Predicted Maximal Oxygen Consumption (VO2MAX) Values Obtained During The Maximal Treadmill Test Using Different Protocols

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Abstract: : **Background**: VO$_2$MAX is the sole major criterion for endurance assessment. By using the regression equation the necessity of the sophisticated gas analyzer is eliminated. The usability and applicability of such equations are questioned due to non-uniformity, standardization and other variables. **Methods**: 100 healthy young male subjects were recruited and each performed all the four selected treadmill protocol viz. Bruce, Modified Bruce, Ellestad and Balke. VO$_2$MAX was calculated for each person for each protocol by using regression equation. **Results**: Mean and SD values of VO$_2$MAX of each protocol were, Balke (41.94 ± 2.15), Bruce (64.55 ± 6.7), Ellestad (61.17 ± 7.5), Modified Bruce (64.36 ± 5.4). There was difference among different protocols ($p<0.05$), except between Bruce and Modified Bruce ($p>0.05$). These were compared with ACSM predicted equation based on age and height (51.5$\pm$7.4). Later Paired t-test was applied. There is no statistically significant difference between the Bruce and Modified Bruce protocols. Highest difference was observed between the Balke and Bruce protocol and between Balke and Modified Bruce, as was the difference between Balke and Ellestad protocol. **Conclusion:** For endurance testing Ellestad protocol can be a suitable option in resource crunch settings as the Balke protocol underestimates and Bruce overestimates the VO$_2$MAX. Devising a ramp protocol for the population subset's need can be the best option. [Chavda V et al NJIRM 2013; 4(2) : 149-155]

Key Words: Endurance testing, Ramp protocol, Regression equation,VO$_2$MAX,,Treadmill protocol.

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Introduction: Treadmill testing is one of the most commonly employed tests to ascertain the cardiorespiratory fitness status of an individual. It is of prime importance in cases of exercise prescription and endurance testing as well as helpful in unmasking the coronary ischemia.

Maximum oxygen consumption (VO$_{2MAX}$) reflects the maximum capacity of a person to absorb, carry and consume Oxygen. It is the most important parameter of individual fitness and an objective and independent parameter of cardiovascular disease prognosis[1.]

Treadmill testing is performed, while testing cardiorespiratory fitness, with the help of maximal treadmill protocols like Bruce, Ellested, Balke etc.. It is therefore the protocol which we select or the protocol which we devise is the major variable in treadmill testing and hence it determines the outcome of our testing.
Employing these protocols under different environmental and subject conditions is again another variable. So in order to have an accurate

or constant readings from the exercise protocol testing in terms of maximal oxygen consumption; it is advisable to test different exercise protocol in similar setting. B. DAVIES et al have compared different methods of VO$_{2MAX}$ estimation and found that there is no significant difference in VO$_{2MAX}$ attainment using different protocols[2].

Various cardiologist and sport physiologist have defined many protocols. They are chosen depending upon the condition of the subject or the need of the subject or depending upon the parameter to be evaluated. We chose four protocols which best suited for our study. They are *BRUCE, MODIFIED BRUCE, ELLESTAD* and *BALKE* exercise protocols. These protocols are chosen because extensive research has been done on these protocols, they are easy to employ in the study population and they give consistent results when repeated over time. All of them except MODIFIED BRUCE are maximal protocol as they test the endurance of the athlete to the limit and hence give the near perfect value of VO2$_{MAX}$.With each protocol, the measurement of performance is

expressed in basal metabolic equivalents (METs). One MET equals the resting oxygen consumption rate of 3.5ml O2/kg/min.

In our study we use the regression equationfor estimation of VO$_{2MAX}$ using treadmill time and other physiological variable of the patient; instead of using sophisticated gas analyzer. The regression equations are of great help in resource crunch settings. There are different equations for different protocols. They are validated in large number of population so they reliably predict the VO$_{2MAX}$ of a subject.

Treadmill protocols are designed meticulously by keeping in mind the subject, the machine and the test conditions. It take into account the need for which the exercise is done like for endurance testing or for ischemia evaluation. The different stages of a protocol are assigned the values of possible (Metabolic Equivalents) METS that a person is supposed to consume if undergoes that stage. And from this METS values the speed and grade values for that particular stage are calculated so as to conform to the expected METS value[3.] Northridge et al devised a test in which the work rate is increased exponentially in order to provide test durations that do not appreciably differ among subjects varying widely in exercise tolerance. A group of researcher has devised a protocol suitable for patient population or others with low exercise tolerance[4.] From amongst these protocols of exercise we can come to know the best suited protocol in our test conditions and in our subjects. By experience we may design a different protocol for testing cardiorespiratory fitness in our subjects.

Material and Methods: The study was approved by Institutional Review Board (IRB) of the Government Medical College Bhavnagar. A group of one hundred subjects were recruited for the study, based on inclusion and exclusion criteria.

INCLUSION CRITERIA
• Normal healthy subjects of 15 to 35 years of age groups.

• Without having any cardiovascular conditions like coronary artery diseases, hypertension, atherosclerosis, mitral valve prolapse etc.
• Ability for following them up until the end of study
• Other criteria as may be specified by the physician

EXCLUSION CRITERIA
• All those who stands excluded by physician.
• History of chest pain on exertion or rest.
• History of severe breathlessness on exertion or rest.
• Physically handicap.
• Fail to give written informed consent.

The written informed consent was the one which was approved by the IRB of the Government Medical College Bhavnagar. After the enrollment, they were grouped into four groups of 25 each. This is so because we needed to assign each of the four protocol i.e. BRUCE, MODIFIED BRUCE, ELLESTAD and BALKE exercise protocol to each of 100 subjects. Subjects were given enough time to rest and recover, so as not to have any unwanted carry forward effect on the subsequent protocol testing.

Thus the whole study was undertaken in the Department of Physiology, Government Medical College Bhavnagar.CARDIVISION TREADMILL™ contain a treadmill machine proper i.e. the exercise device, an electrocardiography (ECG) recorder, a computer, a printer and resuscitative equipment. Other associated instrument includes sphygmomanometer and an automated blood pressure recording instrument.

Pre-test subject evaluation and clearance for adverse cardiovascular comorbidities was done meticulously and the physician's clearance was obtained for each of them.

CALCULATION OF VO2$_{MAX}$: Our main aim is to calculate VO2$_{MAX}$ using different treadmill protocols mentioned above. Since we do not use gas analyzer for oxygen consumption estimation,

we have to rely on various validated regression equation and on heart rate VO2$_{MAX}$ relationship. The regression equation differs from protocol to protocol, but the central theme behind the heart rate VO2$_{MAX}$ relationship is constant. The regression equation mainly requires the length of time on a particular protocol. It may also require the height, weight, BMI, maximum heart rate, resting heart rate, 4-minute heart rate etc. as per the protocol used.

FOR BRUCE PROTOCOL[5]:

VO$_{2max}$ (ml/kg/min) = 14.76 - (1.379 × T) + (0.451 × T^2) - (0.012 × T^3)
Where, 'T' represents time in minutes.

FOR MODIFIED BRUCE PROTOCOL[6]:

VO$_{2max}$(ml/kg/min) = S×0.1 + S×G×1.8
'S' is the speed of the treadmill in meters per minute , multiply miles per hour by 26.8
'G' is the gradient in percent point. Derived by deviding the gradient which is in percentage by 100.

FOR BALKE PROTOCOL[7]:
VO$_{2max}$(ml/kg/min) = 1.444×T +14.99
Where, 'T' represents time in minutes.

FOR ELLESTAD PROTOCOL[8]:
In case of Ellestad protocol graphical technique of plotting of heart rate (HR)versus the metabolic equivalent is used.
Terminate the test when the HR reaches 85% of the age-predicted maximal HR.
 To calculate, estimated VO2$_{MAX}$:
a. Make a graph plotting METS on the x-axis and HR on the y-axis.
b. A line is then drawn through the HR points from 10% grade to the final work rate.
c. The line is then extended to the person's estimated maximal HR.
d. A vertical line is dropped from the point where the plotted line meets the person's estimated maximal HR to the x-axis to estimate the maximum METS that the subject would have achieved.

e. Lastly, to calculate estimated VO2$_{MAX}$ (ml/kg/min), multiply the estimated maximal METS by 3.5.

Statistical Analysis: The values of VO2$_{MAX}$ that is achieved using the different protocols was tabulated using Microsoft excel. The mean of all the VO2$_{MAX}$ values for a particular protocol is taken. This similarly is done for all the four protocols. Now, by using these means, ANOVA i.e. analysis of variance is done. If on analysis of variance the difference in values turns out to be significant, we can conclude that there is a difference in VO2$_{MAX}$ values depending upon the protocol used.After finding out the overall difference, the next step is to make out the best protocol among them. This is done by applying unpaired t-test. In this test we compare any two protocols at a time like 1-2, 1-3, 1-4, 2-3, 2-4, and 3-4.

Result: On analysis of the data obtained from the treadmill testing it was found that the values of the VO$_{2MAX}$are not constant in all the protocol. The following table shows the mean of the VO$_{2MAX}$values obtained from different protocols with their standard deviations (SD).

Table-1: Average Vo$_{2max}$ Values With Their Standard Deviations Of Four Different Protocols. Acsm Predicted Values Are Added For Comparision.

Protocol	Balke	Bruce	Ellested	Modified	ACSM Predicted*
Mean	41.9	64.5	61.2	64.4	51.5
Sd	2.2	6.7	7.5	5.4	7.4
Mean +2sd	46.2	77.9	76.1	75.2	66.3
Mean - 2sd	37.6	51.2	46.2	53.6	36.7

*Last column contains predicted with the help of Age and Height, which can be used as the reference value. ACSM-American College of Sports Medicine.

Clearly from Table-1 it is obvious that the mean VO$_{2MAX}$valuefor Bruce and Modified Bruce are maximum followed by Ellestad. Least values are observed with Balke protocol. The ACSM predicted values are in-between the Ellestad and Balke protocol. The difference which we have observed in the mean of different samples of VO$_{2MAX}$ further needed to be verified by the use of different statistical measures of the difference. As shown in Table-2; analysis of variance was the first measure we used to know if there is any variability between different measures of VO$_{2MAX}$ estimation.

TABLE-2: *ANOVA*

Source of Variation	SS	df	MS	F	P-value	F crit
VO$_{2MAX}$	38501.54	4	9625.3	248.2444	**1.8× 10^{-106}**	2.394476
Error	15354.43	396	38.8			
Total	57469.9	499				

*The ANOVA (analysis of variance) table. This is done with five variables of VO$_{2MAX}$; four from protocols which are tested and one from ACSM predicted equation. P-value is significant in this case, showcasing the difference in VO$_{2MAX}$ values from the protocols selected.

There was difference among different protocols (p<0.05), except between Bruce and Modified Bruce values (p>0.05). These two protocols however have significant difference when compared with other two protocols. To further support our finding and to quantify the difference; Paired Sample t-test was applied, taking in to consideration two samples at a time and obtaining six results. In this analysis; there is no statistically significant difference between the Bruce and Modified Bruce. Highest difference was observed between the Balke and Bruce protocol and between Balke and Modified Bruce , as was the difference between Balke and Ellestad protocol.

Discussion: Michael L. Pollock[9]et al have observed lower value of VO$_{2MAX}$ for Balke protocol than with the other protocols used. They have attributed this difference to the slower increment in work load (0.5 METS per minute). This slower increment is reflected in the formula for calculation of VO$_{2MAX}$ in our conditions.

A possible explanation for higher values for Bruce and its sibling Modified Bruce is provided by Myres and Bellin[10]who have shown that the Bruce protocol overestimates exercise capacity in untrained people and has lowered sensitivity for detecting coronary diseases, due to the large and unequal increase in exercise intensity during the test. Due to this large and unequal increments we uses larger MET values for a particular test and that is seems to be reflected in the regression equation devised for estimation of VO$_{2MAX}$ from treadmill time under the Bruce and Modified Bruce protocols. Ellestad protocol too has larger increments in METS, thus reflecting a small but definite error in VO$_{2MAX}$ estimation and making itself unsuitable for sole screening purposes like in endurance testing without Gas analyser.

B. Davies[2]et al in their study did not find any significant differences using different protocols in the same subjects. We, however, found differences in mean of the different protocols. As shown in Table-1, mean values were: Balke (41.94), Bruce (64.55), Ellestad (61.17), and Modified Bruce (64.36). From this data we can presume that Bruce and Modified Bruce have similar values and they are closely followed by the VO$_{2MAX}$ values of the Ellestad protocol. Drawing any similarity between this study and the above mentioned study would be erroneous as that study is done under different variables and it has a small sample size of five subjects and they have used Gas analyser to calculate VO$_{2MAX.}$

Historically, comparison of VO$_{2MAX}$ values with the standard reference values is a problem area of evaluation. This is because of wide variation in reference value from person to person and in same person under different time frame. To set a normal value for comparing and also for predicting the suitability of a test, we used the VO$_{2MAX}$ prediction

equation given by ACSM (American College of Sport Medicine); which is shown in the column 6 of table 1.

Michael L. Pollock[9] et al in their comparative analysis of four different protocols (Bruce, Balke, Ellestad and multistage Running) found that VO$_{2MAX}$ values of Balke, when compared to the running protocol (39 vs. 41 ml./Kg/min.) is significantly different. The Balke protocol showed lower values at maximum in VE and RQ than the other three tests as well as the most gradual rate of progression in MET cost (0.5 METS per minute). The increase for the Bruce and Ellestad tests was from 1 to 1.5 METS per minute, and a rapid initial increase (9 METS in the first 3 minutes) made the running test undesirable as a screening method. In our study also Balke protocol shows lower values than the other three protocols, corroborating their finding.

If we compare our data with the data observed in a Brazilian study by Artur Haddad Herdy[1]et al we can conclude; by mean to mean analysis of the two studies; that the VO$_{2MAX}$ values obtained by us with Bruce and Modified Bruce overestimates the endurance, as shown in Table 1. In the Brazilian study the mean VO$_{2MAX}$ for active and sedentary men in the age group of 15-24 years was 50.6 ± 7.3 and 47.4 ± 7.9 ml/kg/min respectively. In another similar study by Mays RJ[10] and colleagues the mean VO$_{2MAX}$ was 46.3± 1.3 ml/kg/min. The values of VO$_{2MAX}$ in our study were; Balke (41.94 ± 2.15), Bruce (64.55 ± 6.7), Ellestad (61.17 ± 7.5), Modified Bruce (64.36 ± 5.4) and from ACSM equation 51.51 ± 7.4 ml/kg/min. The relation of mean and standard deviation is clear from Table 1.

The purpose of the Balke treadmill protocol was to evaluate physical fitness, while the Bruce protocol was meant to evaluate cardiovascular function. Bruce has tried to isolate the cardiovascular influence on maximal oxygen consumption by classifying subjects as sedentary or active by their exercise habits. Both Balke and Bruce have proposed that maximal oxygen consumption can be estimated from the exercise time when gas measurements could not be made[11.]

In a study by Victor F. Froelicher[12] et al (comparing Bruce, Balke and Taylor protocols) the coefficient of variation for the Balke protocol was greater, suggesting that a similar study with a larger number of subjects might demonstrate a significant difference between the protocols. They undertook the study in 15 volunteers, clearly paving the way for study with larger number of subjects, like ours.

During ANOVA test, there was difference among different protocols (p<0.05), except between Bruce and Modified Bruce values (p>0.05). These two protocols however have significant difference when compared with other two protocols.

There is no statistically significant difference between the Bruce and Modified Bruce protocols. This is in line with the study of Matthew J. Faber[13]et al who have found Bruce and Modified Bruce similar in terms of the outcome variables like VO$_{2MAX}$, heart rate and blood pressure response etc. While the later was found to have strong subject preference and physician acceptance.

Thus, taking into account the possible overestimation and underestimation, we can say that the normal values of VO$_{2MAX}$ lies somewhere between these two, while comparing the Bars showing ACSM (American College of Sports Medicine) predicted value with other protocols in Table 1. This is also true for the values of VO$_{2MAX}$ obtained by the ACSM equation. So the normative data in our population is closer to the ACSM equation. Taking the mean value of all the protocols that are carried out is a possible alternative.

For the endurance testing of the athlete it is difficult to choose the best protocol from amongst the four. Bruce protocol overestimates VO$_{2MAX}$ in undertrained and overestimates in well-trained, while the Balke has limitation due to smaller workload, but Ellestad protocol data which lies between these two; can be used as a good alternative. Individualised Ramp protocols are the better candidate for endurance testing than the defined protocols, as they individualise the

treadmill speed and grade depending upon the subject's capability and preference by taking into consideration the subject's height, weight, age, gender, and training status. This individualisation helps to devise a protocol that is best suited for a particular person, based on the above mentioned criteria. For this Ramp protocol is the only option.S.Walsh and colleagues in their study of individualised Ramp protocol have shown the usability of the same in endurance testing and have compared the same with the commonly used fixed increments protocols.

Janos Porszaszi[4] et al in their study of Ramp protocol have stated that the set work rate profile for fixed increment tests, results in widely varying test durations in subjects who vary in exercise tolerance. Consequently, such protocols with their predetermined work rates do not optimize the test design with respect to the subject's known or predicted functional capacity, as recommended. Myers and his associates[14], however, designed a test that was promising in this regard: the work rate incrementation, achieved by both speed and grade changes, was designed to produce a linear increase in oxygen uptake (not work rate per se, however) with the test lasting approximately 10 min. In their large-cohort study, the measured VO2_{MAX}, though approximately linear, differed markedly from that predicted. This, presumably, is consequent in part to the nonsteady state ramp predictions being based on steady-state predictions of O_2 uptake, the response of which is known to become nonlinear at work rates above the lactate threshold. Northridge et al devised a test in which the work rate is increased exponentially in order to provide test durations that do not appreciably differ among subjects varying widely in exercise tolerance.

Conclusion: Analysing the results we found that the Balke protocol for testing the endurance gives the VO2max values; obtained through regression equation; that are closer to the population mean. While the more commonly employed Bruce protocol overestimates the endurance due to larger initial workload. The VO2max values for Modified Bruce protocol were closely related to

that of Bruce protocol. The Ellested protocol VO2max values were somewhere between Balke and Bruce protocol with skewness towards Bruce protocol values. For endurance testing Ellested protocol can be a suitable option in resource crunch settings as the Balke protocol underestimates the VO2max. Devising a ramp protocol for the population subset's need can be the best option. Further studies with Gas analyser are required to quantify the observed variation in our population and thus the usability of western designed protocols can be estimated in them.

The regression equations designed to obviate the need of sophisticated gas analyser in treadmill testing should be validated for different populations and for different test conditions. The overestimation of VO2_{MAX} values as seen with certain protocols is may be because of above mentioned variables during treadmill testing.

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