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A review: Maximal oxygen uptake (VO_2 max) and its estimation methods

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Abstract
The maximal oxygen consumption [VO_2 max] attained during a graded maximal exercise to voluntary exhaustion has long since been considered by the World Health Organization as the single best indicator of cardio respiratory fitness.
VO_2 max is the maximum amount of oxygen a person can intake and the value does not change despite an increase in workload over time period. VO_2 max is expressed as liters/min as an absolute value or in milliliters /kg/min as relative VO_2 max. The VO_2 max can be estimated using direct or indirect methods.
The purpose of this Review is to Describe VO_2 max and analyze the contemporary research available in VO_2 max measurements carried out in all Populations and includes Direct method (Laboratory method) and Indirect methods (Field test) for VO_2 max estimation. There are no such review in literature which describes all the direct and indirect methods at one plot.
This Review strives to put all the possible methods to estimation of Vo_2 max together at one plot, and it suggests that there are two kinds of methods to estimate Maximum oxygen consumption(Vo_2 max) of individual, one is Direct method & another is Indirect method (Performance based predictive equations & Non- exercise based predictive equations). As the Equipment required for estimation by Direct method is not easily available everywhere, it is more convenient to estimate Vo_2 max using Indirect method.

Keywords: Cardio-respiratoty fitness, VO_2 max, trademill test, field test

Introduction
Physical fitness" A person's ability to work effectively, enjoy leisure time, be healthy, resist hypo-kinetic disease or condition and meet emergency situations." It is a multidimensional state of being that usually refers to two aims: Performance, which consists of six skill-related fitness components and Health that includes five health-related fitness components, each of which contributes to total quality of life [1].
In this sense, among its components, great emphasis has been given to cardio-respiratory fitness (CRF), also known as aerobic fitness or maximal aerobic power [2].
Cardio-respiratory fitness, also called cardiovascular fitness or maximal aerobic power, is the overall capacity of the cardiovascular and respiratory systems and the ability to carry out prolonged strenuous exercise [3].
There are many factors which help to develop physical fitness, but regular physical activity is the key aspect to achieve optimal physical fitness. The insufficient physical activity is the risk factor for non-communicable disease such as cardio vascular disease, diabetes mellitus, stroke, cancers and health outcomes such as mental health injuries and obesity [4].
Physical activity related to mental health outcomes in aspect of neurobiological to increase the neurotropic gene and protein expression, grey matter volume and activation and release of endogenous opoids and in psychological aspect to increase physical self-perceptions, Social connectedness and mood and emotions and in behavioral aspects to increased sleep volume and quality and coping and self-regulation skills in daily life activities.
Cardiovascular fitness is important for athletic performance in many sports, but also in everyday activities such as walking, running and climbing stairs. In adults, fitness is a strong and independent predictor of Cardio-vascular disease and all-cause mortality and morbidity. Studies suggest that cardio-respiratory fitness in young people is declining. Accurate Measurement of Cardio-respiratory fitness is essential to determine fitness levels and to monitor intervention effects. Cardio-respiratory fitness is typically reported as VO_2 max, the

Maximal oxygen uptake that can be achieved during maximal intensity exercise [5].

The maximal oxygen consumption [VO_2 max] attained during a graded maximal exercise to voluntary exhaustion has long since been considered by the World Health Organization as the single best indicator of cardio respiratory fitness [3].

Thus, the review further describes the Maximum oxygen consumption (VO_2 max) and the different methods (Direct & Indirect methods) describe for its measurements along with the discrepancy of the equation on different population on the basis of ethnicity.

Maximum Oxygen Consuption (VO_2 Max)

VO_2 max is the maximum amount of oxygen a person can intake and the value does not change despite an increase in workload over time period. VO_2 max is expressed as liters/min as an absolute value or in milliliters /kg/min as relative VO_2 max. The VO_2 max can be estimated using maximal or sub maximal tests, by direct or indirect methods. The most commonly used tests are walking/running tests followed by cycling and step tests [6].

Maximal oxygen uptake (VO_2 max) is one of the most ubiquitous measurements in all of exercise science. Hill *et al* gave the concept that there exists a finite rate of maximal oxygen transport from the environment to the mitochondria to support oxidative production of ATP to do physical work.[7]

VO_2 max has been used diversely in clinical science as a measure of exercise performance [8]. A marker of population-based fitness and cardiovascular disease [9]. VO_2 max applications are numerous, ranging from elite athletes to individuals with several pathologic conditions [10].

A person's VO_2 max is the gold standard of assessing their cardio-respiratory endurance. People who possess a low VO_2 max have an increased chance of premature death, as well as the development of numerous chronic diseases, whereas individuals with a high VO_2 max have less chance of developing chronic diseases, all-cause mortality, and coronary artery disease [11].

The primary criterion for attainment of VO_2 max is a plateau in VO_2 [12]. Several secondary criteria exist in the case of a plateau in VO_2 not being reached, which include a rise in respiratory exchange ratio (RER) above 1.15, blood lactate concentration above 8 m mol/l and increase in heart rate to age-predicted maximum [13].

Maximum Oxygen Consuption (Vo_2 Max) Estimation

A person's maximum aerobic power (VO2max) can be estimated using maximal or sub maximal tests, by direct or indirect methods.

Direct Method: (Laboratory method) measure an individual's expired gases to analyze their pulmonary ventilation, inspired oxygen, and their expired carbon dioxide. Direct measures accurately determine an individual's maximum oxygen consumption by breath by breath analysis.

Indirect Methods: which include field tests, estimate a person's aerobic capacity based off their heart rate, their distance covered, and or their time of trial when using a certain protocol [11].

Field Test which provide the prediction of Vo_2 max using mathematical models, are an interesting alternative for the evaluation of Cardio-respiratory, Since they demonstrate important advantages, such as low operating costs, ease of application and access to test locations and opportunity to evaluate a large number of subjects simultaneously.

On the other hand, Field tests for evaluating Cardio-respiratory fitness use indirect methods to estimate Vo_2 max present considerable measurement errors. Thus, when choosing a indirect method (field protocol) from those proposed in the literature to evaluate Cardio-respiratory fitness, it is important to check whether it is valid for the desired population [14].

Direct Test: VO_2 max can be measured objectively and reliably in the laboratory, through direct analysis of the gases involved in pulmonary ventilation, while performing progressive and maximal tests on various treadmills or cycle ergometer using various Protocols [14]. Direct measurement of VO_2 max is highly valid and reliable [5].

Table 1: Bruce Protocol [15]

Stage	Speed (mph)	Elevation (%)	Duration(min)
1	1.7	10	3
2	2.5	12	3
3	3.4	14	3
4	4.2	16	3
5	5.0	18	3
6	5.5	20	3
7	6.0	22	3

Table no 1 showed that in Bruce protocol the treadmill is started at 1.7 mph and at a gradient of 10%. At every 3 minute intervals the incline of the treadmill increases by 2% and the speed increases as shown below the table until exhaustion. Bruce's reports on treadmill exercise tests, developed in 1949 to evaluate cardio-respiratory fitness in patients with suspected coronary heart disease and athletes.[15]

Table 2: Modified Bruce Protocol [16]

Stage	Speed (mph)	Elevation (%)	Duration (min)
0	1.7	0	3
0.5	1.7	5	3
1	1.7	10	3
2	2.5	12	3
3	3.4	14	3
4	4.2	16	3
5	5.0	18	3
6	5.5	20	3
7	6.0	22	3

Table no 2 showed that Modified Bruce protocol starts at a lower workload than the standard test and it is typically used for elderly or sedentary patients. The first two stages of the modified Bruce test are performed at a 1.7mph & 0% grade and 1.7% & 5% grade and the third stage corresponds to the first stage of the standard Bruce Protocol.

Table 3: Balke protocol [17]

Stage	Speed (MPH)	Elevation (%)	Duration (min)
1	3.0	0	3
2	3.0	2.5	3
3	3.0	5.0	3
4	3.0	7.5	3
5	3.0	10	3
6	3.0	12.5	3
7	3.0	15	3
8	3.0	17.5	3
9	3.0	20	3
10	3.0	22.5	3

Table no 3 showed that The Balke Treadmill Test was developed as a clinical test to determine peak VO_2 in cardiac patients. The elevation in workload is moderate and speed is constant (3mph) throughout whole procedure and therefore considered safe even for patients with severe left ventricular dysfunction [17].

Table 4: Graded Exercise protocol [18]

Stage	Speed(mph)	Elevation (%)	Time(min)
1	Walk at self-paced	0	3
2	4.3-7.5	0	3
3	4.3-7.5	2.5	1
4	4.3-75	5.0	1
5	4.3-7.5	7.5	1
6	4.3-7.5	10.0	1
7	4.3-7.5	12.5	1
8	4.3-7.5	15.0	1

Table no 4 showed that Graded exercise protocol is starts very slowly and gradually increases over time. It starts with 0% elevation for 3 min at walking speed than speed increased with same incline and after 6 min inclination continuously increases 2.5% at every stage.

Table 5: Asymptomatic Cardiac Ischemia Pilot (ACIP) Protocol [19].

Stage	Speed (mph)	Elevation (%)	Duration (min)
1	2.0	0	3
2	2.5	2.0	3
3	3.0	3.0	3
4	3.0	7.0	3
5	3.0	10.5	3
6	3.0	14.0	3
7	3.0	17.5	3
8	3.0	21.0	3
9	3.1	24	3
10	3.4	24	3

Table no 5 showed that asymptomatic cardiac ischemia pilot protocol is developed to test for patients with established Cardiac vascular disease. The protocol is 3-minute stages, with continuous increments between stages after 3 minute stage. The speed is no more than 3.4 mph in complete protocol

Table 6: Ellestad Protocol [20]

Stage	Speed (mph)	Elevation (%)	Duration (min)
1	1.7	10	3
2	3.0	10	2
3	4.0	10	2
4	5.0	10	2
5	6.0	15	2
6	7.0	15	2
7	8.0	15	2

Table no 6 shows that Ellestad Protocol starting at low speed with 10% elevation, every 3 minutes intervals speed is increasing and elevation increased at 4th stage.

Table 7: Gerkin Protocol [21]

Stage	Speed (mph)	Elevation	Duration (min)
0	3.5	0	3
1	4.5	0	1
2	4.5	2	1
3	5	2	1
4	5	4	1
5	5.5	4	1
6	5.5	6	1
7	6	6	1
8	6	8	1
9	6.5	8	1
10	6.5	10	1
11	7	10	1
12	7	12	1
13	7.5	12	1
14	7.5	14	1

Table no 7 showed that the Gerkin protocol is mainly used for assessing cardio-respiratory fitness in firefighter profession. This Protocol is 1-minute stage protocol with maximum 14% elevation, and speed between 3.5 mph-7.5 mph.

Table 8: Healthy Active Living and Obesity research group Protocol (HALO - PROTOCOL) [22]

Stage	Speed(mph)	Elevation	Duration
0	Self-paced	0	4
1	Self-paced	3	4
2	Self-paced	6	4
3	Self-paced	9	4
4	Self-paced	12	4
5	Self-paced	15	4
6	Self-paced	18	4

Table no 8 showed that The HALO protocol consists in a walking test at constant speed (brisk but comfortable) during 4-min stages to ensure that steady state of VO2 and HR is reached. After a 4-min warm-up, the incline of the treadmill is increased by 3% over each subsequent stage.

Table 9: McHenry Protocol [23]

Stage	Speed (mph)	Elevation	Duration (min)
1	2.0	3	3
2	3.3	6	3
3	3.3	9	3
4	3.3	12	3
5	3.3	15	3
6	3.3	18	3
7	3.3	21	3

Table no 9 showed that Mc Henry Protocol is 3 minute stage protocol for young adults with constant speed (3.3 mph) and 3% elevation increased at every 3 minute intervals.

Table 10: Naughton Protocol [24]

Stage	Speed (mph)	Elevation	Duration (min)
1	1.0	0	3
2	1.5	0	3
3	2.0	3.5	3
4	2.0	7	3
5	2.0	10.5	3
6	2.0	14.0	3
7	2.0	17.5	3
8	3.0	12.5	3
9	3.0	15	3
10	3.0	17.5	3

Table no 10 showed that Naughton protocol is 3 minutes stage protocol. Protocol is starting with low speed (1 mph) and 0% elevation followed by 3.5% elevation increase at every step. Naughton Protocol is using for Athletes and Runner.

Table 11: Stanford Protocol [25]

Stage	Speed (mph)	Elevation	Duration (min)
1	3.0	0	2
2	3.0	2.5	2
3	3.0	5.0	2
4	3.0	7.5	2
5	3.0	10.0	2
6	3.0	12.5	2
7	3.0	15.0	2
8	3.0	17.5	2
9	3.0	20.5	2
10	3.0	22.5	2

Table no 11 showed that Stanford protocol is 2 minute stage protocol with constant speed of 3.0 mph and 0% elevation at starting followed by 2.5% increases every stage

Table 12: STEEP Protocol [26]

Stage	Speed (mph)	Elevation	Duration (min)
1	1.5	0	1
2	2	0	1
3	2	1.5	1
4	2	3	1
5	2.5	3	1
6	2.5	5	1
7	2.5	7	1
8	3	7	1
9	3	9	1
10	3	11	1
11	3.5	11	1
12	3.5	13	1
13	3.5	16	1
14	4.2	16	1
15	5	16	1

Table no 12 showed that Steep protocol is 1-minute stage protocol, starting with 1.5 mph and 0% elevation. Speed is not more than 3.5 mph.

Table 13: Taylor Protocol [27]

Stage	Speed (mph)	Elevation (%)	Duration (min)
1	3.5	10.0	3
2	7.0	0	3
3	7.0	2.5	3
4	7.0	5.0	3
5	7.0	7.5	3

Table no 13 showed that protocol is 3minute stage protocol, 5-10 minutes rest periods between stages. Taylor protocol is initially started with 3.5% speed and 10% elevation followed by speed increases and elevation decreases. Taylor protocol is useful for Runners.

Table 14: Modified Balke-Ware Protocol [28]

Stage	Speed (mph)	Elevation (%)	Duration (min)
1	2.0	0	3
2	3.3	0	3
3	3.3	5	3
4	3.3	10	3
5	3.3	15	3
6	3.3	20	3
7	3.3	25	3

Table no 14 showed that the United States Air Force School of Aerospace Medicine (USAFSAM) provide Modified Balke-Ware protocol for estimating VO_2 max in young adults and patients of coronary artery disease. The treadmill testing procedure included initial walk then followed by speed at 3.3 mph with 5% grade increases each minute until a maximum effort had been performed.

Astrand-Ryhming Protocol

The first sub-maximal cycle test was designed by Astrand and Ryhming. Astrand-Ryhming test extrapolates to the predicted maximal heart rate achieved from sub-maximal power output method of prediction. Subject pedal on a cycle ergo meter at a constant workload for 7 minutes. Heart rate is measured every minute, and steady state heart rate is determined [29].

VO_2 max (ml/kg/mim) [30] = (0.00212 × W + 0.299) / (0.769 × HRmax - 48.5) × 100

W is maximal workload achieved during test expressed in Watt's,

HRmax stands for maximal heart rate achieved.

Physical working capacity (PWC) test Protocol

Physical Working Capacity 150 (PWC150) test, which uses power output achieved at a target HR of 150 beats per minute (bpm) as a prediction method. This test requires the subject to cycle for 6 min following a 10 min rest, cycle for another 6 minutes and heart rate measured [31].

VO2max = 3.5 + 12 × Wend.

Wend is maximal workload achieved during test divided per kilogram of body mass.

Indirect Test

Due to the high cost, use of sophisticated equipment, need for trained evaluators to administer the tests, and high time demand for each evaluation, Direct tests use becomes limited in environments such as schools, sports clubs, and population-based studies.[14] Thus, application-based field tests, which provide the prediction of VO2 peak using mathematical models, are becoming an interesting alternative for the evaluation of CRF, since they demonstrate important advantages, such as low operating costs, ease of application and access to test locations, and the opportunity to evaluate a large number of subjects simultaneously [32]. Indirect tests have the benefit of lower level of required exertion. This lower level of exertion greater chance of successful completion and greater safety for clinical population eg. Obese or extremely sedentary individuals. There are many equations to predict maximal oxygen uptake from sub-maximal exercise protocol. The equations are differ on the basis of criterion validity and the actual development sample population eg. Age, race and sex [33].

a. Performance based test

1. 1.5 Mile Run Test

The 1.5 miles is covered in as fast a time as possible. Only the time for the run, in minutes and seconds and the heart rate at the end of the test is recorded. VO_2max is computed with the following equation [34]:

VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) = 88.02 + (3.716 * gender) - (0.0753 * body weight in pounds) - (2.767 * time for 1.5 miles in minutes and fractions of minutes)

Where gender = 1 for males and 0 for females.

2. Storer Maximal Bicycle Test

This test is perform on Bicycles, throughout the test RPM are constant at 70 rpm and power output 50 watts initially followed increased by 15 watts each minute. VO_2max is computed using the following gender specific equations [35]

For Males: VO_2max ($ml \cdot min^{-1}$) = (10.51 * watts) + (6.35 * wt in kg) – (10.49 * age) + 519.3

For Females: VO_2max ($ml \cdot min^{-1}$) = (9.39 * watts) + (7.7 * wt in kg) – (5.88 * age) + 136.0

3. The 1-Mile Jog Test

This test is performed over a 1 mile measured distance. The time for the mile should be greater than 8 min for males and greater than 9 min for females. The time to run the mile (in min and seconds) and the heart rate at the end need to be recorded. At the completion of the mile, the heart rate should be taken within 15-20 seconds. VO_2 max is computed using the formula [34].

VO2max ($ml \cdot kg^{-1} \cdot min^{-1}$ = 100.5 + (8.344 * gender) – (0.0744 * weight) - (1.438 * mile time) - (0.1928 * heart rate)

Where: gender = 1 for male; 0 for female Weight = pounds

Time = minutes and fraction of minutes (14:30 = 14.5 minutes)

4. The YMCA Sub-maximal Bicycle Test

The YMCA Cycle ergometer test predicts VO_2 max by extrapolating heart rate (HR) responses relative to power output increases, whereby age predicted maximal heart rate (APMHR) is used to define maximal power output. Peak power output (Wpeak) is then used to estimate VO_2 max using the following metabolic equation [36]

VO_2 max (ml/kg/min) = 7 + [1:8 (6.12Wpeak) /BM]

5. Queen's college step test (QCT)

The step test was performed using a tool of 16.25 inches height. Stepping was done for a total duration of 3 minutes at the rate of 24 steps up per minute for males and 22 steps up per minute for females which was set by a metronome. After completion of exercise, the carotid pulse rate was measured from the fifth to the twentieth second of recovery period. The 15 seconds pulse rate was converted into beats per minute and following equation was used to predict VO_2 max [37]

For males: VO_2 max = 111.33 – [0.42 × pulse rate beats/min]

For females: VO_2 max= 65.81–[0.1847×pulse rate beats/min].

6. Canadian Aerobic Fitness Test (CAFT) [38] and modified CAFT (m CAFT) [39]

The test is a simple, progressive, sub-maximal aerobic test. Subjects step up and down a double step (40.6 cm height), following the instructions and stepping rhythm as determined by recorded music (using the LP record or tape), based on their age and sex. Stepping is performed with a six pace cycle: one foot on the middle step, two on the top step, one on the middle step, and both feet on the ground. The subject starts with a warm up, stepping for 3 minutes at a rhythm. Pulse rate is measured for 10 seconds (between 5 & 15 seconds after stepping). If the pulse rate is within a specified safety zone (see table) [38], stepping is recommenced at 3 minutes 25 seconds, using a rhythm appropriate to the individual's age. After another 3 minutes of stepping, the pulse is taken again. If the pulse ceiling still has not been reached, the subject continues for a third stage, at a stepping rate appropriate to a sperson.

1. Estimated VO_2 max (ml/kg/min) = 42.5+16.6 XVO_2 (L/min)*-0.12 X body weight (kg)-0.12X HR following last stage (bpm)-0.24X age (y)
2. Estimated VO_2 max (ml/kg/min) = 32.0+16.0X˙VO2 for final stage (L/min)-0.17X body weight (kg)- 0.24X age (y)

7. Single-Stage Sub-maximal Treadmill Walking Test (SSTWT) **[40]**

Establish a safe, but comfortable, walking speed between 2.0 and 4.5 mph, at a 0% grade for 4 min; an HR between 50% and 70% of age-predicted HR max should be obtained. Increase the grade to 5% and walk at the established speed for 4 min. Record the HR and RPE at the end of the warm-up session and the first stage. Reduce the grade to 0% and continue walking slowly to cool down.

Estimated VO_2 max (ml/kg/min): 15.1+21.8X speed (mph)-0.327 X HR (bpm)-0.263X speed X age(Y)+0.005X HR X age+ 5.981

Y= sex (0=women, 1 = men)

8. 12-Minute Run Test (12-MRT) **[41]**

The individual is instructed to "cover the longest possible distance in 12 min, running preferably but walking whenever necessary to prevent becoming excessively exhausted". Record the distance in miles completed in 12 min. On completion of the test, the individual should continue walking to cool down.

Estimated VO_2 max (ml/kg/min) = 35.97 X distance (mile) – 11.29

9. 20 –meter Shuttle test (20- MST) **[42]**

The individual runs between 2 lines 20 m apart; when the individual hears a short sound, has to be on 1 of these 2 lines, and when a long sound is heard, it indicates a change in stage. The first stage is 8.5 kmh for women and 10 kmh for men; the speed is increased by 0.5 kmh per 1-min stages. The individual continues until they unable to maintain the rhythm of running. The speed at the last completed running stage is termed the "maximal aerobic speed" (MAS). On completion of the test, the individual should continue walking to cool down.

Estimated $V0_2$ max (ml/kg/min) = 31.025+3.248 X speed (km/h) - 3.248 X age (Y) + 0.1536 X (ageX speed)

10. 1-Mile Track Walk Test (Rockport Fitness test) [43]

The individual is instructed “to walk as fast as possible”. Record HR at the end of every quarter mile. Record the time to complete the test (in minutes). On completion of the test, the individual should continue walking to cool down.

VO_2 max ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$) = 132.853 – (0.0769*weight) - (0.3877 * age) + (6.315 * gender) - (3.2649 * mile walk time) - (0.1565 * ending heart rate)

Where: Gender = 1 for male, 0 for female

Weight = pounds

Mile walk time = minutes and fractions of minute (14:30 = 14.5 min)

11. Self-Paced Walking test (SPWT) [44]

The individual is instructed to walk a measured distance (250 m) at 3 different speeds, with a 5-min rest between trials: (a) rather slowly (slow pace), (b) at a normal pace, neither fast nor slow, and (c) rather fast, but without overexerting yourself (fast pace). Record the time in seconds for each of the 3 trials. Following the 3 trials, the individual should continue walking slowly to cool down.

Estimated VO_2 max (ml·kg-1 ·min-1) = 15.1 +21.8 (speed in mph) - 0.327 (HR in bpm) - 0.263 (speed x Age in years) + 5.98 (gender; female = 0, male = 1) + (0.0050X HR xAge)

12. Modified Shuttle Walking Test (MSWT) [45]

The test starts with a triple beep; after that, a single beep indicates when the individual should be walking around the cone; a triple beep also signifies a change in stage. The individual is instructed: “Walk at a steady pace, aiming to turn around when you hear the signal, you should continue to walk until you feel that you are unable to maintain the required speed without becoming unduly breathless”. The MSWT starts at 0.50 m/s (1.12 mph) for level 1; each level lasts 1 min, and the speed is increased by 0.17 m/s for 12 min; the final speed is 2.37 m/s. The individual continues until: (a) he or she is too breathless to maintain the required speed, (b) he or she is more than 0.5 m away from the cone when the beep is sounded, or (c) attainment of 85% of age predicted HR max. The total number of completed shuttles (10-m lengths) at each level is recorded (in meters). On completion of the test, the individual should continue walking slowly to cool down.

VO_2 max (ml/kg/min) = [-0.457 + (gender × 0.139) + (weight × 0.025) + (DW × 0.002)]

DW= Distance walked

13. Bag and Carry test [46]

The individual is instructed to walk the circuit carrying a package weighing 0.9 kg, with both arms, for 7.5m up and down of stairs. On completion of each circuit, 0.9 kg of weight is added to the package, the individual continues until he or she is no longer able to complete the circuit carrying the package, record the heaviest weight the individual carried. It requires 10 min to complete.

14. Lough borough Intermittent Shuttle Run Test (LIST) [47]

LIST involves running between two lines 20 m apart at various speed related to individual estimated VO_2 max dictated by audio signals from a micro-computer. The test comprises two parts: Part a & Part B. Part A is a set pattern of a 15-min intermittent high intensity running, and Part B is an open-ended intermittent shuttle running designed to exhaust the participant within 10 min.

15. 12- Minute walk test (12-MWT) [48]

The individual walks a measured Distance. For the 12-MWT, the individual is instructed “to cover as much ground as possible on foot in 12 minutes and to keep going continuously if possible but not to be concerned if you have to slow down or rest”, at the end of the test, subjects should feel they could not have cove red more ground in the time.

VO_2 max (ml/kg/min) = (35.97 x miles) - 11.29.

16. 6- Minutes’ walk test (6-MWT) [49]

For the 6-MWT, the individual is instructed “to walk from end to end, covering as much ground as possible in 6 minutes”, at the end of the 6 or 12 min, the individual is instructed to stop, the total distance is recorded**.**

VO_2 max (ml/kg/min) = 553.289 + (-2.11 x age) + (45.323 x sex) men=1, women=0

17. Milfit (Miltary Fitness) Test [50]

VO_2 max is predicted by using a bicycle ergo meter. The initial work load of the test is 50 W, and it will be increased by 25W every 2 minutes until exhaustion. The pedaling rate is set between 60 and 80 rpm. Then Predicted VO_2 max measurements according to the following equation:

VO_2 max (ml/kg/min) = 12.35* P max/kg + 3.5

P max = highest work rate (power) achieved during the test as wattsBody mass as kilogram

18. The Single Stage Treadmill Walking Test (Ebbeling Equation) [51]

The walking speed for the test is individually determined based on the participant’s gender, age, and fitness level.

Estimated VO2 max (ml·kg-1 ·min-1) = 15.1 +21.8 (speed in mph) - 0.327 (HR in bpm) - 0.263 (speed x Age in years) + 5.98 (gender; female = 0, male = 1) + (0.0050X HR x Age)

19. Yo-Yo intermittent recovery test [52]

Yoyo intermittent recovery test is common and known to coaches and is used in sports bearing an intermittent nature, such as basketball, badminton, and soccer. This test includes repetitive 2-by-20 shuttle runs between the starting, turning, and ending point, which are performable with the increasing sound of a horn controlled by a recorder. Behind the starting point and in 5 meters, there is another obstacle at which the subjects perform a 10-second active break including slow 2-by-5-meter run after the starting point between each 2-by-20-meter run. During the test, when a subject fails to reach the ending line for two times, the test will be over. The mileage is recorded at this time and the results are shown. Eventually, player’s VO2max is calculated by this formula

VO_2 max (ml/min/kg) = mileage of the test • 0.0136 + 45.3

20. Hoff test [53]

Hoff test is performed on a flat surface on which cones and obstacles are placed in certain distances. Currently, this test is executable both in 10-minute and 8-minute runs, and the 8-minute version has been used in the present survey. The subject directs the ball forward by dribbling the cones along the path, then three obstacles are placed with 20- centimeter height over which the subject passes the ball. After that, the subject ends the route. The subject must be over the longest distance over 8 minutes. Each time the subject reaches the end of the rout, he/she must try to run from the starting point again for the time to be up. The total mileage is recorded, and VO2max can be calculated according to that.

VO_2 max (ml/min/kg) = mileage of the test • 0.0136 + 45.3

21. Foote-Val Test [54]

Foote-Val is an intermittent incremental test with thirty seconds of passive recovery between each step. The first step is designed as a warm-up for two minutes. All other steps for one minute followed by a recovery phase of thirty seconds. For each step in this test, the intensity is set by speed in km/h. The first level starts at 6.5km/h and intensity is increased by 0.5 km/h between each workout phase. To ensure players accurately follow intensity increases, a specific soundtrack is played to provide audio feedback to players, allowing them to adjust their speed at each extremity of the test area (20m). A single beep signals the beginning or intermediate positions in the step, while a double beep indicates the end of test.

22. American College of Sports Medicine (ACSM's) Running Equation [55]

American College of Sports Medicine (ACSM) has published metabolic equation for the indirect measurement of VO_2 max while running. ACSM's running equation using treadmill speed and grade. The VO_2 max measured using the following equation:

VO_2 max (ml/kg/min) = 0.2 (speed) + 0.9 (speed) (fractional grade) +3.5

23. American College of Sports Medicine (ACSM's) Walking Equation [56]

ACSM's walking equation is developed using highly fit male subjects or based on estimates ACSM'S walking equation is low speed and low fractional grade treadmill equation for VO_2 max estimation.

VO_2 max (ml/kg/min) = 0.1(speed) + 1.8 (speed) (fractional grade) + 3.5

S: speed; G: grade

24. The FRIEND (Fitness Registry and the Importance of Exercise National Database) equation [57]

FRIEND equation is given by Fitness Registry and the Importance of Exercise National Database (FRIEND) for CRF assessment. Treadmill speed and treadmill grade is considered in the final model as predictors of measured VO2 max and the VO_2 max measured using the following equation:

VO_2 max (ml /kg/min) = [speed (m/min) x (0.17+ fractional grade x 0.79) + 3.5

b. Non- exercise based Predictive Equations

1. Wasserman's Equation

Wasserman's Equation has been formulated on the basis of normative data obtained from Caucasian population. This non-exercise based VO_2 max is estimated by age, body mass index and body surface area [58].

Male: - VO2 max (L/min) = wt X [50.72-(0.372 X age)]/1000;

Female:-VO2 max (L/min) = (wt+42.8) X (22.78-0.17 X age)/1000.

2. National Aeronautics and Space Administration (NASA) /Johnson Space Centre Physical Activity Rating (PA-R) scale

VO_2 max was calculated taking into account subjects PAR Score, BMI and gender. The PAR is a physical activity questionnaire which has a score of 0-7 [59].

Male: VO2max (ml/kg/min) = 67.350 – [0.381 x age (years)] – (0.754 x BMI) + (1.951 x PAR);

Female: VO2max (ml/kg/min) = 56.363 – (0.381 x age (yrs)) – (0.754 x BMI) + (1.951 x PAR)

3. The Jackson Non-Exercise Test

The estimation of VO_2 max with this test requires a score from a simple exercise history questionnaire in addition to age, height, weight and gender. No exercise is performed but a measure of past exercise is determined by the physical activity questionnaire [60]. The VO_2 max is computed using the formula:

VO2max (ml /kg/min) = 56.363 + (1.921 * PA-R) - (0.381 * AGE) - (0.754 * BMI) + (10.987 * Gender)

Where: Male = 1, Female = 0

BMI = Weight in kg / Height2 in meters

PA-R = Score on the physical activity questionnaire

The PA-R is a physical activity questionnaire which has a score of 0 - 7.

4. The George Non-Exercise Test

This non- exercise based equation included various demographic (age, gender), biometric (body mass), and questionnaire (participants perceived functional ability [PFA] to walk, jog, or run given distances, and their self-reported level of physical activity [PA-R]) information [61]. The VO_2 max using the following formula:

VO_2max (ml/·kg/min) = 45.513 + (6.564 * Gender) – (0.749 * BMI) + (0.724 * PFA) + (0.788 * PA-R)

Where: Gender = 1 for male and 0 for female;

BMI = Weight in kg / $Height^2$ in meters

PFA = sum of both PFA scales.

PA-R = number form PA-R scale.

Conclusion

This Review strives to put all the possible methods to estimation of Vo_2 max together at one plot, and it suggests that there are two kinds of methods to estimate Maximum oxygen consumption (Vo_2 max) of individual, one is Direct method & another is Indirect method (Performance based predictive equations & Non- exercise based predictive equations). When choosing a indirect method, it is important to check whether it is valid for the desired population. Bruce Protocol is commonly used treadmill exercise protocol for direct method and Queen's college step test, 20 meter Shuttle Run test and 6 minute walk test is common indirect test for VO_2 max estimation. As the Equipment required for estimation by Direct method is not easily available everywhere, it is more convenient to estimate Vo_2 max using Indirect method. In spite of this convenience there are few drawbacks of indirect method, one of these that it does not give the exact estimation of VO_2 max. The another is predictive equation cannot be applied to every population due to differences of ethnicity. With the help of estimated VO_2 max we can find out physical fitness in individuals and creating awareness about physical activity and life style modification for primary prevention of cardiovascular, metabolic and mental disorders.

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