Evaluation of Maximum O_2 Consumption: Using Ergo-Spirometry in Severe Heart Failure

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Abstract- Although sport-physiologists have repeatedly analyzed respiratory gases through exercise, it is relatively new in the cardiovascular field and is obviously more acceptable than standard exercise test, which gives only information about the existence or absence of cardiovascular diseases (CVDs). Through the new method of exercise test, parameters including aerobic and anaerobic are checked and monitored. 22 severe cases of heart failure, who were candidates of heart transplantation, referring to Massih Daneshvari Hospital in Tehran from Nov. 2007 to Nov. 2008 enrolled this study. The study was designed as a cross-sectional performance and evaluated only patients with ejection fraction less than 30%. O_2 mean consumption was 6.27±4.9 ml/kg/min at rest and 9.48±3.38 at anaerobic threshold (AT) exceeding 13 ml/kg/min in maximum which was significantly more than the expected levels. Respiratory exchange ratio (RER) was over 1 for all patients. This study could not find any statistical correlations between VO_2 max and participants' ergonomic factors such as age, height, weight, BMI, as well as EF. This study showed no significant correlation between $VO_{2\ max}$ and maximum heart rate (HR_{max}), although O_2 maximum consumption was rationally correlated with expiratory ventilation. This means that the patients achieved maximum ventilation through exercise in this study, but failed to have their maximum heart rate being led probably by HF-induced brady-arrhythmia or deconditioning of skeletal muscles.

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Introduction

O_2 consumption, even exceeds 8 times when we are exercising heavily, resulting in increased CO_2 release. This increase in respiratory activity could be functionally affected by cardiovascular (CVD) or respiratory diseases even at rest (1).

Although sport-physiologists have repeatedly analyzed respiratory gases through exercise, it is relatively new in the cardiovascular field and is obviously more acceptable than standard exercise test, which gives only information about the existence or absence of CVD (2-4).

Through the new method of exercise test, parameters including aerobic and anaerobic are checked and monitored.

Cardiovascular diseases are strongly effective on stroke volume (SV), mediated by abnormal motility of cardiac septum, valvular retardation and stenosis. Whereas, respiratory and muscular problems, as well as hematologic diseases mostly affect arterial and/or venous O_2 consumption, consequently VO_2 max (described in methodology) (5). VO_2 max is really the best reproducible index of ability of the cardiopulmonary system, which decreases in the elder 5-10% considering life style. Probably because of higher hemoglobin consideration, more muscular tissue and larger SV, VO_2 max is absolutely 10-20% more among men (6-8).

Anaerobic parameters, often evaluated through functional exercise testing, are beneficial in case of chronic heart failure (CHF) (5,9-11). Anaerobic metabolism usually starts during the second half time of exercise, when muscular O_2 providing is much difficult and lactic acid increases in muscles and blood stream.

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Anaerobic threshold (AT) is defined by the amount of O_2 taken by muscles when lactic acid starts to accumulate in blood (11). AT is much useful to predict perioperative mortality among the elderly and high risk people (12).

Regarding limited studies on severe heart failure, we decided to use ergo-spirometry to measure PVO_2 (maximum of O_2 consumption) as a predictive factor of patients' morbidity and/or mortality through evaluating the mentioned parameters (13,14).

Materials and Methods

Participants:
22 severe cases of heart failure, who were candidates of heart transplantation, referring to Massih Daneshvari Hospital in Tehran from Nov. 2007 to Nov. 2008 enrolled this study.

The study was designed as a cross-sectional performance and evaluated only patients with ejection fraction less than 30%. People with unstable hemodynamic situation and/or a history of respiratory diseases were excluded.

Immediately before exercise test, participants were examined for dyspnea and hemodynamic condition to prevent adverse events during the test. Afterwards, they were asked to sign an informed consent form acknowledging that the aim and process of the study was explained and accepted.

Exercise test protocol

The main means to the exercise was fixed bicycle under model Ergo-line D-72475 BITS (Ergometric-800) manufactured by *** (***). It was connected to a respiratory gas analyzer system. Ramp protocol was set up on 10 watt/min, and an expert aided the patients to maximum exercise level.

Measured variables

Heart rate, heart rate reservation, O_2 pulse, VO_2, VCO_2, VE and breath reservation (BR) were monitored and evaluated through three stages including at rest, anaerobic threshold (AT) and maximum exercise. The variables were mentioned as percentiles of projected maximum levels.

Fick equation was highly used to calculate VO_2 as follows:

$VO_2 = (SV \times HR) \times (CaO_2 - CvO_2)$

CaO_2 stands for arterial while CvO_2 stands for venous O_2 conservation. VO_2 means consumed O_2 at the tissue level through the evaluation time. Fick equation defined functional aerobic capacity as follows:

$VO_{2\,max} = (SV_{max} \times HR_{max}) \times (CaO_{2\,max} - CvO_{2\,min})$

which describes the person's maximum ability of taking, transporting and consuming oxygen (5-7).

Three-lead electrocardiography reported heart rate, while O_2 saturation was monitored via pulse oxymetry. Maximum voluntary ventilation (MVV) was calculated by FEV1 forty-time multiplying.

Statistics

All the relevant variables were reported as mean ± SD (standard deviation). Paired t-test was used to compare maximum of each variable to its predicted measure for each person. Significance was described as a P value lower than 0.05, considering a 95% confidence interval of normality, through Kolmogrov-Smirnov test. Some correlated variables needed linear regression performed by SPSS 12 for windows.

Results

We recruited 22 patients with severe heart failure; including 19 men and 3 women who referred to and were followed by cardiology ward and clinic of Massih Daneshvari Hhospital, Tehran, Iran.

Patients were 20-70 years old with the mean age of 44.86±13.3. Table 1 summarizes patients' demographic characteristics. Ejection fraction (EF) was 21.25±6.23 on average with a range of 10-30.

As can be seen in table 2, O_2 mean consumption was 6.27±4.91 ml/kg/min at rest and 9.48±3.38 at anaerobic threshold (AT) exceeding 13 ml/kg/min in maximum which was significantly more than the expected levels ($P<0.001$). Respiratory exchange ratio (RER) was over 1 for all patients.

This study could not find any statistical correlations between VO_2 max and participants' ergonomic factors such as age, height, weight, BMI, as well as EF (Table 2). VO_2 max, experienced a direct correlation with the maximum ventilation (VE max), VE max/MVV and the maximum heart rate (HR max) with a P value less than 0.001, 0.004, and 0.017, respectively.

Table 1. Demographic data of participants.

Variables	N(%)	Mean±SD	Range
Age	22	44.86±13.3	20-72
Male	19	--	--
Female	3	--	--
Weight	20	67.55±8.82	51-81
Height	20	167±9.3	143-188
BMI	20	24.3±3.7	17.84-34.23

Table 2. Ergo-spirometry findings.

Variable	N(%)	Mean±SD	Range	P-Value
HR	22			
Rest	22	98.86±27.3	59-181	
Ant	22	112.81±23.3	49-154	
Max	22	133.27±28.2	57-191	<0.001
Max Pred	22	76.18±16.2	33-105	
HRR	22			
Rest	22	77.18±29.1	0-118	
Ant	22	62.77±22.2	25-123	
Max	22	42.27±28.4	0-115	<0.001
Max. Pred	22	284.86±187.84	0.767	
O2Pulse	22			
Rest	22	4.04±2.06	0-8	
Ant	22	5.77±2.11	2-9	
Max	22	7±2.3	3-11	<0.001
Max.Pred	22	48.6±14.1	20-73	
VO2	22			
Rest	22	0.42±0.31	0.05-1.52	
Ant	22	0.64±0.23	0.24-1.07	
Max	22	0.92±0.35	0.37-1.52	<0.001
Max Pred	22	38.69±16.9	0.27-67	
VO2/kg	22			
Rest	22	6.27±4.90	8.5-24.12	
Ant	22	9.48±3.38	3.59-15.7	
Max	22	13.6±5.28	5-24.12	<0.001
Max Pred	22	39.5±15.05	13-67	
VCO2	22			
Rest	22	0.41±0.38	0.04-1.82	
Ant	22	0.64±0.23	0.24-1.06	
Max	22	1.06±0.41	0.38-1.82	<0.001
Max Pred	22	41.3±16.1	12-71	
RER	22			
Rest	22	0.93±0.11	0.76-1.23	
Ant	22	1±0.01	0.97-1.02	
Max	22	1.15±0.08	1.02-1.34	<0.001
Max Pred	22	88.8±6.5	78-103	
EF	20	21.25±6.2	10-30	
FEV1	22	2.29±0.56	1.11-3.2	
MVV	22	91.94±22.5	44.4-128	

Table 3. Pearson correlation coefficient between VO2 Max and some variables

Variables	Correlation Coefficient	*P* Value
VE max	0.822	<0.001
VE max/MVV	0.584	0.004
HR max	0.502	0.017
HRR max	-0.587	0.004
HR max/HR pred	-0.223	0.319

VO_2 max, also had reverse relationship with HRR max during maximum exercise defined by a *P* value<0.004. Furthermore, VE max/MVV showed a rational correlation with VO_2/kg max as table 3 reports.

Considerably, there was an obvious ergo-spirometric relationship between O_2 consumption in AT and the maximum exercise situation (P<0.001) through this study.

Discussion

Ergo-spirometry and analyzing respiratory gases are highly useful in diagnosing cardiopulmonary problems, providing more effective treatment as well as helping surgeons select people to get heart transplantation. Heart failure causes inefficient blood supply, especially during exercise resulting in decreased $VO_{2\ max}$. This would be strongly affected by disrupted cardiac chronotropism, low blood pressure, peripheral low O_2 consumption and insufficient ventilation reserve.

This study showed no significant correlation between $VO_{2\ max}$ and maximum heart rate (HR_{max}), although O_2 maximum consumption was rationally correlated with expiratory ventilation. This means that the patients achieved maximum ventilation through exercise in this study, but failed to have their maximum heart rate being led probably by HF-induced bradyarrythmia or deconditioning of skeletal muscles.

There is no reason to ignore very low cardiac output and its effect on limited exercise ability due to excessive muscular exhaustion and fatigue, among our participants.

Participants, in this study, were younger than Ramos-Barbon's (15) and Ingle's (16) performances. There was also difference in EF comparing this study to Ramos's in which EF was averagely reported 23.3 ± 16.4.

Severe heart failure might be more symptomatic and clinically prominent in our country considering lower $VO_{2\ max}$ (13.6 ml/kg/mg) among our patients compared to Ingle's (19.6 ml/kg/mg) (16). Furthermore, all the participants who enrolled this work had RER>1, while 54% reported RER>1 during Ingle's study. This could be resulted by a more severe HF in the current study leading to a faster change from aerobic into anaerobic (low AT) ventilation in less exercise.

Demographic characteristics, BMI and EF were not related to PVO_2 in this study, unlike Ramos's trial that reported significant reserve relationship between PVO_2 and age. EF would be related to PVO_2, if a wider spectrum of CHF cases, apart from EF proportion, enrolled the research.

Finally, VO_2 in AT was constantly correlated to VO_2 max as can be seen in figure 1 which affirms Ramos's finding. This is needed to conduct wider study in all stages of heart failure using ergo-spirometry to find any relationship between patient's characteristics as well as the outcome for people who get heart transplantation through follow up.

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