



Peak cardiac power output and cardiac reserve in sedentary men and women

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Abstract

Background and Purpose: Cardiac power output (CPO) and cardiac reserve (CR) are novel parameters of overall cardiac function. The purpose of this study was to determine differences in values of the CPO at rest and peak exercise and CR in sedentary men and women.

Material and Methods: Thirty healthy men (age 21.2 ± 0.7 years, body mass 63 ± 6.3 kg, height 168.3 ± 5.1 cm) and thirty healthy women (age 21.3 ± 1.9 years, mass 82.5 ± 7.9 kg, height 181.9 ± 4.9 cm) were included in this study. Echocardiography was used to assess cardiac and hemodynamic parameters. CPO was calculated, at rest and after performed maximal bicycle test, as the product of cardiac output and mean arterial pressure, and CR as the difference of CPO value measured at peak exercise and at rest.

Results: At rest, the two groups had similar values of cardiac power output ($1.04 \pm 0.3W$ versus $1.14 \pm 0.25W$, $p > 0.05$). CPO after peak exercise was higher in men ($5.1 \pm 0.72W$ versus $3.9 \pm 0.58W$, $p < 0.05$), as was cardiac reserve ($3.96 \pm 0.64W$ versus $2.86 \pm 0.44W$, $p < 0.05$), respectively. After allometric scaling method was used to decrease the effect of body size on peak CPO, men still had significantly higher peak CPO ($2.79 \pm 0.4 W m^{-2}$ versus $2.46 \pm 0.32 W m^{-2}$, $p < 0.05$). At peak exercise, a significant positive relationship was found between cardiac power output and end diastolic volume ($r = 0.60$), end diastolic left ventricular internal dimension ($r = 0.58$), stroke volume ($r = 0.86$) and cardiac output ($r = 0.87$).

Conclusion: The study showed that men had higher CPO after peak exercise and greater cardiac reserve than women, even after decreasing body size effect.

INTRODUCTION

In medical researches in the past cardiac function was usually assessed using either blood flow or blood pressure. Previous studies have shown that these variables do not provide a good correlation with exercise capacity (1, 2) or prognosis in patients (3). Cardiac power output (CPO) is a relatively novel measure of overall cardiac function (4). It is an integrative measure of cardiac performance, taking into account both flow [cardiac output (CO)] and pressure [mean arterial pressure (MAP)] generating capacities of the heart. Maximal value of CPO achieved after maximal stimulation of the heart (CPO_{peak}) is a good index of cardiac performance and exercise capability. Cardiac reserve (CR) is another parameter that was introduced by Tan. The reserve capacity of the heart

is a direct indicator of capability of the heart as a mechanical pump. It can be calculated as a difference of CPO value measured at peak exercise and CPO value measured at rest (4).

In the past CPO values were used as prognostic value in clinical populations. Cardiac power output has been shown to be a powerful predictor of mortality in patients with chronic heart failure, broad spectrum of patients with acute cardiac disease and in those with cardiogenic shock (5, 6, 7). There is little data about CPO in healthy population. It seems that there is only one study providing physiological range of CPO, CPOpeak and CR values in healthy humans (8). Bromley and colleges conducted research on 102 healthy adults from local population in the UK. There is no data about values of CPO and CR in population of other countries. Our previous study concentrated on difference of CPO values in male athletes and non-athletes (9). But till now, there were no data available for female population. This study contributes to the goal of determination the values of CPO, CPOpeak and CR in young males and females.

MATERIAL AND METHODS

The Medical ethics committee of Medical faculty Novi Sad approved this research protocol. Sixty participants were recruited for this study and assigned to two groups. The first group consisted of thirty sedentary women aged 21 ± 1.6 years. The second group consisted of thirty sedentary males, 21 ± 1.7 years old. Participants were considered sedentary if they were not involved in organized physical activity in last 12 months. After anamnestic data were collected participant with any history of hypertension, cardiac, or any other medical conditions known to affect cardiovascular function were excluded. The research has been carried out in accordance with the Declaration of Helsinki (2000) of the World Medical Association and all subjects gave informed consent for taking part in the experiment.

Data were collected in morning hours. Protocol had two stages and was specially made for this research. At first stage of experiment participants were tested during rest. Blood pressure (BP) was recorded manually by auscultation, and heart rate and ECG monitoring were achieved with an integrated system of Polar cardio computer (Polar Electro Oy, Finland). After 10 minutes of rest in lying position, echocardiographic parameters were recorded. Recording was conducted with the participant lying in the left lateral decubitus position with the left arm supporting the head. Standard parameters were measured as recommended by the American Society of Echocardiography: LVPWd =left ventricle posterior wall thickness; IVSTd = end diastolic intraventricular septal wall thickness (mm); LVIDd = end diastolic left ventricular internal dimension (mm); IVSTs = end systolic intraventricular septal wall thickness (mm);

LVIDs = end systolic left ventricular internal dimension (mm); EDV =end diastolic volume (ml), ESV =end systolic volume (ml); stroke volume (ml); ejection fraction (%), (11). All echocardiographic measurements were made using the Nemio 20 (Toshiba, Japan) ultrasonography system.

At stage two of the experiment maximal exercise testing was performed on a Secacardiostest cycle ergometer (Vogel & Halke, Hamburg, Germany). Starting load was 50W and participants cycled with velocity of 50 revolutions per minute. Intensity was increased for another 25W automatically at the end of each 2-min stage. The test was terminated depending on individuals exercise capacities. Reasons for ending the test were twofold, the demand of participants, and when participants were not able to maintain cadence of 50 revolutions per minute. When test termination became imminent, BP and echocardiographic parameters needed for determination of CO were recorded as previously described.

After all measurements were done, needed parameters were calculated. Cardiac output was calculated as the product of stroke volume (SV) and heart rate (HR). Mean arterial pressure was calculated by the following formula: $MAP = (SBP - DBP) / 3 + DBP$, where DBP is the diastolic blood pressure and SBP the systolic blood pressure in millimeters of mercury (mmHg). Cardiac power output was calculated as follows: $CPO = MAP \times CO \times K$, where K is the conversion factor ($2.22 \cdot 10^{-3}$) into watts (12). Cardiac reserve (CR) was calculated, as the difference between CPO at peak exercise and at rest.

Descriptive statistics were computed and presented in a standard format. Unpaired t-tests were used to assess the difference between two groups. Pearson's correlation coef-

TABLE 1

Heart's size and volumes of women and men.

	Women (X±SD)	Men (X±SD)
IVSTd (mm)	7.64±0.75	9.24±0.87*
LVIDd (mm)	46.07±3.74	50.06±3.66*
LVPWd (mm)	7.65±0.81	9.11±1.16*
EDV (ml)	98.64±18.57	117.83±17.45*
IVSTs (mm)	12.70±1.59	13.17±1.27
LVIDs (mm)	28.17±4.94	31.98±4.11*
ESV (ml)	31.3±8.0	42.66±11.19*

* p<0.05

IVSTd = end diastolic intraventricular septal wall thickness (mm); LVIDd = end diastolic left ventricular internal dimension (mm); LVPWd =left ventricle posterior wall thickness; EDV =end diastolic volume (ml); IVSTs = end systolic intraventricular septal wall thickness (mm); LVIDs = end systolic left ventricular internal dimension (mm); ESV =end systolic volume (ml)

TABLE 2

Hemodynamic Parameters and main cardiac pumping capability of women vs. men during rest and at peak exercise.

	Women		Men	
	Resting	Peak Exercise	Resting	Peak Exercise
Heart rate (beats/min)	77.77±8.54	173.4±5.87	78.47±13.1	185.1±3.36 ^b
Stroke volume (ml)	66.37±11.59	97.13±10.87	75.16±11.86 ^a	110.32±14.45 ^b
Mean arterial blood pressure (mmHg)	88.64±8.10	99.06±7.66	87.27±6.50	112.65±6.42 ^b
Cardiac output (l/min)	5.21±1.31	16.84±1.90	5.88±1.26 ^a	20.42±2.70 ^b
Cardiac power output (W)	1.04±0.29	3.90±0.58	1.14±0.25	5.10±0.72 ^b

^aSignificantly different from resting value of women $p < 0.05$

^bSignificantly different from peak exercise value of women $p < 0.05$

ficient was used to assess the relationship between cardiac power output at peak exercise with other structural cardiac parameters. In all cases statistical significance was accepted at the $p < 0.05$ level. Data are presented as mean \pm SD unless otherwise indicated. All statistical analyses were conducted using version 10 of SPSS (SPSS Inc., Chicago, IL, USA).

RESULTS

Women and men were almost the same age, but there were significant differences ($p < 0.05$) in body height and body weight between these two groups (age 21.2 ± 0.7 years, body mass 63 ± 6.3 kg, height 168.3 ± 5.1 cm vs. age 21.3 ± 1.9 years, mass 82.5 ± 7.9 kg, height 181.9 ± 4.9 cm).

Heart's size and volumes of all subjects measured at rest were in physiological limits. There were significant difference between groups in all heart's size and volumes parameters measured by echocardiography, except in IVSTs parameter (Table 1) The group of men had higher stroke volume (75.2 ± 11.9 ml versus 66.4 ± 11.6 ml, $p < 0.05$) and cardiac output (5.9 ± 1.3 l versus 5.2 ± 1.3 l, $p < 0.05$), but the two groups had similar values of cardiac power output (1.04 ± 0.3 W versus 1.14 ± 0.25 W, $p > 0.05$).

CPO after peak exercise was higher in men (5.1 ± 0.72 W versus 3.9 ± 0.58 W, $p < 0.05$), as was cardiac reserve (3.96 ± 0.64 W versus 2.86 ± 0.44 W, $p < 0.05$), respectively. In order to decrease the effect of body size on peak CPO, allometric scaling model was used as suggested by Chantler *et al.* (13). Peak CPO was allometrically scaled to body surface area using the exponent for body surface area of 0.81 as suggested (13). After allometric scaling method was used, men still had significantly higher peak CPO (2.79 ± 0.4 W m^{-2} versus 2.46 ± 0.32 W m^{-2} , $p < 0.05$).

TABLE 3

Correlations between peak cardiac power output and heart's parameters.

	Peak cardiac power output (Pearson's correlations r)
IVSTd (mm)	-0.06
LVIDd (mm)	0.58*
LVPWd (mm)	-0.03
EDV (ml)	0.60*
IVSTs (mm)	0.07
LVIDs (mm)	0.11
ESV (ml)	0.16

* $p < 0.05$

IVSTd = end diastolic intraventricular septal wall thickness (mm); LVIDd = end diastolic left ventricular internal dimension (mm); LVPWd = left ventricle posterior wall thickness; EDV = end diastolic volume (ml); IVSTs = end systolic intraventricular septal wall thickness (mm); LVIDs = end systolic left ventricular internal dimension (mm); ESV = end systolic volume (ml)

Hemodynamic parameters and cardiac pumping capability of women and men at rest and at peak exercise are presented in Table 2.

Duration of the exercise test in men was longer than in women, and men tolerated greater work rate at peak exercise (178.3 ± 28.4 vs. 115 ± 16.9 watts, $p < 0.05$).

Data from men and women were combined together and correlation between peak cardiac power output and heart's parameters was investigated. A significant positive relationship was found between peak exercise cardiac power and end diastolic volume and end diastolic left ventricular internal dimension. These results are shown in Table 3.

Also, at peak exercise, cardiac power output was well correlated with stroke volume ($r=0.86$) and cardiac output ($r=0.87$). The coefficient of correlation was moderate between CPO and mean arterial pressure ($r=0.64$) and work rate output ($r=0.52$).

DISCUSSION

Cardiac power output is a novel hemodynamic measure and by incorporating both pressure and flow domains of cardiovascular system, is an integrative measure of cardiac performance (4). Also, as CPO is measured both at rest and at peak exercise, the functional reserve capacity of the heart can be obtained.

This study provides values of cardiac power output at rest and peak exercise in healthy sedentary women and men in our population. Participants were considered sedentary if they were not involved in any organized physical activity in last 12 months. Major finding of this study suggests that men have greater cardiac pumping capability than women, even after decreasing body size effect.

Maximal cardiac power output observed in the present study for both women and men is within the range previously reported by Bromley for normal healthy UK population (8). Results for group of men are similar to those reported for sedentary men in our previous study (9), but lower than those reported for athletes (9, 10).

Previous studies have shown that cardiac power output obtained at peak exercise is the major determinant of physical functional capacity and maximal oxygen consumption in healthy adults and heart failure (14, 15, 16). Our results also suggest that CPO is good predictor of exercise capacity, as there was a significant positive correlation between peak CPO and work load achieved at cycle ergometer.

Understanding the structure and function correlation is also very important. We have conducted this research using echocardiography for determining CO instead of rebreathing method used by other authors (17). This allowed us to compare not only function, but also cardiac structure in our participants. Heart's size and volumes of all our subjects measured at rest were in physiological limits (18). Jakovljevic *et al.* have shown that peak CPO well correlates with cardiac output ($r=0.92$) and stroke volume ($r=0.90$) (19). In our study correlations are very similar to previous study, $r=0.87$ for cardiac output and $r=0.86$ for stroke volume. This suggest that only CO and SV truly reflect CPO. Other parameters are not so good surrogates for overall cardiac function.

Wernstedt *et al.* found significant correlation between left ventricular end-diastolic volume and maximal oxygen consumption (20). The present study have showed similar to previous study that coefficient of correlation was moderate between CPO and the left ventricular end diastolic diameter and volume, as the standard echocardiography

measures. As this correlation was only moderate, these parameters also can't be used as good indicators of overall function and pumping capability of the heart.

Females in general have smaller body dimensions and smaller chest dimensions, which in turn may influence the gender related difference in heart size (20). Previous studies have shown that anthropometric parameters also affect the values of cardiac function and for data CPO to become independent of body size, the correct scaling method must be applied. In the present study we were making between group comparisons and allometrically scaled cardiac power output to body surface area (13). After allometric scaling method was used to decrease the effect of body size on peak CPO, men still had higher values of peak CPO and CR.

CONCLUSION

The present study shows that men have higher CPO after peak exercise and greater cardiac reserve than women, even after decreasing body size effect. Peak cardiac power output was well correlated with stroke volume and cardiac output, and the coefficient of correlation was moderate between CPO and mean arterial pressure, work rate output, left ventricular end diastolic diameter and volume. The strength of these relationships suggest that only CO and SV are good indicators of cardiac pumping capability. Further studies are needed to investigate cardiac pumping capability in women and men of different age.

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