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## Original research article

# The determinants of blood pressure response to exercise



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## ARTICLE INFO

## Article history:

Received 7 January 2015

Accepted 14 March 2015

Available online 3 April 2015

## Keywords:

Exercise blood pressure

Exercise stress test

Test protocol

## ABSTRACT

**Introduction:** There is currently no consensus on the definition of normal BP (blood pressure) increase during exercise and thus of the exaggerated BP response to exercise. The aim of the present study was a description of the relationship between BP and work rate corrected by body weight on cycle ergometer. A secondary objective was to explore the possible components of this relationship.

**Materials and methods:** An observational study with retrospective analysis of the BP data acquired during standard stress tests on cycle ergometer was performed. For the analysis each work rate was expressed corrected to the patients' body weight.

**Results:** We analysed BP data from a total of 313 stress tests. From the linear regression analysis we found that at the first exercise step systolic BP depends primarily on resting BP ( $p = 0.001$ ), on W/kg ( $p = 0.001$ ), on BMI ( $p = 0.005$ ) and age ( $p = 0.002$ ) ( $BP = -25.059 + 0.927 \cdot BP_{rest} + 31.625 \cdot W/kg_1 + 0.840 \cdot BMI + 0.235 \cdot age$ ) and diastolic BP depends primarily on resting BP ( $p = 0.001$ ), and on resting diastolic BP ( $p = 0.033$ ):  $BP = 29.790 + 0.583 \cdot BP_{rest} + 0.071 \cdot BP_{rest}$ . On subsequent steps age did no more influence systolic BP and resting diastolic BP remained the main determinant of diastolic BP.

**Conclusion:** The main finding of this study is the confirmation that the exercise blood pressure depends principally on resting blood pressure and work rate and to a lesser amount on BMI and age. In future studies work rate should be corrected by body weight at submaximal levels.

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## Introduction

Elevated resting blood pressure (BP) is an established predictor of cardiovascular morbidity and mortality and it is one of the

components of total cardiovascular risk in SCORE charts [1]. BP increases physiologically during exercise to enable adequate blood supply to working muscles [2] and its increase is proportional to exercise intensity [3]. There is currently no consensus on the definition of normal BP increase during

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<http://dx.doi.org/10.1016/j.crvasa.2015.03.010>

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exercise and thus of the exaggerated blood pressure response to exercise (ExBP) [4].

Several studies have used ExBP to predict the development of future hypertension [5–7] and cardiovascular events [8–10]. These studies were conducted principally on treadmill and used mostly peak systolic BP or absolute increase from resting to peak values of the systolic BP [11].

The expression of the work intensity corrected to body weight on the cycle ergometer is linearly proportional to the multiples of the metabolic equivalents (METs). Only minority of the studies used METs for the correction of blood pressure response to exercise and all except one were performed on treadmill [5,6,12,13]. We found no studies on cycle ergometers taking into account the weight of the patients for the correction of work intensity (in contrast on treadmill which is inherently a weight bearing exercise). Radvanský et al. used the definition of abnormal blood pressure response to exercise as any increase of more than 30 mmHg per 1.0 W/kg [14].

The aim of the present study was a description of the relationship between BP and work rate corrected by body weight on cycle ergometer. A secondary objective was to explore the possible components of this relationship.

## Materials and methods

An observational study with retrospective analysis of the blood pressure data acquired during standard stress tests on cycle ergometer was performed. Basic demographic data and the patients' medication were recorded before each test. Data from a total of 313 stress tests performed between January 2011 and December 2012 were included. There were 136 patients with hypertension, who were taking a mean of  $1.8 \pm 0.9$  antihypertensive drugs from all groups of antihypertensive drugs. Forty-three patients had known coronary artery disease; there were 37 patients with type 2 diabetes, and 17 patients had chronic obstructive pulmonary disease. One-hundred and sixty-four patients were taking drugs affecting blood pressure; 75 patients were taking beta-blockers and 7 patients were taking verapamil. Basic demographic data according to the presence or absence of clinically documented hypertension are summarised in Table 1. Suspected coronary artery disease was the clinical indication for the stress test in 184 patients, preventive check-out in 89 patients, dyspnoea in 27 patients, examination before non-cardiac surgery in 7 patients and blood pressure reaction to exercise in 6 patients.

Exercise stress tests on cycle ergometer (Ergoline e-bike, GE) were performed according to the guidelines of the Czech Society of Cardiology [15]. In brief, a 3-min work rate step protocol was used and the workloads were chosen by the attending physician in multiples of 25 W according to patients' age, performance status and comorbidities. On each step heart rate, systolic (BP<sub>sys</sub>) and diastolic (BP<sub>dia</sub>) blood pressures were recorded. The numbered suffixes correspond to the number of work rate step, and the suffix 0 is for baseline data.

For the analysis each workload was expressed corrected to the patients' body weight, i.e. workload divided by the body weight (W/kg) for each 3-min step.

**Table 1 – Patients' demographic data according to the hypertensive status.**

|                                              | Without hypertension | With hypertension        |
|----------------------------------------------|----------------------|--------------------------|
| N                                            | 174                  | 136                      |
| Age (years)                                  | 52 ± 13              | 59 ± 13 <sup>*</sup>     |
| Height (m)                                   | 174 ± 9              | 173 ± 9                  |
| Weight (kg)                                  | 81.2 ± 14.7          | 86.7 ± 17.4 <sup>*</sup> |
| BMI (kg/m <sup>2</sup> )                     | 26.9 ± 4.0           | 28.9 ± 4.5 <sup>*</sup>  |
| N (without any medication)                   | 91 (53%)             | 14 (10%)                 |
| N (with antihypertensive medication)         | 36 (21%)             | 116 (85%)                |
| Number of antihypertensive drugs (mean ± SD) | 1.7 ± 0.8            | 1.8 ± 0.9                |

<sup>\*</sup> For  $p < 0.05$ .

Blood pressure measurements were done by one experienced nurse at the beginning of the third minute of each workload. Blood pressure was measured manually by an aneroid sphygmomanometer using the auscultatory method. BP<sub>sys</sub> was recorded at the appearance of the Korotkoff phase I sound and BP<sub>dia</sub> at the disappearance or muffling of the Korotkoff sounds (phase IV or V); the preference was at the complete disappearance of the Korotkoff sound, and in the case of uncertainty diastolic pressure was not noted. Heart rate was measured online from the ECG recording by the cardiological software (GE Cardiosoft V6.51).

For the purpose of the current study we included only exercise tests where the blood pressure was measured by the same experienced nurse. Exaggerated blood pressure response to exercise was considered if any measurement of blood pressure during the exercise test was higher than 200 mmHg for BP<sub>sys</sub> or higher than 100 mmHg for BP<sub>dia</sub>, for both male and female subjects [15].

## Statistics

Data are expressed as mean ± standard deviation for numerical variables.

Between group differences were tested using Student's unpaired t-test.

Before linear regression analysis we calculated Pearson's correlation coefficients separately for BP<sub>sys</sub> and BP<sub>dia</sub>. A linear regression analysis with multivariate models was used with stepwise variable selection.

The value of  $p < 0.05$  was considered significant. All calculations were performed using statistical software SPSS 13.0 (SPSS Inc., Chicago, IL 60606-6412).

## Results

From the 313 stress tests seven patients did not finish the entire first step; another 88 patients finished the exercise during the second step, and only 13 patients attempted the fourth step. The reasons for stopping the test were electrocardiographic changes ( $n = 36$ ), blood pressure increase ( $n = 7$ ) and the will of the patients to stop the test ( $n = 17$ ), all other patients attained at least 85% of predicted heart rate.

**Table 2 – Work rate steps and haemodynamic parameters.**

|                                       | Baseline – resting condition | Step 1       | Step 2       | Step 3       | Step 4       |
|---------------------------------------|------------------------------|--------------|--------------|--------------|--------------|
| Number of patients who begun the step | 313                          | 313          | 306          | 222          | 13           |
| Step duration (s)                     | N/A                          | 179 ± 3      | 160 ± 41     | 102 ± 60     | 91 ± 54      |
| Intensity absolute (W)                | N/A                          | 65.7 ± 24.4  | 113.7 ± 36.4 | 161.4 ± 52.9 | 194.2 ± 49.1 |
| Intensity by body weight (W/kg)       | N/A                          | 0.8 ± 0.3    | 1.4 ± 0.5    | 1.9 ± 0.6    | 2.24 ± 0.61  |
| Heart rate                            | 73.7 ± 12.9                  | 116.6 ± 18.8 | 138.9 ± 21.6 | 150.8 ± 20.4 | 152.5 ± 26.9 |
| BP <sub>sys</sub>                     | 124.5 ± 15.9                 | 151.9 ± 23.0 | 174.3 ± 26.4 | 184.4 ± 28.5 | 188.1 ± 24.6 |
| BP <sub>dia</sub>                     | 77.8 ± 8.9                   | 84.0 ± 9.4   | 88.5 ± 9.6   | 90.9 ± 11.4  | 88.8 ± 8.5   |

The data from the consecutive work rate steps are summarised in [Table 2](#).

Pearson's correlation coefficients were calculated separately to select appropriate variables for the stepwise linear regression analysis. Due to the low number of patients this analysis was not performed for the step four. The correlation coefficients are listed in [Table 3](#).

### Linear regression analysis

From the linear regression analysis we found that BP<sub>sys1</sub> depends primarily on BP<sub>sys0</sub> ( $p = 0.001$ ), on W/kg<sub>1</sub> ( $p = 0.001$ ), on BMI ( $p = 0.005$ ) and age ( $p = 0.002$ ):

$$BP_{sys1} = -25.059 + 0.927 \cdot BP_{sys0} + 31.625 \cdot W/kg_1 + 0.840 \cdot BMI + 0.235 \cdot age.$$

BP<sub>sys2</sub> depends primarily on BP<sub>sys0</sub> ( $p = 0.001$ ), on W/kg<sub>2</sub> ( $p = 0.001$ ), on BMI ( $p = 0.001$ ):

$$BP_{sys2} = -22.432 + 0.883 \cdot BP_{sys0} + 27.501 \cdot W/kg_2 + 1.722 \cdot BMI.$$

BP<sub>sys3</sub> depends primarily on BP<sub>sys0</sub> ( $p = 0.001$ ), on W/kg<sub>3</sub> ( $p = 0.001$ ), on BMI ( $p = 0.012$ ):

$$BP_{sys3} = -18.399 + 0.888 \cdot BP_{sys0} + 27.515 \cdot W/kg_3 + 1.462 \cdot BMI.$$

From the linear regression analysis BP<sub>dia1</sub> depends primarily on BP<sub>dia0</sub> ( $p = 0.001$ ), and on BP<sub>sys0</sub> ( $p = 0.033$ ):

$$BP_{dia1} = 29.790 + 0.583 \cdot BP_{dia0} + 0.071 \cdot BP_{sys0}.$$

From the linear regression analysis BP<sub>dia2</sub> depends primarily on BP<sub>dia0</sub> ( $p = 0.001$ ) on BMI ( $p = 0.017$ ) and W/kg<sub>2</sub> ( $p = 0.006$ ):

$$BP_{dia2} = 27.983 + 0.523 \cdot BP_{dia0} + 0.510 \cdot BMI + 3.704 \cdot W/kg_2.$$

BP<sub>dia3</sub> depends only on baseline BP<sub>dia0</sub>:

$$BP_{dia3} = 40.691 + 0.637 \cdot BP_{dia0}.$$

### Subgroup analysis

No difference in both systolic and diastolic blood pressures was found between patients with positive ( $n = 32$ ) and negative ( $n = 281$ ) stress tests. Patients without any antihypertensive medication had lower BP<sub>sys0</sub> than patients taking antihypertensive drugs ( $120.6 \pm 15.0$  vs.  $128.0 \pm 16.0$ ,  $p < 0.001$ ); otherwise there were no statistically significant differences in systolic blood pressures in subsequent stress test steps. There were no statistically significant differences in BP<sub>dia0–3</sub>.

Statistical differences in both resting systolic and diastolic blood pressures were found between patients experiencing an abnormal hypertensive blood pressure response and normal BP response. Thus the linear regression analysis was recalculated according to these two groups. Patients with an abnormal blood pressure response had significantly higher resting BP<sub>sys0</sub> ( $132.8 \pm 14.8$  vs.  $122.6 \pm 15.5$ ,  $p < 0.001$ ) and higher resting BP<sub>dia0</sub> ( $81.3 \pm 9.1$  vs.  $77.0 \pm 8.7$ ,  $p < 0.001$ ). There was no statistically significant difference between work intensities corrected by body weight at subsequent exercise steps. The partial-regression coefficients for systolic and diastolic blood pressures are summarised in [Table 4](#).

### Discussion

Our study suggests that resting blood pressure and work rate were the main components of exercise blood pressure with a smaller influence of BMI and age.

**Table 3 – Pearson's correlation coefficients between systolic and diastolic blood pressures and appropriate variables for the stepwise linear regression analysis.**

|                    | Age    | Gender  | BMI    | BP <sub>sys0</sub> | BP <sub>dia0</sub> | W/kg <sub>1</sub> | W/kg <sub>2</sub> | W/kg <sub>3</sub> |
|--------------------|--------|---------|--------|--------------------|--------------------|-------------------|-------------------|-------------------|
| BP <sub>sys1</sub> | 0.116* |         | 0.137* | 0.639***           | 0.393***           | 0.183***          |                   |                   |
| BP <sub>sys2</sub> |        |         | 0.153* | 0.493***           | 0.353***           |                   | 0.264***          |                   |
| BP <sub>sys3</sub> |        | 0.265** |        | 0.523***           | 0.334***           |                   |                   | 0.403***          |
| BP <sub>dia1</sub> |        |         | 0.281* | 0.421***           | 0.672***           |                   |                   |                   |
| BP <sub>dia2</sub> |        |         | 0.350* | 0.379**            | 0.626***           |                   |                   |                   |
| BP <sub>dia3</sub> |        |         | 0.440* | 0.453*             | 0.413*             |                   |                   |                   |

\* For  $p < 0.05$ .

\*\* For  $p < 0.01$ .

\*\*\* For  $p < 0.001$ .

**Table 4 – The partial-regression coefficients for systolic and diastolic blood pressures separately for patients with abnormal BP response and with “normal” BP response to exercise.**

| Abnormal BP response |   | Number | Constant | BP <sub>sys0</sub> | W/kg   | Heart rate at baseline | Age   | BMI   |
|----------------------|---|--------|----------|--------------------|--------|------------------------|-------|-------|
| BP <sub>sys1</sub>   | N | 256    | –11.695  | 0.827              | 23.314 | 0.148                  | 0.202 | 0.622 |
|                      | Y | 57     | 16.596   | 0.942              | 36.162 |                        |       |       |
| BP <sub>sys2</sub>   | N | 193    | 0.341    | 0.751              | 23.706 |                        |       | 1.538 |
|                      | Y | 47     | 63.093   | 0.856              | 16.833 |                        |       |       |
| BP <sub>sys3</sub>   | N | 67     | 46.921   | 0.766              | 19.023 |                        |       |       |
|                      | Y | 26     | *        |                    |        |                        |       |       |
| Abnormal BP response |   | Number | Constant | BP <sub>dia0</sub> | W/kg   | Heart rate at baseline | Age   | BMI   |
| BP <sub>dia1</sub>   | N | 256    | 23.696   | 0.602              | 3.852  |                        |       | 0.348 |
|                      | Y | 57     | 27.411   | 0.754              |        |                        |       |       |
| BP <sub>dia2</sub>   | N | 193    | 51.328   | 0.460              |        |                        |       |       |
|                      | Y | 47     | 37.063   | 0.706              |        |                        |       |       |
| BP <sub>dia3</sub>   | N | 67     | 48.877   | 0.499              |        |                        |       |       |
|                      | Y | 26     | 50.088   | 0.371              |        |                        |       |       |

\* Linear regression was not performed due to low number of patients.

Systolic blood pressure depended primarily on resting blood pressure, which is consistent with the finding of other studies, where the exaggerated blood pressure response remained non-significant after adjustment to resting blood pressure [8]. This finding is not surprising as it is known that the set-point for blood pressure regulation is set higher in patients with long standing hypertension [16,17]. Taking into account the higher set point it is not surprising that for an increase of 1.0 W/kg in work rate there is an average increase of approximately 27–31 mmHg, which is consistent with the definition of normal blood pressure increase in Radvanský et al. [14].

Systolic blood pressure depended also on body mass index in all work rate steps. The contribution of BMI was not small, e.g., in our population mean BMI was 28.3 and 27.0 for men and women, respectively, and thus during the first work rate step BMI contributed to final BP by 24 mmHg and 23 mmHg in men and women, respectively. Obesity is a pro-hypertensive state and weight gain of 10 kg is associated with a 2.2-fold higher risk of developing hypertension [18].

Diastolic blood pressure depended basically on resting diastolic blood pressure. Physiologically it should remain the same or mildly decrease [19]. The slight increase of BP<sub>dia</sub> could be explained by the study population with few young patients or by the inherent difficulty of measuring diastolic blood pressure during exercise [18].

The abnormal blood pressure response is a marker of disarranged blood pressure regulation both at rest and during exercise. One of the potential mechanisms is endothelial dysfunction which is often present in patients with hypertension [20,21]. Patients with an abnormal BP response had higher resting BP and higher increase per W/kg during the first exercise step. We can only speculate where is the threshold for hypertensive reaction related to W/kg (equivalent to METs). Our data suggest that the BP increase threshold of abnormal BP response at submaximal intensity levels lays around 30 mmHg per 1.0 W/kg.

We suppose that BP at submaximal exercise levels is a better indicator of abnormal BP regulation than peak BP. BP increases

proportionally to increasing exercise intensity, and an absolute value of peak systolic BP of 200–220 mmHg could be an ExBP e.g. in a 70-year-old sedentary male weighing 70 kg whose peak work intensity was 105 W (1.5 W/kg of body weight) as well as normal peak systolic BP in a 25-year-old male cyclist weighing 70 kg whose peak work intensity was 350 W (5.0 W/kg of body weight).

Furthermore Mundal et al. found that in healthy middle aged men blood pressure increment of more than 48.5 mmHg at submaximal workload (100 W) during exercise stress test on cycle ergometer was independently associated with cardiovascular mortality and the risk of myocardial infarction [22]. In the Framingham Heart Study patients with diastolic BP above 95th percentile that was taken during second stage of exercise using the Bruce protocol was predictive of the risk for new-onset hypertension in normotensive men and women [5].

In future studies dealing with blood pressure response to acute exercise on cycle ergometer we propose to correct the work rate by body weight. We propose a protocol of at least two 3-min steps (0.5 W/kg and 1.0 W/kg, corresponding to 2.3 MET and 4.7 MET, respectively).

The main limitation of the study is its retrospective nature and the fact that the study population was not homogeneous. Another limitation is that we only approximated the adjusted work rate by body weight and we did not measure blood pressure on exact work rate. Thus it could be regarded only as a descriptive study to generate new hypothesis. More studies are needed to ascertain the normal values and prognostic significance of blood pressure increase per W/kg.

## Conclusion

The main finding of this study is the confirmation that the exercise blood pressure depends principally on resting blood pressure and work rate and to a lesser amount on BMI and age. In future studies work rate should be corrected by body weight at submaximal levels.

## Conflict of interest

The authors declare that they have no conflict of interest.

## Ethical statement

The research was done according to ethical standards.

## Informed consent

For this retrospective descriptive study informed consents where not necessary.

## Funding body

The study was financially supported by a research grant from the Czech Society of Cardiology.

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