max of a subject is determined by allowing the subject to exert a standard work-load on bicycle ergometer & measuring his/her highest O_2 uptake with the help of the Douglas bag, the latter collecting the expired air.

Procedure

The subject is allowed to sit on a bicycle ergometer and 5-10 minutes of rest on bicycle is given. During this time the subject is informed about the procedure of the test, the rate & rhythm of the pedaling etc. The initial power selected should be relatively low &

gradually increased until a heart rate (H.R) around 140 beats/min for subjects below 50 years of age & approx 120 beats/ min for older subjects is reached. This is the warming up period. The steady state H.R. is recorded. The maximal O_2 uptake is then predicted from H.R. A power is then chosen that will require an O_2 uptake approximately 10-20% higher the predicted maximum using the following table (Table of Astrand). If the subject at the end of first minute on this selected power has difficulty in keeping up the pedaling rate & starts to hyperventilate markedly, the power is lowered slightly to allow the subject to continue for a total of about 3 minutes. If on the other hand the subject after 1-2 minute appears to have more strength left than originally predicted, the work rate is slightly raised.

Table of Astrand

Watts	Work rate kmp/min	O_2 uptake in lit/min
50	300	0.9
100	600	1.5
150	900	2.1
200	1200	2.8
250	1500	3.5
300	1800	4.2
350	2100	5.0
400	2400	5.2

The objective is to collect two Douglas bags of expiratory air. This requires a collection of not less than 1 minute. It is a matter of experience to decide when to put the mouth piece and respiratory valve of the apparatus (Douglas bag) in place, on the subjects and when to the collection of air sample.

Blood for the determination of lactate conc. can easily be determined after taking the blood from the finger tip of the subject during exercise.]

Accurately measuring VO_2 max involves a physical effort sufficient in duration and intensity to fully tax the aerobic energy system. In general clinical and athletic testing, this usually involves a graded exercise test (either on a treadmill or on a cycle ergometer) in which exercise intensity is progressively increased while measuring ventilation and oxygen and carbon dioxide concentration of the inhaled and exhaled air. VO_2 max is reached when oxygen consumption remains at steady state despite an increase in workload.

True VO_2max testing is sometimes not feasible, but there are other ways to calculate it. Measuring VO_2 max requires an all-out (maximal) effort performed under a strict protocol using open-circuit spirometry. These protocols involve specific increases in the speed and intensity of the exercise and collection and measurement of the volume and oxygen

concentration of inhaled and exhaled air. This determines how much oxygen the athlete is using.

[It's a painful point in VO2 max testing where the athlete transitions from aerobic metabolism to anaerobic metabolism. At that point, it is not long before muscle fatigue forces the athlete to stop exercising.]

During the test, the athlete wears headgear which contains a non-rebreathing valve which the person holds in the mouth, like a snorkel. Room air is inhaled through the valve and air which is exhaled goes through a tube into a metabolic measurement cart. This cart measures the amount of oxygen and carbon dioxide in the exhaled air, as well as the volume of air. Knowing that room air contains 20.93% oxygen and 0.03% carbon dioxide, the amount of oxygen consumed can be computed after correction for barometric pressure, humidity and temperature.

Because direct measurement of maximal oxygen uptake is usually not feasible, as it requires the use of open-circuit spirometry, there are many alternative methods, both maximal and submaximal, which can be used to calculate or estimate VO_2 max.

- **Fick Equation** - VO_2 max is properly defined by the Fick Equation:

  $\mathrm{VO_2\ max} = Q \times (\mathrm{C_aO_2} - \mathrm{C_vO_2})$, when these values are obtained during an exertion at a maximal effort.

  where Q is the cardiac output of the heart, C_aO_2 is the arterial oxygen content, and C_vO_2 is the venous oxygen content.
  ($C_aO_2 – C_vO_2$) is the arteriovenous oxygen difference.

- **Cooper Test** - The Cooper Test was designed by Dr. Kenneth H. Cooper in 1968 for military use. Essentially, subjects run as far as they can in 12 minutes. Based on the measured distance, an estimate of VO_2 max [in mL/(kg·min)] is:

  $$\mathrm{VO_2\ max} = \frac{d_1}{}$$

  where d_{12} is distance (in metres) covered in 12 minutes.

<u>Factors affecting VO_2 max:</u>

The factors affecting VO_2 are often divided into supply and demand factors. Supply is the transport of oxygen from the lungs to the mitochondria (including lung diffusion, stroke volume, blood volume, and capillary density of the skeletal muscle) while demand is the rate at which the mitochondria can reduce oxygen in the process of oxidative phosphorylation.
[Tim Noakes, describes a number of variables that may affect VO_2 max: age, gender, fitness and training, changes in altitude, and action of the ventilatory muscles.

Cardiac output, pulmonary diffusion capacity, oxygen carrying capacity, and other peripheral limitations like muscle diffusion capacity, mitochondrial enzymes, and capillary density are all examples of VO_2 max determinants.]

- **Age** - Generally, VO_2 max is the highest at age 20 and decreases nearly 30 percent by age 65, however
  .
- **Gender** - Because of differences in body size and composition, blood volume and hemoglobin content, a woman's VO_2 max is in general about 20 percent lower than a man's VO_2 max. There are, however, many female athletes have higher VO_2 max values than men.

- **Altitude** - Because there is less oxygen at higher altitude, an athlete will generally have 5 percent decrease in VO_2 max results with a 5,000 feet gain in altitude.
- Drug: Erythropoietin can boost VO_2 by a significant amount. This makes it attractive to athletes in endurance sports like professional cycling.

Significance:

- Maximal oxygen uptake (VO_2 max) is widely accepted as the single best measure of cardiovascular fitness and maximal aerobic power.
- VO_2 Max represents the efficiency of the respiratory (lungs), cardiovascular (heart), circulatory (blood) and muscular systems' abilities to perform under increased work demands.
- VO_2 max measures one's ability to generate work over a prolonged period of time. It is generally considered an oxygen delivery measure (marker). A high maximal capacity to deliver blood means there is the potential for more muscles to be active simultaneously during exercise.
- VO_2 max is a good index of cardiorespiratory fitness and a good predictor of performance capability in aerobic events such as distance running, cycling, and swimming.
- VO2 max, or maximal oxygen uptake, is one factor that can determine an athlete's capacity to perform sustained exercise.