Acta of Bioengineering and Biomechanics
Vol. 13, No. 2, 2011

Original paper

Influence of load magnitude and duration on the relationship between human arterial blood pressure and flow rate

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This article analyses the dependence of load value, age, gender and pathology on arterial blood pressure and blood flow rate. Three male and female different age groups were examined. The load applied ranged from 50 W to 150 W. The hodograms for different genders and age groups were made. These hodograms show the human adaptability to chosen maximal values of arterial blood pressure and blood flow rate and the influence of warming-up on the process of adaptation. It was found out that the maximum blood flow rate delayed the maximum arterial blood pressure during a certain period of time. The criterion for evaluating human efficiency was established. It was revealed that the hodograms for humans with certain pathology differ in curve shapes and their interlocations from those for healthy humans. It was shown that the results obtained could be used to determine a human adaptability to the load applied and human efficiency level.

Key words: *gender, load time, blood flow rate, arterial blood pressure, hodograms, efficiency*

1. Introduction

Most of scientific studies are devoted to the influence of the effect of blood flow parameters on arterial blood pressure (BP) or flow rate [10], [11], [13]. It was noticed that the level of pathology in cardiovascular system has a significant influence on a local blood pressure (in the place of pathology) and velocity. Several scientific works [2], [9] evaluated the influence of the magnitude of the load, age and gender on arterial blood pressure. Although numerous studies of blood flow have been conducted [13], [9], [6], only a few have considered realistic anatomy under correct physiological conditions as well as vessel wall mechanics. Papers [1], [4]–[7], [9] analyze the variety of methods and the ways of evaluating the arterial blood pressure (BP).

Both medical and sport centers investigate arterial blood pressure in cardiovascular system [13], when 50 W, 100 W loads are applied only in male or only in female groups during experiment lasting from 15 to 30 min [3], [14]. WILLIAMSON et al. [16] analysed the influence of load (from 50 to 125 W) on cardiovascular system when the first and the second heart failure signs are diagnosed. They examined younger groups applying the load gradually; however, physical load examinations were not performed in older groups when a constant load was applied.

In one age group (52.0 ± 6.8 years) [6], male representatives were examined. The relationship between an arterial blood pressure and the physical load measured was investigated. The measurements of a physical load were stopped when systolic blood pressure reached 240 mm Hg and diastolic blood pressure reached 130 mm Hg. The same group took place in the examination where gradual loading was applied (from 50 to 150 W). The examination was not carried out at a constant loading and female representatives did not participate in the examination.

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Received: June 22nd, 2010
Accepted for publication: March 2nd, 2011

VAINORAS et al. [15] studied the relationship between systolic blood pressure and electrocardiogram parameters when a physical load was applied, because human physical fitness is closely correlated with systolic BP variations. Veloergometric, gradually increased, provocative physical load methodology was performed in the research. An initial 50-W load used in the veloergometry was increased every minute by 50 W for males and by 25 W for females. The load was applied until clinical features that limited load appeared. All participants were divided into 6 groups according to gender (male and female) and age (20–30, 30–40 and 40–50 years). The representatives of both genders and different age groups took place in the examination with the load applied gradually. However, a constant load applied for a certain period of time was not investigated.

The analysis of the above examinations showed that they were made to study particularly BP in blood vessels and some variations in their strength characteristics. Therefore the results obtained in most cases are fragmentary and do not show clearly how the variations of BP in vessels depend on age, gender and pathology. Besides, there are only few results of examining the variations of BP in arterial vessels for a certain period of time when a constant load is applied.

Therefore the aim of this work was to analyse the relationship between the arterial blood pressure and blood flow rate at different loads and different ages and to show that the parameters mentioned affect our physical fitness.

2. Methods

The dependence of load value, age, gender and load time on arterial blood pressure and flow rate was analysed. Males and females from different age groups were examined. Their representatives were divided into 3 groups according to age: up to 20-year-olds, 21–30-year-olds, 31–40-year-olds. Each group consisted, on average, of 10 people. The medical personnel took part in all examinations. The load applied ranged from 50 W to 150 W. A "Kettler" veloergometer and computerized "Siemens" and SpaceLabs Medical" data recording system were used during examination. Arterial blood pressure variations with the load applied for a certain period of time were recorded. Mathematical statistical methods, i.e., mathematical programing package MatLab 7.1, were used for processing the data obtained.

During preliminary examinations it was noticed that the time necessary to reach the maximum of blood flow rate $t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0}$ (figure 2) that satisfies the condition $\frac{\partial S(t)}{\partial t}=0$ is shorter than that necessary to reach the maximum of arterial blood pressure $t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}$ (figure 1) that satisfies the condition $t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0} < t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}$. Therefore, the time of examinations was determined based on the following requirements:

$$t_e > t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0} \wedge t_e > t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}, \tag{1}$$

where:

t_e – the time of examination,

$t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0}$ – the time of reaching the maximum of blood flow rate,

$t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}$ – the time of reaching the maximum of arterial blood pressure,

^ – conjunction (logical multiplication).

Further $t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0}$ will be used to simplify k_{KT} and $t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}$ that will be used as k_{KS}.

Arterial blood pressure and blood flow rate (figures 1 and 2) are given in relative values that can be calculated as follows:

$$k_{KSi} = \frac{P(t_i)}{P(t_0)} \quad \text{and} \quad k_{TKi} = \frac{v(t_i)}{v(t_0)}, \tag{2}$$

where:

$P(t_i)$ and $v(t_i)$ – the i-th arterial blood pressure and blood flow rate, respectively,

$P(t_0)$ and $v(t_0)$ – arterial blood pressure and blood flow rate, respectively, of human at rest (before experiment).

If an increase in blood flow rate is directly proportional to an increase in heart rate, its value in any i-th moment of load applying can be put in the form:

$$v_i = v_0 \frac{S_i(t_i)}{S_0}, \tag{3}$$

where:

$S(t_i)$ – heart rate at the i-th time,

S_0 – heart rate at rest (before experiment).

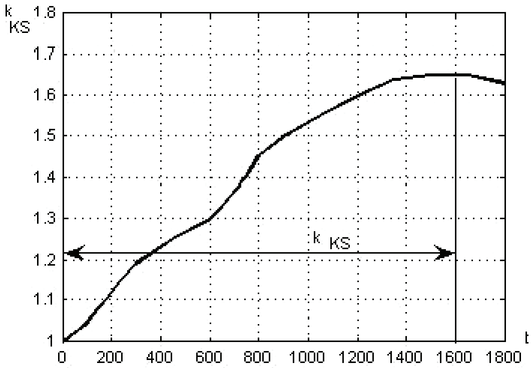

Fig. 1. Arterial blood pressure versus load time
at 150-W load applied in 21–30 years old male group

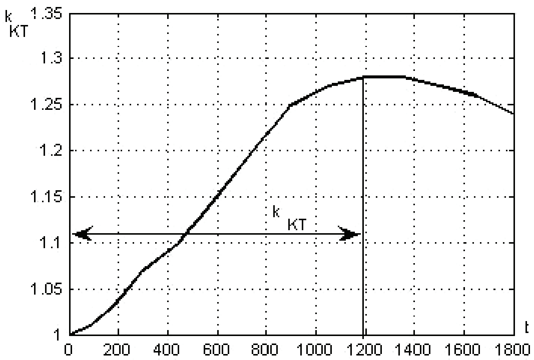

Fig. 2. Blood flow rate versus load time
at 150-W load applied in 21–30 years old male group

Relative values of blood flow rates can be expressed by

$$k_{KT} = \frac{v_0 \dfrac{S(t_i)}{S_0}}{v_0} = \frac{S(t_i)}{S_0}. \qquad (4)$$

The relationship between blood flow rate and arterial blood pressure was established based on hodograms and the expression $S(t_i) = fP(t_i)$, when $0 \le t \le t_e$, where: $S(t_i)$ – blood flow rate, $P(t_i)$ – arterial blood pressure.

3. Results

The dependence of arterial blood pressure and blood flow rate on time when different loads were applied (from 50 W to 150 W) was determined for both genders and different age groups. The hodograms $S(t_i) = fP(t_i)$ for different genders and age groups were made. Some characteristic cases are given in the diagrams (figures 3–7).

Hodograms with different loads (figures 4a, b and 5) show that with a prolonged time of loading both blood flow rate and arterial blood pressure increase. Arrow in the hodograms shows time increment direction. When certain time k_{KT} is reached, blood flow rate reaches its maximum value which is different for different loads. For example, when 50-W load is applied (figure 4a) the maximum relative rate of blood flow is close to 1.12, when 100-W and 150-W loads are applied those rates are 1.15 and 1.24, respectively. But maximum arterial blood pressure is reached later – when blood flow rate

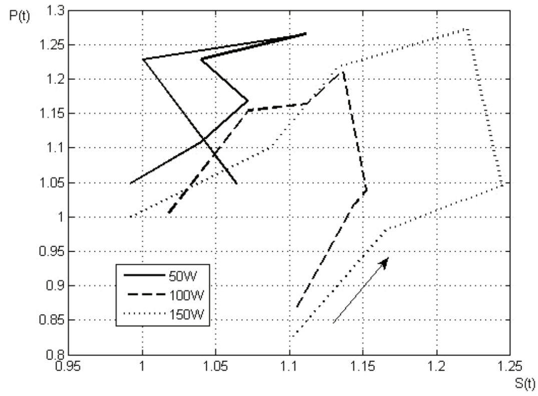

Fig. 3. Arterial blood pressure versus blood flow rate
in 31–40 years old male groups, no warming-up

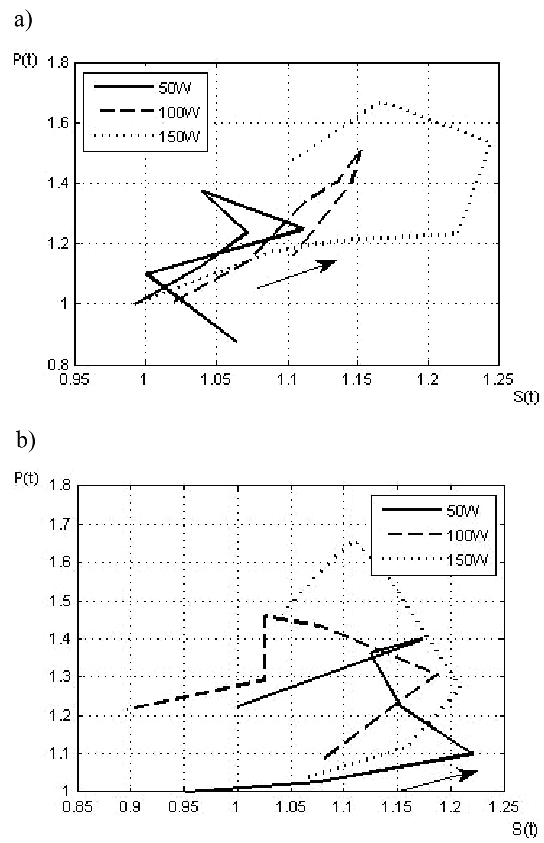

Fig. 4. Arterial blood pressure versus blood flow rate
in 21–30 years old male groups (a) and female groups (b)
after warming-up

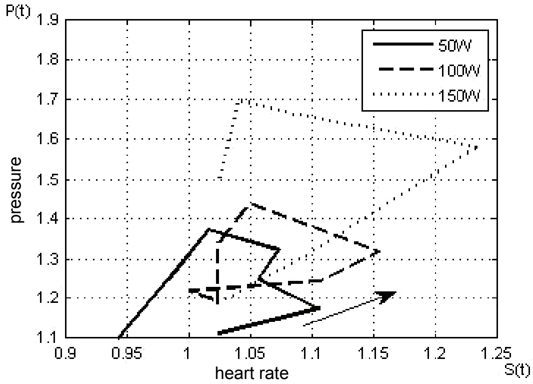

Fig. 5. Arterial blood pressure versus blood flow rate in 31–40 years old female group after warming-up

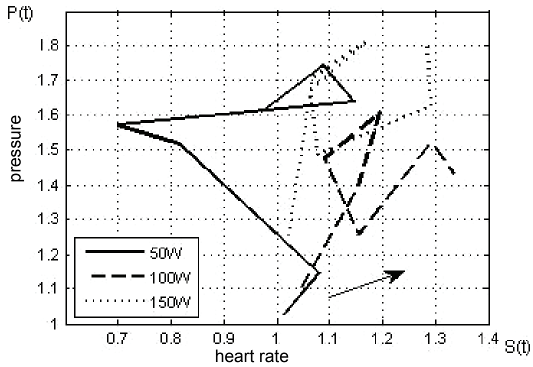

Fig. 6. Arterial blood pressure versus blood flow rate in 31–40 years old female group with pathology

is already reduced (figures 4a, b and 5). For example, in the hodogram (figure 5) it can be seen that when 150-W load is applied for 5 min, relative blood flow rate is reduced from 1.25 to 1.03, while relative arterial blood pressure reaches 1.7 when its value with maximum blood flow rate are 1.6. It is noticed that when blood flow rate and arterial blood pressure are constant at different loads applied for a certain time, arterial blood pressure is unlike (figures 4 and 5).

Comparing the hodograms in figures 3, 4a, b and 5 it can be noticed that in athletes or blue-collar workers, without warming-up (figure 3) and at smaller load applied, arterial blood pressure is higher than when the maximum load is applied. In the case of an initial warming-up (figures 4a, b and 5), the hodograms representing smaller load are located below these for larger load and when smaller load is applied, arterial blood pressure is also lower. This why an initial warming-up reduces arterial blood pressure even if small loads are applied, hence additional risk factors are eliminated.

The hodograms in figures 4a, b, 5 and 6 show that for human with pathology (figure 6) the dependence of arterial blood pressure on blood flow rate differs from that for humans without pathologies (figures 4a, b and 5).Therefore, this dependence can be used to evaluate human physical fitness rather than to estimate the adaptability to physical loading.

It was noticed that if $t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0}$ and $t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}$, human starts to feel fatigue. Hence, the extreme time durations and fluxion zero values could be used to evaluate the ability of human to adapt themselves to the load applied and the duration of their physical efficiency. A chosen work duration and the ability to apply load criterion can be expressed as follows:

$$D_{KT} = \frac{1}{\frac{\partial S(t)}{\partial t}} \quad \text{and} \quad D_{KS} = \frac{1}{\frac{\partial P(t)}{\partial t}}, \qquad (5)$$

where:

D_{KT} – the criterion of efficiency duration estimated based on maximum blood flow rate,

D_{KS} – the criterion of efficiency duration estimated based on maximum arterial blood pressure.

Graphical interpretation of these criteria is shown in figure 7.

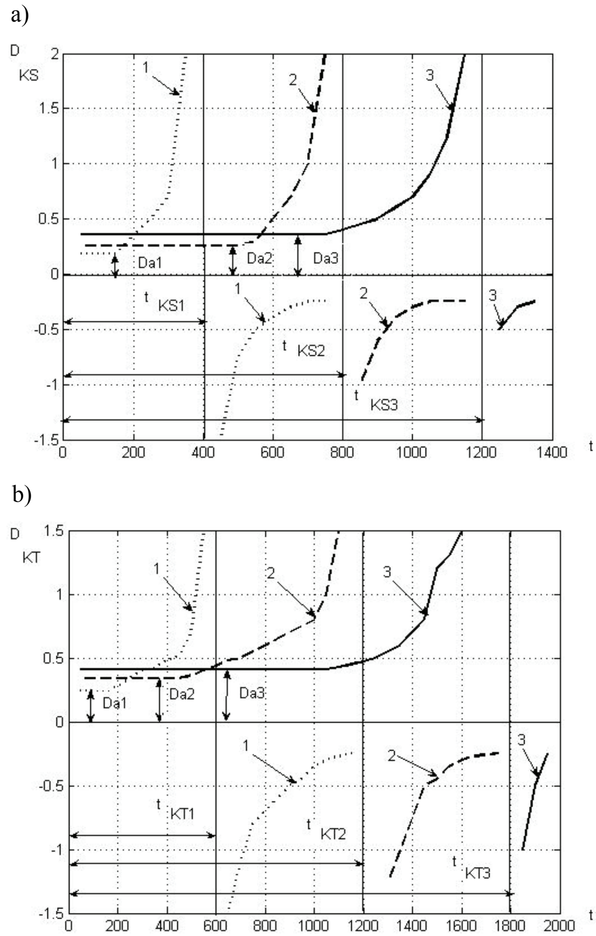

Fig. 7. The criterion of efficiency duration: a) evaluating extreme value of arterial blood pressure: 1 – at 50 W, 2 – at 100 W, 3 – at 150 W; b) evaluating extreme value of blood flow: 1 – at 50 W, 2 – at 100 W, 3 – at 150W

4. Discussion

In medicine, there are various ways to assess efficiency: aerobic and not aerobic efficiency training methods and means, continuous working methods, work with rest methods and other ways [8], [12]. Various researchers analyse variations of arterial blood pressure in cardiovascular system, depending on the load applied [1]–[3], [5]–[9], 14–16]. The studies discuss the influence of jump load on arterial blood pressure and heart rate [14], [15]. It is point out that human physical efficiency is closely related to the variations of systolic blood pressure. With an increase in load a systolic blood pressure is also increased. The examinations carried out prove that with an increased load duration, blood flow rate and systolic blood pressure are also increased. The results obtained during this research are similar to those in literature. However, our hodogram representing a functional dependence of blood pressure on heart rate shows a new aspect. We have found that from the beginning a human body is adapting to the load applied. The adaptation is shown by a slightly increased blood pressure or heart rate followed by the reduction of the mentioned factors values. The results presented show that the longer the period of adaptation to the load applied, the shorter the worm-up time. The hodograms show this clearly. There is a mixed relationship between arterial blood pressure and heart rate. When there is different time moment and the same heart rate, arterial blood pressure is various; or when there is the same arterial blood pressure and different time moment, the heart rate is various. It was found out that in the arterial blood pressure and heart rate diagrams there occurred two maxima and using the features of the functions $t_{KT}\Big|_{\frac{\partial S(t)}{\partial t}=0}$ and $t_{KS}\Big|_{\frac{\partial P(t)}{\partial t}=0}$ the efficiency parameters could be evaluated. The evaluation of efficiency parameters allows us to obtain an initial efficiency reserve with the load applied and approximate efficiency time.

Many investigators [4]–[6], [9], [12], [15] report that because of a physical load not only varies heart work, but also cardiovascular functional readings, a whole body condition. One of cardiovascular readings mostly investigated is heart rate. Heart rate is increased during physical load from the very beginning of load application. Our investigations confirm these statements. Our dependences of arterial blood pressure on heart rate in the form of hodograms and the parameters of efficiency evaluation can show human adaptability to the load applied. That shows the efficiency reserve and duration reduction.

5. Conclusion

The following conclusions can be drawn:

1. The dependence of arterial blood pressure on blood flow rate at different loads applied is given in the form of hodograms for both genders and different age groups. The hodograms allow us:
   - to estimate the maximum arterial blood pressure and blood flow and their extreme discrepancy during the time of load applying;
   - to show that at the same blood flow rate but with different load duration an arterial blood pressure differs, that a longer time of load applying is responsible for a higher arterial blood pressure value;
   - to estimate the ability of human to adapt to the load applied.
2. It was found out that arterial blood pressure starts to decrease when human starts to feel fatigue.
3. The hodograms allow us to determine the importance of an initial warming-up before physical load application.
4. The criteria of efficiency estimation allow us to determine an effective work duration and efficiency reserve.
5. The methodology given can be used to determine human physical efficiency.

References

[1] Beverly B., Green M.D., Andrea J. et al., *Effectiveness of home blood pressure monitoring, web communication, and pharcist care on hypertension control*, The Journal of the American Medical Association, 2008, Vol. 299, No. 24, 2857–2867.

[2] Laukkanen R.M., Kalaja M.K., Kalaja S.P. et al., *Heart rate during aerobic classes in women with different previous experience of aerobics*, European Journal of Applied Physiology, 2001, 84, 64–68.

[3] Leung J.H., Wright A.R., Cheshire N., Crane J., Thorn S.A., Hughes A.D., Xu H., *Fluid structure interaction of patient specific abdominal aortic aneurisms: A comparison with solid stress models*, Biomedical Engineering OnLine, 2006, 256–281.

[4] Mariūnas M., *Research of the influence of load, systolic bood pressure and pathology on local pressure in elastic arteries*, Journal of Vibroengineering, 2008, Vol. 10, No. 3, 335–340.

[5] Mariūnas M., Daunoravičienė K., Griškevičius J., Anddrašiutė J., *Research of relation between muscle biosignal and systolic blood pressure, and application of its characteristics for evaluation of efficiency*, Journal of Vibroengineering, 2008, Vol. 10, No. 3, 329–334.

[6] MARIŪNAS M., KUZBORSKA Z., *Research into the heart rate and blood pressure dependence on loading and time*, Journal of Vibroengineering, 2009, Vol. 9, Issue 3, 51–54.
[7] MARIŪNAS M., UZDILAITĖ G., *Reserch on the influence of pathology level to stresses in elastic arterines*, Journal of Vibroengineering, 2006, Vol. 8, No. 3, 30–34.
[8] MARTINELLI F.S., CHACON-MIKAHIL M.P., MARTINS L.E. et al., *Heart rate variability in athletes and nonathletes at rest and during head-up tilt*, Brazilian Journal of Medical and Biological Research, 2005, 38(4), 639–647.
[9] MICHAEL F., ROURKE O., *Vascular mechanics in the clinc*, Journal of Biomechanical Engineering, 2003, No. 36, 623–630.
[10] MILLER T., ROGER V., MILAVETZ J., HOPFENSPIRGER M. et al., *Assessment of the exercise electrocardiogram in women versus men using tomographic myocardial perfusion imaging as the reference standard*, Am. J. Cardiol., 2001, 87, 868–873.
[11] PANDIT A., KASSAB G., *Biaxial incremental homeostatic elastic moduli of coronary artery: two-layer model*, Am. J. Physiol. Heart Circ. Physiol., 2004, 287, H1663–H1669.
[12] PODERYS J., BULIUOLIS A., PODERYTĖ K., SADZEVIČIENĖ R., *Mobilization of cardiovascular function during the constant-load and all-out exercise tests*, Medicina, 2005, 41(12), 1048–1053.
[13] TANG D., YANG C., KOBAYASHI S., KU D., *Steady flow and wall compression in stenotic arteries: a three-dimensional thick-wall model with fluid-wall interactions*, Journal of Biomechanical Engineering, 2001, Vol. 123, 548–557.
[14] TOTH B., *Analysis of the mechanical parameters of human brain aneurysm*, Journal of Biomechanical Engineering, 2005, Vol. 7, No. 1, 3–22.
[15] VAINORAS A., GARGASAS L., JARUŠEVIČIUS G., ŠILANSKIENĖ A., MIŠKINIS V. et. al., *The bicycle ergometry and the possibility of complex evaluation*, Lithuanian Journal of Cardiology, 1999, 6(4), 760–763.
[16] WILLIAMSON S.D., LAM Y., YOUNIS H.F., HUANG H., PATEL S., KAAZEMPUR-MORFAD M.R., KAMM R.D., *Technical brief on the sensitivity of wall stresses in deseased arterines to variable material properties*, Journal of Biomechanical Engineering, 2003, Vol. 125, February, 147–155.