Evaluation of PWPT-based Method for Cuffless Monitoring of Arterial Blood Pressure

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***Abstract*—Blood pressure is not a constant, it is continuously changing value which could go beyond of the physiological norm. This phenomenon is called the variability of blood pressure allowing to track changes in the circulatory system functioning. This variability could indicate the presence of various diseases and risk of damage of the vital organs. Nowadays, the only widespread way for accurate assessment of long-term variability is to use standard blood pressure monitor for measuring blood pressure and write down the results manually to the patient diary which is not too convenient while controlling this values is very important both in the treatment of patients with hypertension or desease prognosis. Recently, the interest in indirect methods and systems for blood pressure measuring has grown significantly because of their prospects. This paper reviews the Frank's Windkessel model which describes the interaction of blood pressure and pulse wave velocity. The simultaneous effect of changes in blood pressure and quasiperiods imitating heart rate on changes in pulse wave propagation time is studied. The obtained simulation output have been used for testing of the method of indirect evaluation of blood pressure. Besides, achieved practical experimental results are presented.**

I. Introduction

Blood circulation provides all metabolic processes in the human body as a component of various functional systems that provide homeostasis. The human circulatory system represents a vast network of organs and vessels participating in the process of blood circulation. Through various functional parts of the circulatory system, the necessary nutrients delivered to the tissues, transport of hormones and gases occurs, the products of metabolism transferred from the tissue cells to the excretory organs for subsequent removal from the body. The movement of blood through the circulatory system is realized with pressure caused by contraction of the heart. When blood is ejected from the heart and moves through the blood vessels, it affects their walls. The magnitude of this effect is characterized by arterial blood pressure (BP), which is a dynamic indicator and reflects main characteristics of the heart at certain period of time [1].

Constantly elevated level of BP is the main sign of one of the most common diseases of the cardiovascular system - arterial hypertension. This disease usually doesn't have noticeable symptoms and needs constant monitoring of BP level [1], [2]. There are two main types of arterial hypertension - essential and secondary. Most of the cases (up to 95%) of hypertension is essential hypertension, which by definition has no identifiable cause and is associated with a set of factors with different nature (both internal and external). Secondary hypertension has well-defined causes and can be associated with kidney disease, thyroid dysfunction, side effect of taking medications and some others. The only way to diagnose an elevated BP level is to monitor it continuously.

II. Methods of blood pressure monitoring

The most accurate method of measuring blood pressure is a direct (invasive) method, performed by inserting a catheter directly into the cavity of the radial or femoral artery. This method can be used only in medical institutions, usually in intensive care under the control of specialists, because it requires complete sterility to prevent infection. To control BP at home, people usually use non-invasive methods with compression cuffs [2]. Nowadays two main non-invasive methods are used in automated devices for BP measurement: auscultatory, based on Korotkov's tones and oscillometric. Korotkov's method is the only accurate non-invasive method for measuring BP due to the instructions of World Health Organization. In automatic and semi-automatic arterial pressure monitors for home use (the most common ones), the oscillometric method of measuring blood pressure is usually implemented. All compression methods are not suitable for carrying out multiple measurements, because due to clotting of the artery, the blood flow through it is disturbed, and it is necessary to maintain at least a two-minute interval between two repeated measurements.

In recent years, new non-invasive methods for BP measurement has drown more attraction, and the most popular among others is volume-clamp method (first introduced by Czech physiologist Prof. J Penaz in early 1967). Arterial blood volume in the finger is determined by an optical plethysmograph mounted in an inflatable cuff system. A controlled pneumatic cuff system around the finger clamps the artery at its unloaded volume, so that transmural pressure is zero throughout the cardiac cycle. The unloaded volume is detected by periodical calibration. The amplitude and shape of plethysmogram determine the volume-clamp level and servo system loop gain automatically. This is regularly repeated during the measurement as the unloaded volume may change with different physiological states of the vasculature. The finger cuff pressure waveform equals finger arterial pressure and can be measured for several hours, thus this method provides the possibility of long-term registration by non-invasive means of the entire blood pressure curve, which was previously possible only by an invasive method. The stationary device implementing this method is known as Finapres, the portable device is Portapres. Despite the obvious advantages, the volume-clamp method was mainly used for investigation purposes rather than diagnostic ones because of the questionable accuracy of measurements (measured value of diastolic BP is lower than in the brachial artery, and the

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correction depends on the condition of the arteries of the finger), bulky design of devices and their high price.

III. The problem of arterial blood pressure variability

Arterial blood pressure is not a constant value, it changes during the day and can go beyond the limits of the physiological norm. This phenomenon is called blood pressure variability, which reflects the changes occurring in the circulatory process, and can be directly related to the presence of various diseases and the risk of damage to target organs [3]. The reasons for such variability can be divided into the following groups:

1) Beat-to-beat variability associated with the autonomous functioning of the cardiovascular system and the respiratory cycle.
2) Variability within a single visit to the doctor (within-visit variability) - fluctuations in blood pressure when comparing several (usually three) consecutive traditional measurements during one visit to the doctor.
3) Daily variability. To estimate the daily variability a number of authors proposed to analyze separately this index during the periods of sleep and day activity.
4) Variability of blood pressure on different days (day-to-day variability). It is determined on the basis of daily monitoring of BP and takes usually 5-7 consecutive days.
5) Long-term variability - deviations of blood pressure from the average level, recorded for long periods of time (weeks, months). In practice, it is assessed as a visit-to-visit variability based on traditional clinical BP measurements.
6) Seasonal variability. It is known that the lowest values of BP are determined in the summer, the largest - in the winter.

The human circulatory system is a complex mechanism that has the ability to react almost instantly to any changes occurring in the body and normalize the indicators associated with BP. Systemic regulation of BP level is determined by two main mechanisms: a short-term (seconds and minutes), affecting the diameter of the vessels, the heart rate and cardiac output power, and the long-term (hours, days) affecting the volume of circulating blood [4]. Short-term regulation mainly connected with special sensors - baroreceptors, most of them are located in the walls of the aortic arch and carotid sinus. The baroreceptors respond to the dilatation of the vessel walls due BP changes and by means of the autonomic nervous system send the corresponding signals (impulses of a certain frequency) to specialized centers located in the hypothalamus.

Depending on the nature of impulses supplied by baroreceptors, both sympathetic and parasympathetic nervous systems, change the heart rate and diameter of vessels, which allows adjusting the current level of BP according to the individual parameters. In addition to baroreceptors, there are chemoreceptors with a similar mechanism of action, but unlike baroreceptors, chemoreceptors react not to stretching, but to changes in blood composition (the lack of oxygen, excess carbon dioxide and hydrogen ions) [5]. The baroreceptor reflex is rapidly adapting, and therefore effective only for short-term regulation [4]. Long-term mechanisms include the renin-angiotensin-aldosterone system, which provides humoral regulation of blood pressure.

Nowadays an accurate assessment of long-term BP variability is inaccessible for use in everyday practice by professional physicians. Nevertheless, in the management of patients with hypertension should pay careful attention to continuous blood pressure control, especially when prescribing drug-induced antihypertensive therapy, to confirm the therapeutic effect from drugs, help in selecting of treatment strategy (when changing the combination of drugs or their dosage). Close attention deserves patients who have significant fluctuations in BP during repeated measurements, even if the average values of BP in these patients are normal. Such episodic hypertension may be an indicator of increased risk of developing cardiovascular diseases. At the same time, the only method of monitoring BP variability that is available for common usage is home monitoring, then patients use standard oscillometric BP monitors and recording the measurement results in the patient's diary on paper or electronic form in smartphone or tablet application, performed manually, which causes obvious inconveniences.

The only way to obtain objective information about changes in BP over a long period during daily activities is still daily monitoring of BP. The principle of measuring doesn’t differ from the standard methods used in automatic monitors of oscillometric type, while measurements are performed using an occlusion cuff at specified intervals of time. In this case, this method is difficult to call continuous monitoring in the classical sense, because the doctor receives only a set of discrete values of changes in BP with a certain step, rather than a continuous curve of changes in blood pressure.

Therefore, an important task of scientific research is the development of methods and tools available for practicing physicians to assess the long-term variability of BP. In this case, a continuous long-term BP measurement in everyday life will provide important additional information for assessing the overall cardiovascular risk and help to evaluate the effectiveness of treatment and reducing the risk of myocardial infarction and especially strokes in patients with hypertension.

IV. Enhanced Windkessel model of hemodynamic

A pulse wave in the arterial system occur due to the following mechanism: during systole, the pressure inside the left ventricle increases pushing blood through the aorta to the areas with a lower pressure. As a result, a blood flow is formed. This flow is called a pulse wave. The aortic valve ends the systole by closing after emission of a portion of blood from the left ventricle. Then the left ventricle is filled with oxygen-enriched blood from the left atrium lowering the pressure inside itself during this process. This phase of the cardiac cycle is characterized by low blood pressure and known as a diastole. The second component of the pulse wave (so-called reflected pulse wave) is formed in the places of bifurcation of large arteries during the passing of the pulse wave through them. This component spreads in the opposite direction from the peripheral arteries back to the heart. Normally, the reflected pulse wave returns to the heart during diastole after closing the aortic valve and increase diastolic pressure. This improves the blood flow in the heart vessels (coronary arteries) since they are being filled with blood mainly during diastole.

However, the reflected wave could return to the heart before the closure of the aortic valve (i.e, during the systole) which increases systolic pressure. In this case, an additional increase (augmentation) is added to normal systolic pressure formed by the left ventricle which is clearly manifested in the elderly with isolated systolic hypertension. A consequence of the reflection of the wave is a jump in intra-aortic pressure which was not considered earlier. Also, the load on the left ventricle rises because of the augmentation. In addition, it reduces the blood supply of the left and right coronary arteries during diastole. As a result, a cumulative pathological effect takes place and it worsens circulatory hemodynamics and increase intracardiac pressure.

The return time of the reflected wave depends on the value of the pulse wave velocity (PWV) which, in turn, is a function of the elasticity of the arteries. The PWV can be calculated from the following equation (1):

$$PWV = \frac{\Delta x}{PWPT} \qquad (1)$$

where Δx is distance traveled by the pulse wave, PWV – pulse wave velocity, $PWPT$ - pulse wave propagation time.

For large vessels (aorta and arteries), the PWV is modeled by the Moens–Korteweg equation [6], [7]:

$$V = \sqrt{\frac{E \cdot h}{\rho \cdot d}} \qquad (2)$$

where E is the elastic modulus (Young's modulus) of the vessel wall, h - wall thickness, d - inner diameter of the vessel, ρ - blood density. The blood density is usually 1,050 - 1,060 g/cm³. Individual blood density for each person can be considered a constant.

There is an empirical relationship between the elastic modulus E and blood pressure P:

$$E = E_0 e^{a \cdot P} \qquad (3)$$

where E_0 and P are the initial values of the elastic modulus and blood pressure, a - non-dimensional ratio that depends on the properties of the vascular wall and usually has a value 0.016-0.018.

Using equations (2) and (3) we can get the following equation:

$$V^2 = \frac{h}{\rho \cdot d} E_0 e^{a \cdot P} \qquad (4)$$

Assuming that in the certain section of the artery the PWV (V) is a constant PWV is proportional to the ratio of the length L of this section to the pulse wave propagation time T:

$$V = \frac{L}{T} \qquad (5)$$

Thus, formula (4) is transformed to the following form:

$$T^2 = \frac{L^2 \cdot \rho \cdot d}{h \cdot E_0} \cdot E_0 e^{-a \cdot P} \qquad (6)$$

Taking the logarithm of the expression (6), the dependence of the arterial pressure on the PWPT can be obtained:

$$P = -\frac{2}{a} \ln T + \frac{1}{a} \ln \left(\frac{L^2 \cdot \rho \cdot d}{h \cdot E_0}\right) \qquad (7)$$

Formula (7) shows that while maintaining a constant elasticity of the vessel the changes in blood pressure are proportional to the changes in the PWPT which makes it possible to indirectly measure blood pressure by PWPT. Despite this, it is quite difficult to accurately determine the relationship between the PWPT and blood pressure as from practical studies it is known that age, sex and a number of other indicators significantly affect the state of the vessels and PWPT. Therefore, PWPT can be used more likely for assessing the dynamics of blood pressure and monitoring pressure changes. Nevertheless, the individual dependence of the PWPT on blood pressure could be established for each patient and after appropriate calibration using a usual blood pressure monitor it is possible to measure blood pressure [7], [8].

It is important to notice that the model has several assumptions that require further adjustment. The Moens-Korteweg equation have been obtained using simplified mechanical model that is insensitive to minor changes in the diameter of the vessels. Since such changes are not considered in the equation it becomes necessary to use correction factors. There is also a need to note the fact that the frequency of cardiac contractions (HR) affects the PWV as the vascular wall is from viscoelastic material. Deformation resistance of such a material increases with a rise of the rate of deformation which, in turn, growing together with heart rate. This circumstance matters when interpreting the dynamics of PWV under the effects that lead to a change in HR. At the same time, the research show that the relationship between HR and arterial pressure is not obvious as long records do not show any correlation between these quantities, while on the short records the correlation can take relatively large values (up to 0.5) but remains unpredictable since even the sign of the correlation coefficient may change. For a more detailed study of the interaction of blood pressure and PWPT remembering about the influence of the HR the appropriate model should be developed. The Otto Frank model have been chosen as the base for constructing corresponding model.

In the Frank model the full compliance of the arterial system is estimated from the PWV parameters. Because of that the application of this simulation method in the current study is enough appropriate. The hydrodynamic model of Frank allows to describe on physical level the processes of blood flow occurring in the circulatory system properly. Since the model have been developed primarily for qualitative assessment of hemodynamic parameters rather than quantitative, there are following assumptions accepted in it:

- All large vessels are combined in a tank with elastic walls and the volume proportional to the applied pressure; the hydraulic resistance of the tank is neglected.
- Peripheral system consisting of small vessels and capillaries and creating peripheral resistance is taken for a rigid tube with high resistance and elasticity close to zero. In fact, even small vessels have a certain level of elasticity and large arteries have a certain rigidity.
- The elasticity and the resistance of all parts of the system are constant and do not depend on time or spatial localization. The elasticity of the arteries walls is not a constant and can change under the influence of

both internal regulatory mechanisms and external factors.

- The aortic valve opening mechanism is considered as a "black box" controlled from the outside by the heart activity and its properties (including the resistance of the valve itself) are not taken into account in the calculations.

To construct a model of interaction between blood pressure and pulse wave velocity we have been moved on the Frank's model (Frank's Windkessel). The simplest two-element model consists of the resistance R which corresponds to the overall peripheral resistance of the arteries and the capacitance C which acts as an elastic tank. Models built on the electrical analogies are an effective way to analyze hemodynamic processes in the human body. In this case the well-known equations of the network analysis could be used. These equations are effective for calculating using modern circuit simulators that allow to visually represent solutions of systems of complex nonhomogeneous differential equations.

The result of solving the problems related to the analysis of the circulatory processes using equivalent electrical circuits could almost completely correspond to the real hemodynamic processes taking place in the human body in case of the adequacy of the used model and if initial and boundary conditions are chosen properly (based on the experimental data).

To analyze the processes occurring in the developed electrical model we used the Micro-Cap 10 circuit simulator, which is intended for analyzing and simulating processes in the electrical circuits. It provides representation of the solutions of nonhomogeneous differential equations in a convenient graphical form without applying additional calculations together with the regularity of the dynamics of the processes as well as allows to find necessary numerical characteristics.

Fig. 1 shows the schemes implementing the three-element Frank's Windkessel (WK) model: in the hemodynamic (Fig. 1a) and electrodynamic (Fig. 1b) representation. Besides, there is models consisting of two, four or more elements which are considered in detail in the work Westerhof N. at al (2009).

In these schemes the resistance R corresponds to the total peripheral resistance (T_{PR}) which is the sum of all individual resistances of different microcirculation sites, i.e, resistance of the whole vascular bed, wherein the main part of the resistance to flow in the arterial system is set by the smallest arteries and arterioles. Capacity C, in turn, is the total arterial compliance which depends mainly on the elasticity of large (conducting) arteries (the smaller the artery - the less its elasticity and the greater the resistance).

In the Windkessel model it is assumed that during diastole when the arterial valve is closed the pressure decreases exponentially with a time constant τ = RC. Thus, diastolic pressure in the aorta P_{DIA} with the closed valve could be described by a following exponential function:

$$P_{DIA}(t) = P_{SIS} \cdot e^{-\frac{t}{RC}} \quad (8)$$

where P_{SIS} is the maximal systolic pressure.

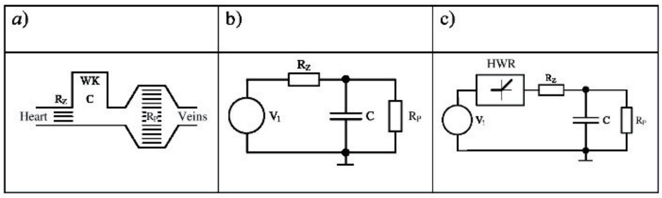

Fig. 1. Three-element WK model: a) hemodynamic, b) electrodynamic and c) improved electrodynamic

Fig. 2 shows the result of the simulation of the three-element WK model (curve 2) when applying to the input unipolar periodic pulses with a period of T = 1 s (curve 1). It is a typical reaction of a first-order dynamic integration unit where P is the pressure expressed in conventional units. In this case, I_{RZ} is the current passing through the resistance R_Z similar to the flow from the heart entering the artery (Fig. 2*b,* curve 2). This current has two flow paths: the direct one during a pulse simulating a systole and the reverse one during a pause imitating a diastole. Such a result is not true for the heart work because normally there is no any return flow to the left ventricle (LV), it should be absent. The presence of an I_{RP} current through the resistance I_{RP} cannot eliminate this contradiction (Fig.*2c,* curve 6).

This problem could be solved using an additional non-linear unit (Fig. 2*c*) simulating the operation of the LV valve of the heart and corresponding to the half-wave rectifier (HWR) described by the following function:

$$\begin{cases} (P - Pv) \leq 0, K = 0, \\ (P - Pv) \leq 0, K = 1. \end{cases} \quad (9)$$

where *Pv* is the value of the pressure at the input of the HWR unit, *P* – the value of the pressure at the output of the HWR unit, *K* - the transfer factor of the unit.

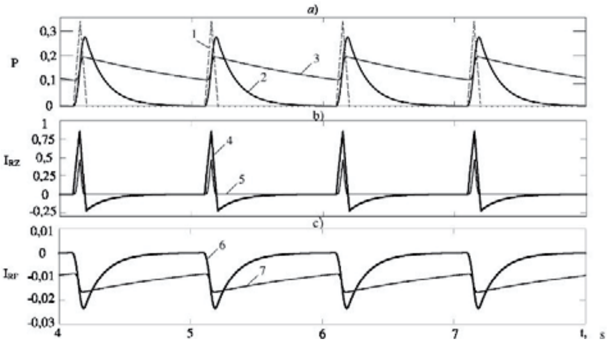

Fig. 2. The result of modeling using the three-element WK model

Fig. 2 shows the result of simulation of the circuit with HWR (curve 3) when unipolar periodic pulses with a period T = 1 s are on the input (curve 1). Thereby, the current passing through the resistance R_Z (Fig. 2*b*, curve 5) flows in only one direction, i.e, now it is absent during the pause simulating the diastole. Such a reaction is not typical for a linear dynamic unit. The current I_{RP} through the resistance R_P (Fig. 2*c*, curve 7) has an almost constant value. The use of HWR eliminated the possibility of discharging the capacitor C back to the signal source V_1 (i.e, in the heart). The resistance R_P provides the return flow to the heart and ensures current circulation only in one direction both during the systole (pulse) and during the diastole (pause).

Thus, the reactions of the original scheme (Fig. 2*b*) and the another one with HWR (Fig. 2*c*) with equal values of R_Z, R_P, C are significantly different. The main difference is in the rise and fall time of P (Fig. 2*a*). The HWR circuit provides a relatively constant level of P and a unidirectional flow.

The use of this model allows to investigate the simultaneous effect of changes in blood pressure P and quasiperiods of T_{RR} imitating heart rate on changes in pulse wave propagation time. As mentioned earlier there is a relationship between the pulse wave propagation time and the blood pressure and it is determined with equation (7):

$$P = -\frac{2}{a} lnT + \frac{1}{a}\ln\left(\frac{L^2 \cdot \rho \cdot d}{h \cdot E_0}\right)$$

where T is the pulse wave propagation time, E - the elastic modulus (Young's modulus) of the vessel wall; h - the thickness of the vessel wall, d - the internal diameter of the vessel, ρ - the blood density, L - the distance that the pulse wave passes (the effect of heart rate and T_{RR} is not taken into account).

While simulating it was considered that the modulus of elasticity E (the product of the values of R_P and C) is a constant during the experiment (this is really so for short periods). The input signal is a 10-second sequence of twelve almost periodic triangular pulses lasting 100 ms and in the first five seconds their duration decreases (from 939 ms to 541 ms) while in the second five ones it is increases (from 502 ms to 1113 ms).

There are two kinds of input pulses during simulation in this work:

1) Having gradually increasing amplitudes (the maximum increase by 1.2 times) in the first five seconds and then gradually decreasing ones (Fig. 3a).
2) Having gradually decreasing amplitudes (the maximum decrease by 0.8 times) in the first five seconds and then gradually increasing ones. (Fig. 3d).

Fig. 3 illustrates the results of the simulation for both kinds: the value of the PWPT corresponding to the values of P (b, c) and T_{RR} (e, f).

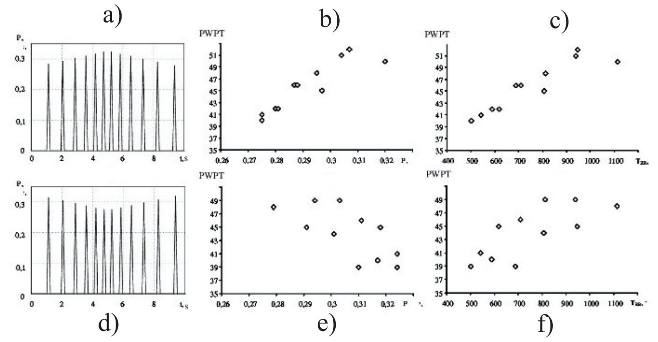

Fig. 3. The effect of changes in blood pressure and quasiperiods T_{RR} imitating heart rate on changes in PWPT

Increased blood pressure causes the elastic walls of blood vessels to stretch which triggers increased generation rates of the action potentials by arterial baroreceptors. Furthermore, baroreceptors can respond to changes in both the average blood pressure and the rate of change in pressure with each arterial pulse. We can conclude, that there exists a strong dependency between BP, PWPT and heart rate, but it's very hard to provide a clear equation, which allows connecting them together. So, measuring of BP with indirect methods can be realized only with appropriate calibration and poor accuracy.

V. Experiments with postural (orthostatic/antiorthostatic) stress tests

To perform some experiments to check correlation between BP and PWTT we need to change BP level in sufficiently wide range. For these purpose we can use some BP changing medicines under the strict supervision of a doctor, but it's not the best solution obtaining reliable results. Also there is known that special consistent orientation of the patient's body can form certain reaction of the cardiovascular system, leading to the changes in main parameters like heart rate, stroke volume and blood pressure. The effect of such action can be enhanced by purposeful changes in body position, determined by a certain sequence of manual treatment and rules of procedures. These requirements are realized in the developed computerized system for the dynamic orientation of the human body [9]. The system includes a special mechanical table with means for distal fixation of the patient's body to provide movements of a person at different speeds along three orthogonal axes, and a hardware-software complex for recording and displaying in real time an electrocardiogram, rhythmogram and the patient's movement in three-dimensional space (Fig. 4).

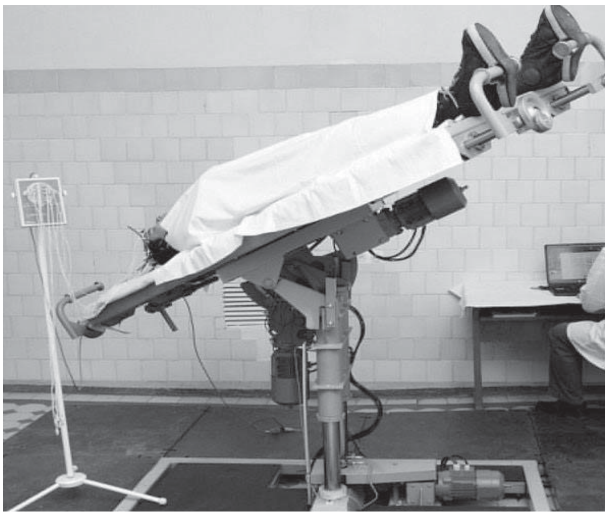

Fig. 4. Computerized system for the dynamic orientation of the human body. Antiorthostatic stress test

This system provides dynamic change of patient position at different speeds and at different angles (with respect to gravity vector). Platform of the patient can be controlled by a special program depending on nosology and rate of the violations; recording and analysis of the patient cardiovascular system functional state is conducted at the same time. The study assessed changes in blood pressure, heart rate and stroke volume in healthy subjects during their orientation in accordance with different movement protocols: from horizontal to vertical and back. The set of biological parameters are recorded simultaneously: ECG from patient's chest, Pulse wave from wrist, continuous blood pressure by Penaz method. Postural effects caused obvious changes in heart rate and blood pressure: transition in antiorthostasis position caused, as a rule, increase of the average heart rate and blood pressure, and decrease of stroke volume, and orthostasis – decrease of average heart rate and blood pressure, and increase of stroke volume. It should be noted that the current changes of beat-to-beat blood pressure values during the patient movement have complex nature.

The data recorded during the test are processed in the MatLab software according to the developed algorithms for indirect evaluation of blood pressure using the pulse wave propagation time: firstly, the characteristic points of the electrocardiogram and pulse wave are calculated; then, time delay between the R-wave and the minimum of the pulse wave are found (Fig.5). A standard blood pressure monitor is used for measuring the systolic pressure values which are used to calculate the elasticity of the vessel walls. Then, the pressure curve was plotted using the obtained PWPT values.

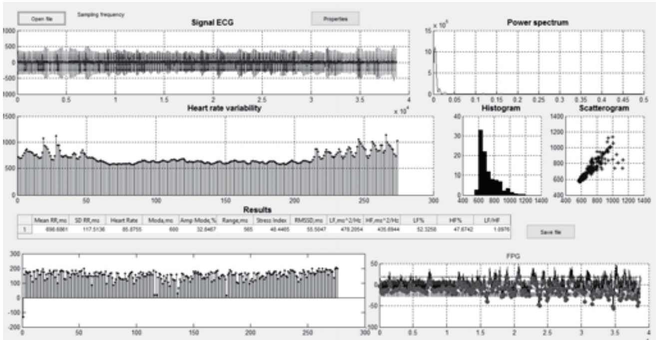

Fig. 5. Processing of obtained data in the MatLab software

To assess the interdependence of pressure calculated from the PWPT and pressure obtained by the Penaz method data from postural samples from fifteen subjects aged 20 to 50 years have been used. The average value of the absolute error is not exceed 15 mmHg, the relative one - is 9%. Approximately one-third of the subjects have an average absolute error of 1 mmHg. The maximum variance of the absolute error did not exceed 45 mmHg. On Fig. 6, results of one probe are presented: solid line is blood pressure calculated from PWPT, dashed line – continuous blood pressure from device, based on Penaz method. The correlation coefficient reaches 0.6 with sufficient averaging of the parameters (lower figure).

VI. Conclusion

Many researchers in their studies focus on the indirect BP measurement from pulse wave transit time as the replacement of standard cuff BP monitors, which is essentially usless, since without the periodic calibration, the accuracy of such systems will be extremely low. The basis of most of the proposed algorithms for estimating blood pressure by PWTT are the regression dependences between these two parameters. This assumes the linear nature of the relationship between BP and GRP. According to the developed model and obtained experimental data, this conclusion is incorrect - the form of this dependence is far away from linear, and is described by more complicated formulas (nonlinear dependences with variable coefficients, individual for each person). At the same time, BP estimation algorithms in most of the works use formulas averaged over different samples of the measured indicators (the coefficients are the same for the entire sample, and not individually calculated for each person). Some researchers suggest a quasilinear character of the dependence at low pressures and exponential at elevated pressures, which makes the algorithm extremely difficult to implement and requires considerable computational resources. As a result, we can conclude that the only way to apply an indirect evaluation of blood pressure is continuous monitoring of blood pressure, which makes it possible to register (with due averaging of the obtained data) changes over long periods of time with less accuracy than standard BP monitors.

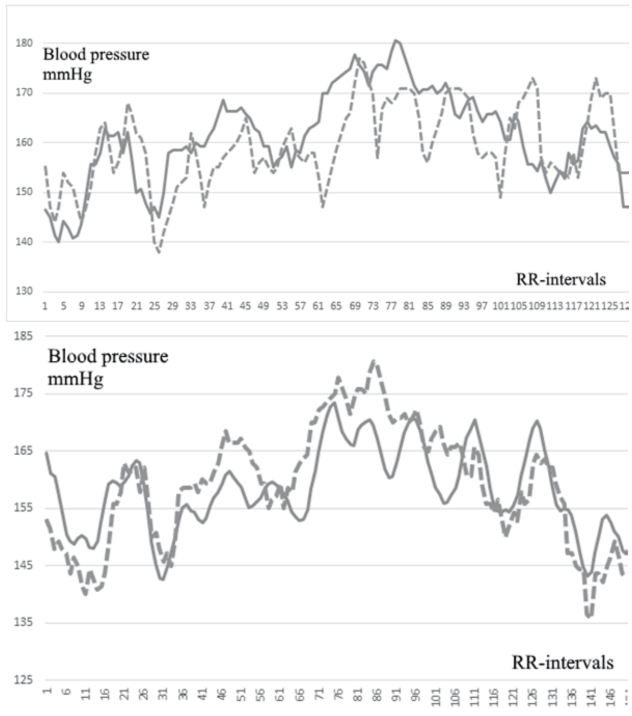

Fig. 6. Comparison of two blood pressure graphs: Penaz and indirect methods

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