CONTINUOUS MONITORING of ARTERIAL BLOOD PRESSURE and PULSE: COMPARISON of MORNING and EVENING READINGS

Abstract. The research is based on long, regular observations of blood pressure and pulse - the heart rate (more than 18 years). The values of these readings are taken from the diary of self-control, which is kept by a patient, one of the authors of this publication, a man born in 1940. Such effective control over the patient's condition, implemented in our case, ensuring its normal vital activity, makes it possible to investigate the influence of external factors on the hemodynamics of the body and the manifestation of the marked temporal characteristics.

A difference between the morning and evening series was noted. The statistical characteristics of evening monitoring readings are more balanced. Spectral analysis allows for a more detailed analysis and comparison of the data. Seven-day component is clearly seen in evening series being modulated with three-year period for the pulse. The morning series are characterized by a “lunar” component with the ~27.35-day period. The absence of a weekly period in the morning readings indicates a rapid (moment of sleep) relaxation of the body from the rhythmic stress of the past day. The manifestation of the "lunar" response can be associated with an increased sensitivity of the body during and after the sleep.

The analysis of pulsatile blood pressure, i.e. the difference between SBP and DBP, provides for more options for assessing the state of the body.

Key words: Heart rate, arterial blood pressure, statistical analysis, spectrum.

1. INTRODUCTION

The work is based on long, regular observations of blood pressure (BP) and pulse - the heart rate (HR). The values of these readings are taken from the diary of self-control, which is kept by a patient, one of the authors of this publication, a man born in 1940. As a result of a medical examination of the patient, conducted in early 1997, Stage II level 2 arterial hypertension (AH) was diagnosed. From April 1997, after outpatient treatment, daily (morning and evening) blood pressure monitoring is performed at home under the doctor's supervision. An analysis of these observations over 18 years is represented below.

AH is a widespread disease that can result in severe cardiovascular complications and mortality of patients due to insufficient monitoring of blood pressure [1, 2]. The simplest and the most efficient way of preventing cardiovascular diseases and development of severe complications is blood pressure monitoring and its timely adjustment. Achieving and maintaining stable blood pressure play a crucial role in reducing cardiovascular risk in patients with arterial hypertension. A significant contribution to achieving these goals is made by the method of blood pressure self-monitoring [3, 4].

This article compares morning and evening monitoring readings and their dynamics from April 1997 to March 2015. All this time the patient has lived in Moscow (Troitsk: 55 ° 48 ' N and 37 ° 32 ' E). Differences in the general characteristics of morning and evening series are investigated, which can be traced in different spectral ranges.

Additional possibilities for assessing the patient's condition are ensured by the analysis of pulse pressure. The paper assesses the relationship morning / evening indications. A long and effective control over the patient's condition, implemented in our case, ensuring its normal vital activity, makes it possible to investigate the influence of external factors on the hemodynamics of the body and the manifestation of the marked temporal characteristics. This defines the main direction of research.

The effect of atmospheric pressure and geomagnetic activity on the interrelation between blood pressure and heart rate is examined in a recent publication of authors [5] based on an annual array of observations. A general evaluation of monitoring data over 13 years is given in an earlier work [6].

Most of the research works compare the characteristics of space weather, geomagnetic activity and weather conditions with the statistics of the ambulance calls, data from intensive care units and observations in the specialized hospital departments [7–10]. In fact, what they investigate is the perturbation of which of the physical and meteorological factors are associated with the medical manifestations with sufficient statistics. Our case examines the manifestation of external factors in the readings that have been obtained during the self-monitoring program of blood pressure in one patient. The authors understand that this is a single experiment, and the conclusions can not be comprehensively generalized without the accumulation of convincing statistics.

2. MATERIALS AND METHODS

2.1. Medical aspects of self-monitoring of blood pressure

The acute stage of manifestation of AH is overcome quickly enough, since the treatment relieves painful sensations and levels the blood pressure. Success in the further prevention of the disease and prevention of the development of severe complications is achieved by control over BP and its timely adjustment. For this, systematic measurements of blood pressure are needed for the duration of a long period of time, which is quite feasible at home. The choice of medicines combining several drugs also contributes to this significantly. Under such a therapy, the result is achieved through prescription of minimal doses and reduction of the side effect manifestations.

Arterial pressure is a rather dynamic value, and one-time measurements of a doctor will not indicate its real value. A daily blood pressure profile will be of a great diagnostic value. Such information is provided by the method of daily monitoring of arterial pressure [11, 12], which has started to be actively studied and implemented in clinical practice since 1990. Daily monitoring of blood pressure is used to diagnose AH, evaluate the effectiveness and safety of treatment. Also, daily monitoring allows to assess the state of the mechanisms of cardiovascular regulation, the temporal dynamics of blood pressure and the equal distribution of the antihypertensive effect of drugs. Scientific research has demonstrated that the values of blood pressure obtained by the self-monitoring method are comparable to the average daily values of blood pressure (via the daily monitoring method). At present, it is considered that the upper limit of the normal blood pressure is 140/90 mm Hg, measured at a doctor's appointment, corresponds to blood pressure of 130 - 135/85 mm Hg when measuring a house [13]. With arterial pressure values above these values, arterial hypertension is diagnosed.

The self-monitoring program itself, conducted in our case, includes**:**

– indications of blood pressure and heart rate were recorded in the morning between 06:00 and 07:00 (immediately after sleep) and in the evening between 17:00 and 19:00 (Moscow time), as an average of three measurements, OMRON M10-1T type tonometers were used;

– antihypertensive drug was taken no more often than once a day - in the morning after measurement;

– visit a doctor for traditional therapy and selection of medications - once a month or less.

For example in 2000 were accepted Betalok (Betalok's dose of 100 mg.) with Kristepin and Sektral (Sektral's dose of 200 mg.) with Kristepin. Antihypertensive drugs are taken 121 times, the average pause in the drugs use is equal to two days.

2.2. General characteristics of monitoring readings

The overview of the weekly monitoring data for 18 years is presented in **Fig**. 1, where the values of SBP (systolic blood pressure) and DBP (diastolic blood pressure) were recorded in millimeters of mercury while, the heart rate (HR) was recorded in the number of beats per minute. The picture demonstrates that the BP normalization took about a year and from the beginning of 1998 the pressure was controlled within the range "normal - elevated normal" according to the standards of the World Health Organization [14].

Fig. 1 Review of monitoring data: HR, SBP, DBP. Axis OX – year.

Statistical estimates of morning and evening readings for the entire period of observations are presented in **Table 1**, which demonstrates the average (**mean**), the square root of the variance (**σ½),** kurtosis (Kurtosis coefficient **-- kurtosis**), and asymmetry (**skewness**) [15]. The Kurtosis coefficient characterizes the deviation of the empirical distribution from the normal distribution, for which this coefficient is three. With **kurtosis < 3,** the distribution curve has a more flattened apex, while with **kurtosis**

> 3 the curve is spikier. For symmetric data, the asymmetry coefficient equals zero, with its positive value the distribution is shifted to the left.

Table 1. Statistical characteristics of daily series.

	mean morning / evening	σ½ morning / evening	kurtosis morning / evening	skewness morning / evening
HR	58.37 / 62.50	4.99 / 6.56	3.45 / 3.09	0.46 / 0.37
SBP	127.26 / 122.66	8.79 / 10.05	4.08 / 3.60	0.47 / 0.41
DBP	81.71 / 78.58	4.85 / 6.18	4.00 / 3.30	0.47 / 0.09

The morning average values of blood pressure are higher than the evening values, although their dispersion in the morning is lower than that of evening values. This distinguishes AP from heart rate - pulse with high average evening readings corresponds to a higher variance, which is quite reasonable. The kurtosis and asymmetry of the morning series exceed those of the evening series (especially in DBP), which indicates a more stable functioning of the body in the evening.

A clear evaluation of the SBP, DBP and HR readings is given in histograms (**Fig**. 2).

Fig. 2. Histograms: morning data (a), evening data (b).

The histograms are plotted with the normal distribution curves (smooth curves) corresponding to the parameters of these series, along the OX axis are plotted in a single numerical scale both mm. gt. column, and the number of beats per minute. There is a reasonable correspondence between the normal distributions and real data, despite the varying degree of local smoothness.

Fig. 3. Seasonal behavior of the HR, SBP, DBP (left side) and their variations (right side).

Fig. 4. Spectrum, neighborhood of 27-day (left) and 7-day (right) components: morning – dash line, evening – dot line**.**

The seasonal behavior of the heart rate, SBP and DBP, i.e., all years average for each month, is illustrated in the left side of **Fig**. 3, while the right side demonstrates variations of corresponding characteristics. The OX axis shows the month of the year. The increased activity of the body in the summer months is clearly reflected in the heart rate readings, and the reduced value of the pulse from November to April corresponds to a quieter rhythm of life during that period. In the behavior of blood pressure, spring and autumn periods are distinguished and the seasonal characteristics of blood pressure in antiphase to heart rate can be noted.

Spectral analysis allows for a more detailed analysis and comparison of the data.

Significant differences in characteristics of the morning and evening series are also manifested in different spectral ranges, which is demonstrated by **Fig**. 4 (spectral amplitudes - in relative units, axis of frequencies OX - in the reverse day). In the morning heart rate readings there is a "lunar" period of 27.35 days, which is not traced in the evening readings. In the evening series, a week-long component is clearly visible, which is modulated in the pulse also for a period of around 3 years. The absence of a weekly period in the morning readings indicates a rapid (moment of sleep) relaxation of the body from the rhythmic stress of the past day. The manifestation of the "lunar" response can be associated with an increased sensitivity of the body during and after the sleep.

2.3. Age dynamics of pulse pressure and its stability.

The analysis of pulsatile blood pressure, i.e. the difference between SBP and DBP, provides for more options for assessing the state of the body. This indicator depends not only on the heart stress, but also on the elasticity of the vessels, the presence of sclerotic changes in them, the state of myocardium. With a significant rise in blood pressure (as a result of stress, physical pressure or other factors), with an increase in SBP, DBP also increases, and their difference normally varies between 40 and 60 mm. gt., since our arteries smoothen the hemodynamic impact after cardiac output. This can explain the difference of correlation between blood pressure and its dispersion noted above, from the corresponding correlation between the pulse and its dispersion. Age-related changes and lower elasticity of the vessels result in an increase of pulsatility, which serves as an indirect indicator of the age of the arteries. The pulse arterial pressure in patients with AH is often elevated and the treatment results in both reduction of SBP, and normalization of the pulse pressure. The observations proved that hypertensive patients above 60 years of age with the elevated pulse pressure are at a greater risk of cardiovascular complications of hypertension (heart attack, stroke, coronary heart disease). Decrease in pulse pressure is associated with a decrease in the volume of cardiac output due to aortic heart disease or hyperthyroidism. The foregoing emphasizes the importance of the analysis of the temporal dynamics of pulse arterial pressure.

Fig. 5. The normalized pulse pressure, axis OX – year.

The figure 5 shows the monthly mean values of pulse pressure normalized to the corresponding half the sum of the upper and lower pressures (2x{[SBP] – [DBP]} / {[SBP] + [DBP]}) for morning and evening indications. **Not only the age dynamics is clearly traced, but also the degree of coordination of the morning and evening readings of pulse pressure.** It is seen that morning indications since 1999 quite orderly. Evening data are close to the morning indications and have a stable trend in the second half of 2000. From this moment, i.e. 60 years of age of the patient, we can talk about a balanced state of his organism. **We should note that this condition was achieved only**

2.5 years after the normalization of BP in early 1998 (Fig. 1).
Here are the estimated change table of mean values of blood pressure with age [16].

Age (year)	SBP	DBP
16—20	100—120	70—80
20—40	120—130	70—80
40—60	< 140	< 90
> 60	~150	~ 90

Then reading **0.43** of normalized pulse pressure corresponds to the age of 40-60 years, and **0.5** corresponds to over 60 years. In our case, the age dynamics of pressure can clearly be seen, and "asymptotic behavior", which is equal to **0.5**, achieved only to 72 years of patient, that confirms the effectiveness of self-control.

2.4. Long-period characteristics of morning and evening correlation series

Even with the visual evaluation of the series of self-control, the differences of relative behavior of heart rate and SBP in different periods can be noted. To describe the degree of coordination of the body and the comparison with the baseline characteristics it is reasonable use of the time dependence of the coefficients of linear correlation of medical parameters. In the time interval dT, for the corresponding fragments of series A and B, the linear correlation coefficient Corr(A&B/dT) is calculated. Scanning interval of dT along the time axis and finding the correlation coefficient at each point in time, we obtain the temporal dynamics of this factor – Corr(A&B/dT**;** t). With this approach, the entire variety of situations is mapped onto the interval of [-1**;** +1] and has an estimated character of the state of the body, but the temporal dynamics and synchronism of the change in correlation coefficients, as well as the degree of their smoothness, allow one to investigate the consistency of the readings and make a comparison with the behavior of other factors.

Fig. 6. Review of correlation series: morning data (a), evening data (b).

The following is an analysis of the correlation series for morning and evening data obtained by scanning interval of 5 days. Dynamics of semiannual (averaged over a half a year) values of the correlation coefficients for the entire range of observations is shown in **Fig**. 6, where: K1- dynamics of the correlation coefficient between the of heart rate and SBP; K2 - the correlation between heart rate and DBP; K3 (t) - between SBP and DBP. On the evening correlation relationships of heart rate with blood pressure clearly distinguish the period of about 3 years. This is consistent with the result of the study, where a clearly pronounced seven-day component of heart rate readings in the evening is also modulated by period of about 3 years (in the spectra of the morning data the SBP, DBP and HR-week component of virtually non-existent).

3. RESULTS

Along with the traditional analysis (statistical estimates, spectrum) of the series of one single investigated parameter, an analysis of the interrelation between two recorded readings of the state of the body has been carried out in this paper. In addition, the pulse pressure and correlation ratios have been analyzed, which are the functions of two variables. Let's emphasize the key results obtained above**:**

- The statistical characteristics of evening monitoring readings are more balanced**;**
- the series of long-term observations are well described through the normal distribution law with the respective average and variance**;**
- additional blood pressure monitoring possibilities as well as assessment of a patients state of the body are provided via characteristics of pulse pressure**;**
- spectra of the evening rows contain a weekly component (with the three-year period of modulation at pulse) that is actually absent in the morning series**;**
- at the same time, in the morning series, in contrast to the evening ones, the "lunar" period T = 27.35 days is clearly distinguished**;**
- the seasonal nature of the indications is also clearly manifested**.**

The increased sensitivity of the body after sleep and its greater susceptibility to external factors are indicated by the less balanced characteristics of morning readings and by manifestation of the "lunar" period. More equilibrium characteristics of the evening series correspond to the stable functioning of the body after an active day. Also, when monitoring blood pressure, it is important to monitor and keep the pulse blood pressure at a normal level.

4. DISCUSSION

Active research on the influence of cosmogeophysical factors on biomedical human readings has been conducted since the beginning of the last century. The relation of acute cardiovascular pathology with the activity of the Sun drew attention of Kindlimann examining the frequency of sudden deaths back in 1910. In 1922, Dr. M. Fort, G. Sardoux and the astronomer J. Vallo report on the increase in exacerbations of various symptoms of chronic diseases during the period of sunspots passing through the central meridian of the Sun. Soon after that, in the 30s, The Dulles brothers studying the effect of solar activity on mortality in the major European capitals noted the existence of a 27-day period in lethal case statistics [17]. This period was associated with the period of rotation of the sun around its axis (~ 27 days). Also in the first half of the 20th century, Chizhevsky's works [18, 19] summarized and presented compelling evidence of the influence of solar processes on the biosphere and human, which laid the foundations of heliobiology. In the second half of the 20th century, Halberg and coworkers investigated the influence of biological rhythms on the state of the body and its sensitivity to various forms of external influences [20-22]. Having formulated the concept of chronome, including circadian rhythms, F. Halberg gave an idea of the temporal coordination of the physiological functions of the body. Biological rhythms are inherent in all levels of the organization of the living nature and are the most important mechanism of the regulation of the body functions, providing homeostasis, dynamic balance and adaptation processes. Their registration in prevention, diagnosis and treatment of diseases gives a positive result. The variety of rhythms and their interrelations are described in full in [23]. Halberg and his colleagues laid the foundations for such areas as chronobiology and chronomedicine, which are successfully developing now. Suffice it to say that in 2017, Michael Rosbash, Jeffrey Hall and Michael Young were awarded the Nobel Prize in Physiology and Medicine for the discovery of the molecular mechanisms controlling the circadian rhythm.

Let's review how our results correspond to the general provisions and concepts.

♦ A clear manifestation of the annual period is the seasonal reaction of the organism to changes in temperature regime and the duration of the daylight hours.

♦ The emphasized "lunar" period in 27.35 days is close to the period of rotation of the Sun around its axis ~ 27 days. To clarify, we analyzed the corresponding 18-year interval of a number of daily Wolf numbers [24]. Spectral analysis of this series identified a period of 26.6 days, which is different from the "lunar". This confirmed the result of the work [6]. The presence of the variation from the gravitational effect in the morning readings is consistent with the possibility of synchronizing individual body functions with the lunar parameters [25, 26].

♦ We have already noted the difference in the statistical estimates of the morning readings from more balanced evening ones, increased sensitivity of the morning state of the body and its higher susceptibility to external influences. A recent publication of the authors [5] also noted a closer relationship of morning readings with variations in atmospheric pressure and geomagnetic activity and the stabilizing role of rhythmic loads that weaken this influence. It is known that in the morning hours the number of cases of myocardial infarction increases.

5. CONCLUSION

Such studies of long-term and regularly conducted medical observations, in spite of isolated cases, are of undoubted interest. The analysis of the dynamics of these readings both increases the effectiveness of treatment, and gives the opportunity to study the influence of external factors on the body. It is important to emphasize that fairly homogeneous series were analyzed in our case, since both time and conditions for taking daily readings were similar. Many researchers attributed the influence of the moon with its synodic period (29.5 days). In our case clearly evident sidereal moon period (27.3 days). Everyone reacts individually to the movement of the Moon. Statistical research on the effect of the Moon usually give less expressed picture than solo monitoring.

We will point out the publications with descriptions of different observations in self-monitoring. We analyze morning and evening series of heart rate in the paper [27], the duration of observations is 560 days. Afanasyev described his own ten-year-long sleep observations [28]. An analysis of 30-minute observations of the pulse and blood pressure in almost 6 months is provided in [29]. A reference to a 40-year-long self-monitoring of the changes in the heart rate of a clinically healthy subject and analysis of the average weekly data of this series are presented in [30]. The result of the analysis of

34,500 self-monitoring procedures in a healthy man over 21 years is included in the article [31]. Five measurements of six physiological parameters were taken on a daily basis. The article [32] analyzed long-term observations of a number of physiological parameters (including pulse with blood pressure) of the eight subjects and emphasized the importance of such studies, although isolated cases. We share this view and make our contribution.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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