Comparative analysis of the blood circulation of the index finger and second toe in middle-aged people in the dynamics of a pharmacological test with nitroglycerin

I.B. Isupov[2], R.Sh. Zatrudina[1], R.A. Kudrin[2], V.Yu. Gribkov[1]

1 Volgograd State University, Russia
2 Volgograd State Medical University, Russia

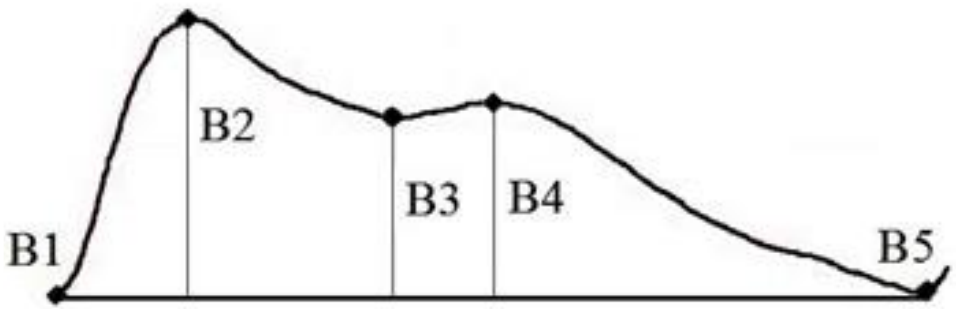
The relevance of the work is determined

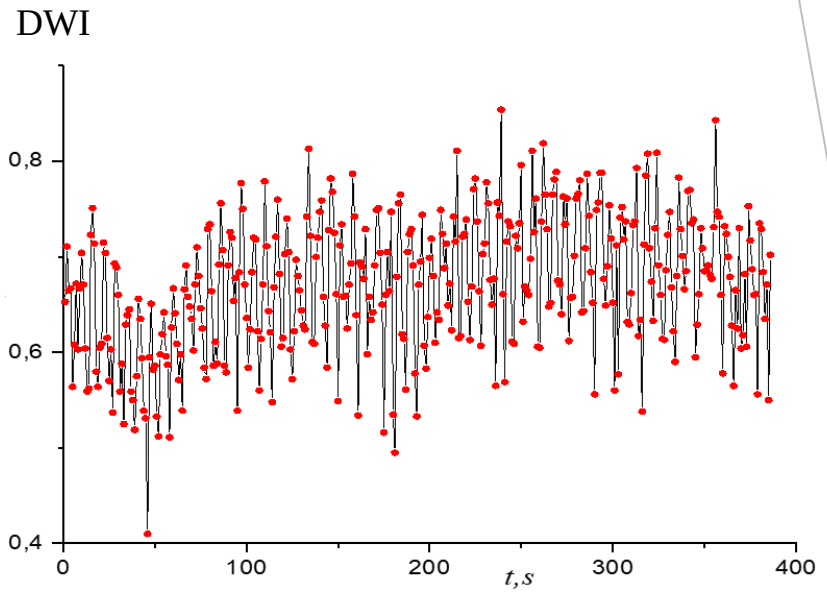
- The main aspect of the use of the nitroglycerin test is the differential diagnosis of functional and morphological changes in the elasticity and tone of the walls of blood vessels of various diameters. Nitroglycerin primarily reduces the tone of venous vessels. Along with a pronounced venodilating effect, it also significantly reduces the tone of small arteries and arterioles, being a non-selective vasodilator.

- It is unclear how different the effect of the drug on the blood circulation of the fingers of the upper and lower extremities is, taking into account the fact that in the same subject the tone of the arteries and arterioles of the upper extremities can be significantly higher than the tone of similar vessels in the foot region.

- It has not been studied to what extent nitroglycerin changes the effectiveness of endothelium-dependent mechanisms for optimizing regional blood flow, which are caused by periodic changes in the activity of parasympathetic centers for the autonomic regulation of systemic hemodynamics, in vessels with increased and decreased initial tone..

Photoplethysmographic indicators





dicrotic wave index $DWI = \frac{B_3}{B_2}$ characterizes the tone of small arteries

$$X_k = \sum_{n=0}^{N-1} x_n\left(\cos(2\pi kn/N) - i * sin(2\pi kn/N)\right)$$

$$Z_k = \sqrt{\left(Re(X_k)\right)^2 + \left(Im(X_k)\right)^2}$$

Materials and research methods

These studies present the results of the analysis of photoplethysmograms (PPG) of the vascular regions of the index finger and second toe of practically healthy middle-aged individuals in the dynamics of a drug test with nitroglycerin. The duration of continuous recording of photoplethysmograms was 5 minutes. Photoplethysmograms were recorded before taking the drug, as well as on the 2-7th, 9-14th, 15-20th, 22-27th, 30-35th, 40-45th, 50th 55th, 57-62nd minutes after sublingual administration of 0.5 mg of the drug "Nitrocor".

Designations for the registration time of photoplethysmograms are presented in the table

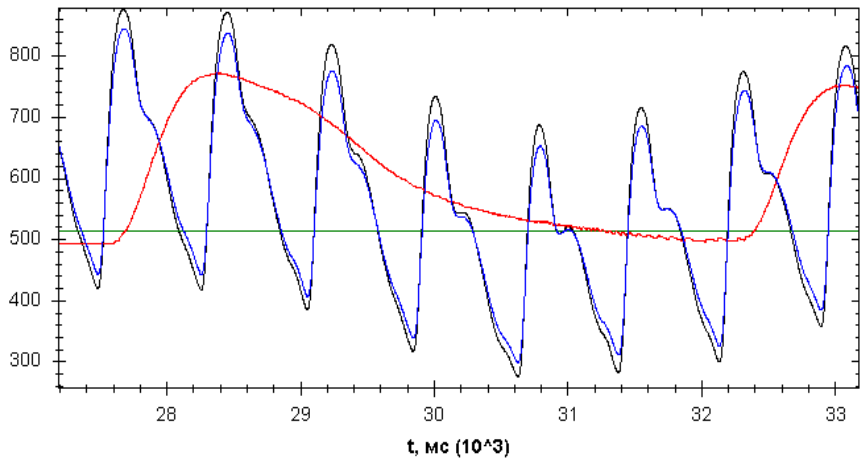
Designation	N0	N1	N2	N3	N4	N5	N6	N7	N8
PPG registration time	Before taking nitroglycerin	2-7 minutes after administration	9-14 minutes after administration	15-20 minutes after administration	22-27 minutes after administration	30-35 minutes after administration	40-45 minutes after administration	50-55 minutes after administration	57-62 minutes after administration

Photoplethysmography of both vascular areas was carried out with a controlled respiratory rate of the subjects. For objective monitoring of respiratory rate, expiratory spirograms were recorded simultaneously with PPG. In middle-aged people, the PPG indicator that most adequately reflects the effect of taking nitroglycerin on the tone of small arteries in the hand and foot regions is the dicrotic wave index (DWI PPG).

From the photoplethysmograms, the dicrotic wave index PPG (DWI PPG) of the index finger and second toe was calculated. The values of the DWI PPG were subjected to contour (stage I), variation-statistical (stage II) and spectral (stage III) analysis. In the process of variational-statistical analysis, the mode (Mo DWI), arithmetic mean, and variation range of the DWI PPG were determined. In the process of spectral analysis, the amplitude of respiratory harmonic and the relative power of spectrum in the low-frequency range of the DWI PPG spectrum was calculated.

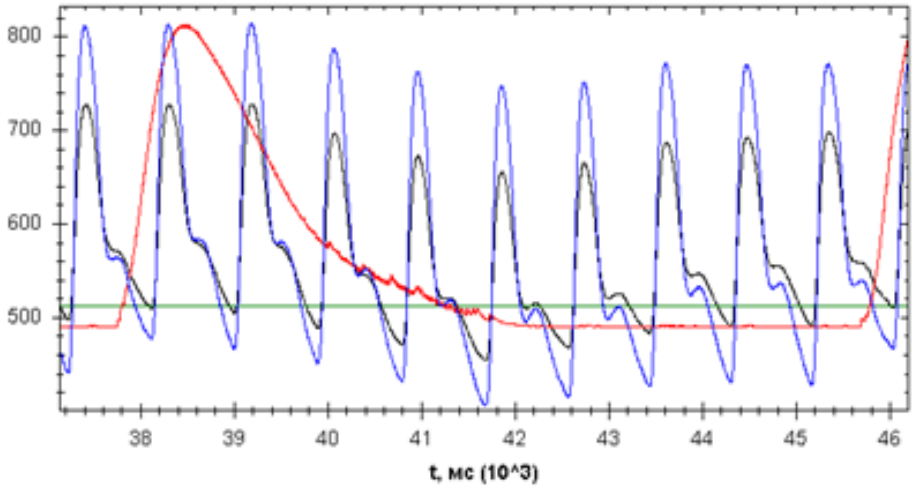
Typical contour of pulse curves

finger PPG



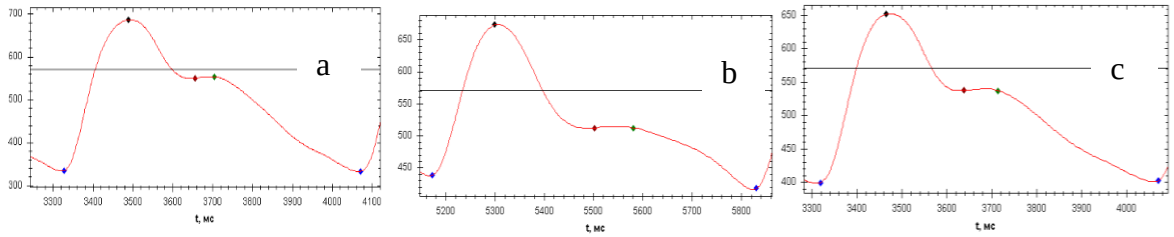
PPG of the index finger of the hand before taking nitroglycerin

toe PPG



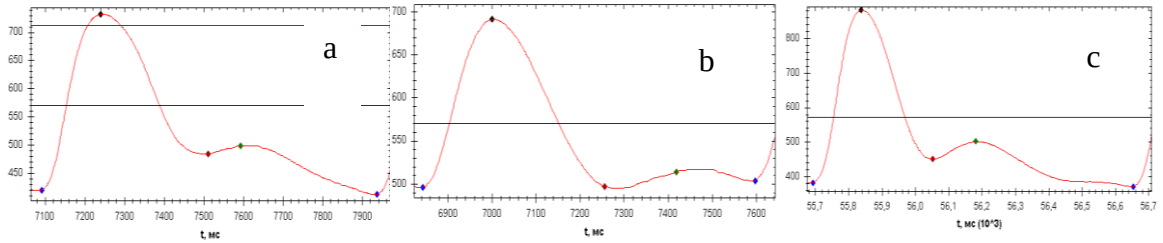
PPG of the second toe before taking nitroglycerin

Contour analysis of PPG



PPG of the index finger of the hand: before taking nitroglycerin (a); 2-7 minutes after taking nitroglycerin (b); at 57-62 minutes after taking nitroglycerin (c)

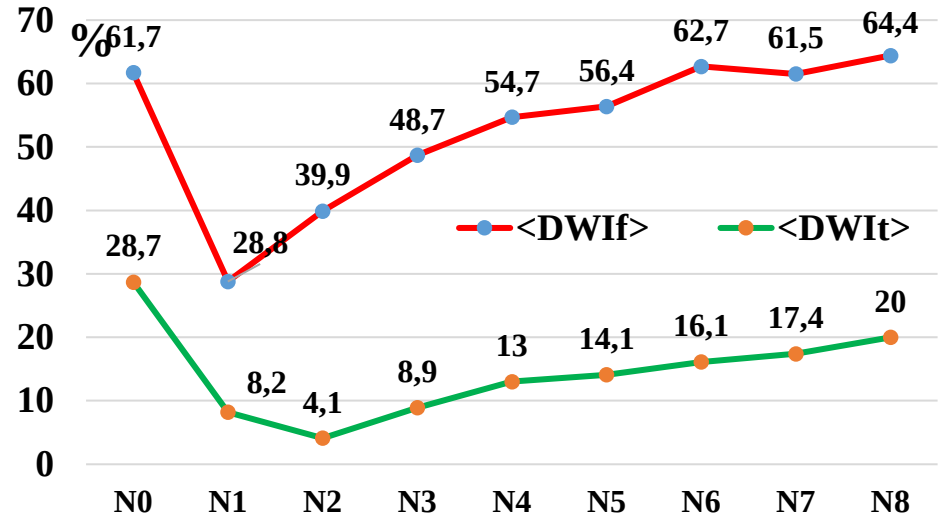
The incisura of the PPG of the index finger of the hand before taking nitroglycerin (a) is located closer to the top of the PPG - the tone of the resistive arteries is high, the PPG has a hypertonic appearance; within 2-5 minutes after taking the drug, the incisura shifts to the base of the PPG - the tone of the resistive arteries decreases (b); by the end of the first hour after taking nitroglycerin, the position of the incisura is restored - the tone of the small arteries returns to the original level (c).

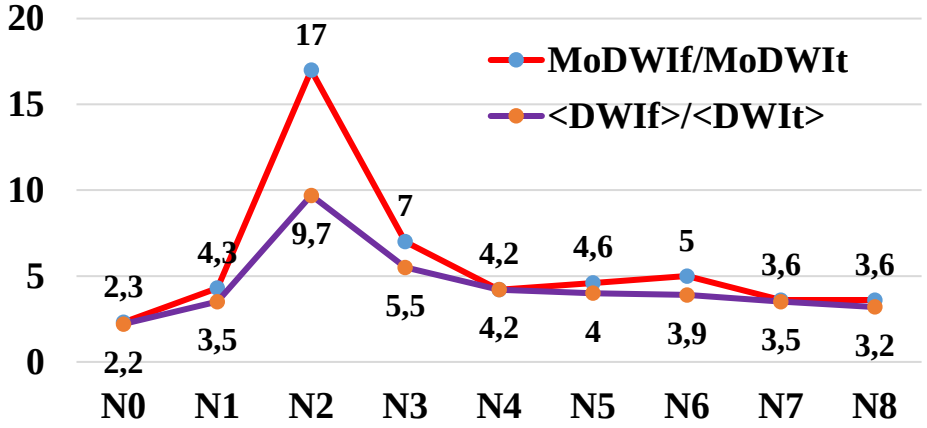


PPG of the second toe: before taking nitroglycerin (a); 2-7 minutes after taking nitroglycerin (b); at 57-62 minutes after taking nitroglycerin (c)

The incisura of the PPG of the second toe before taking nitroglycerin is located closer to the base of the curve (lower) than the incisura of the PPG of the index finger - before taking nitroglycerin, the tone of the resistive arteries of the toe is lower than the tone of the arteries of the hand, the PPG has a hypotonic appearance (a); within 2-14 minutes after taking the drug, the incisura shifts even more to the base of the PPG - the tone of the resistive arteries of the foot decreases significantly, the PPG takes on an atonic appearance (b); by the end of the first hour after taking nitroglycerin, the position of the incisura is restored - the tone of the small arteries of the foot returns to the original level (c).

Dynamics of DWI in the nitroglycerin test





The vasodilating effects of nitroglycerin are very significant in the regions of both the hand and foot, regardless of the initial tone of the resistive arteries. Maximum dilation of the resistive arteries after taking nitroglycerin is observed at 2-7 minutes for the index finger and at 9-14 minutes for the second toe.The drug-induced decrease in the tone of the arteries of the second toe is more significant than the decrease in the tone of the toe. When taking nitroglycerin, severe hypotension (DWI < 30%) and atony (DWI < 10%) of the resistive vessels of the foot occur. After 10-14 minutes of the test, the tone of the small-diameter arteries of both regions begins to increase and is gradually restored by the end of the first hour after taking nitroglycerin.

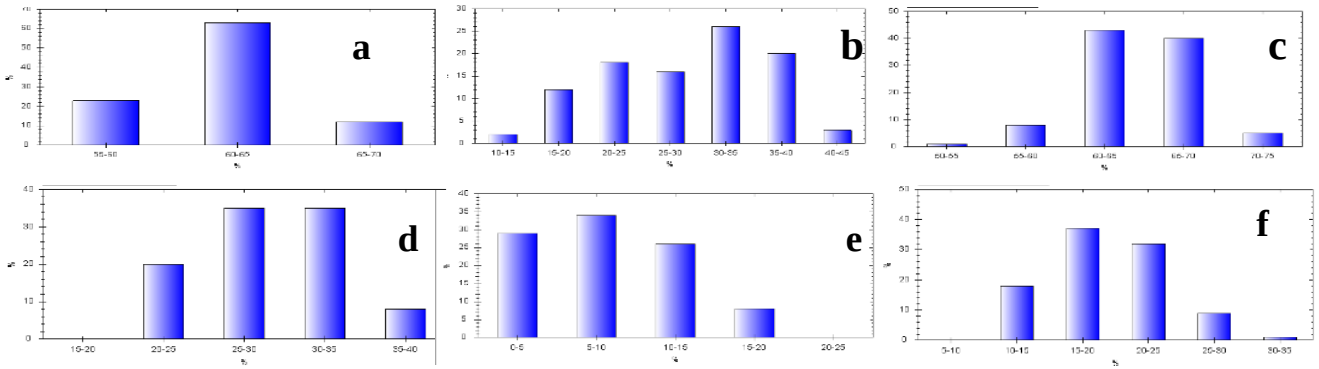
For a comparative assessment of the dynamics of the tone of the resistive arteries of the upper and lower extremities during a pharmacological test, a comparison coefficient of the tone of the arteries of the extremities was introduced as the ratio of the average RDV values on photoplethysmograms of the finger and toe (<DWIf>/<DWIt>). This coefficient is 2.0 – 2.5 before taking the drug; it increases significantly at 2-7 minutes after taking nitroglycerin and gradually decreases, approaching the initial level, at 30-35 minutes after taking it.The increase in the coefficient while taking nitroglycerin is mainly due to the fact that the decrease in the tone of the arteries of the foot is much more pronounced than the decrease in the tone of the arteries of the hand.

Variation-statistical analysis of DWI

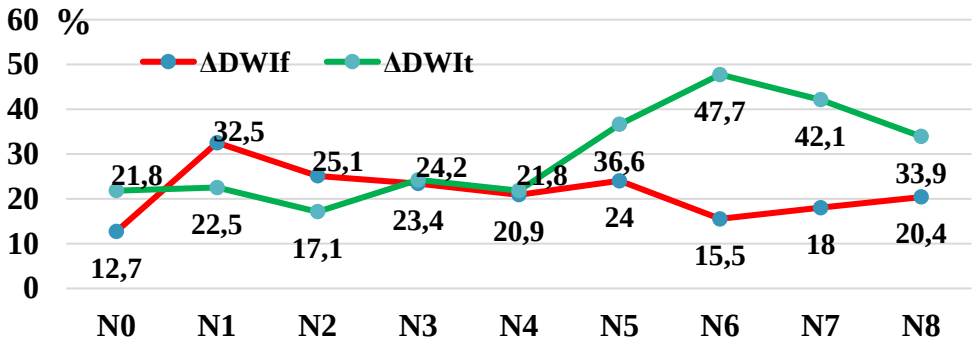
Distribution of DWI

finger

toe



The variation range of the DWI values is proportional to the effectiveness of any tone regulation mechanisms. The variation range of the DWI for the index finger of the hand before taking nitroglycerin is insignificant (a); at 2-7 minutes after taking nitroglycerin, the variation range of the DWI values increases significantly (b), therefore, the increased arterial tone before taking the drug decreases, the elasticity of the vascular walls increases; by the end of the first hour after taking nitroglycerin, arterial tone increases, and the variation range of the DWI approaches the initial values, remaining slightly increased compared to the initial level (c). The variation range of the DWI of the second toe before nitroglycerin administration is insignificant (d); however, despite the decrease in arterial tone 2-7 minutes after taking the drug, the variation range of the DWI does not increase (b) - the tone of the vessels of the foot is low, respectively, the elasticity of the walls of the arteries of the foot before and after taking the drug is equally high (e); by the end of the first hour after taking nitroglycerin, the variation range of the DWI PPG of the foot increases noticeably compared to the initial values (f).



Variation range of IDV PPG of the index finger and IDV PPG of the second toe in the dynamics of the test with nitroglycerin

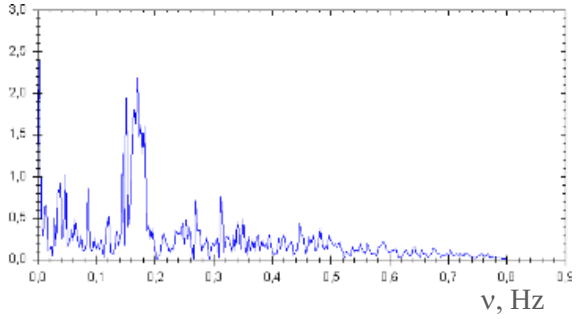
The variation range of the DWI PPG of the index finger in the initial state is insignificant (no more than 12-15%). It increases significantly (up to 30-35%) 2-7 minutes after taking nitroglycerin and gradually returns to the original level by 30-35 minutes after taking the drug. The increase in the variation range of the DWI PPG of the index finger is due to an increase in the elasticity of the walls of the resistive arteries of the hand while taking nitroglycerin. The variation range of the DWI PPG of the second toe in the initial state is slightly higher than the similar parameter of the DWI PPG of the index finger. The dynamics of the range of DWI PPG of the second toe, observed during the first 30 minutes after taking nitroglycerin, is insignificant. After the 30th minute of the test, the variation range of the DWI PPG values of the toe increases noticeably. Apparently, this is due to the restoration of the normal tone of the small vessels of the foot after previous drug-induced atony and, accordingly, a significant increase in the sensitivity of the resistive arteries of the foot to parasympathetic regulatory influences.

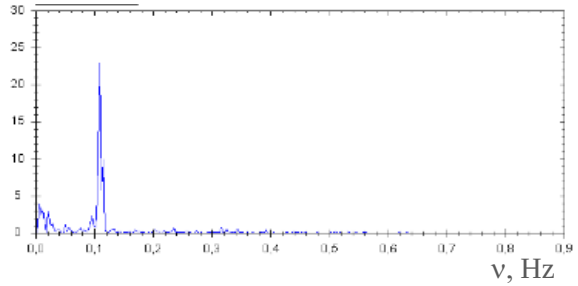
Spectral analysis of DWI PPG

Spectra DWIf PPG of the index finger and DWIt PPG of the second toe

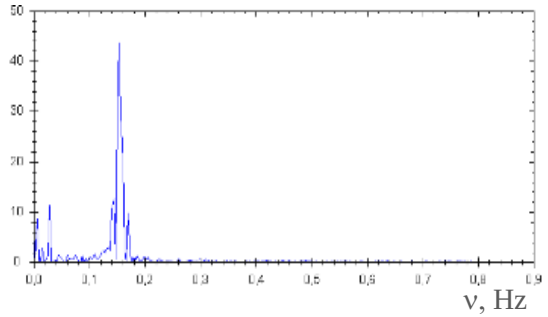
finger

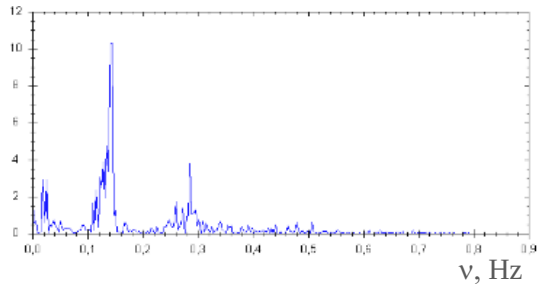
toe



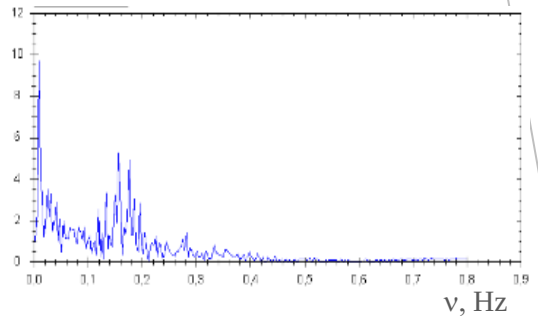


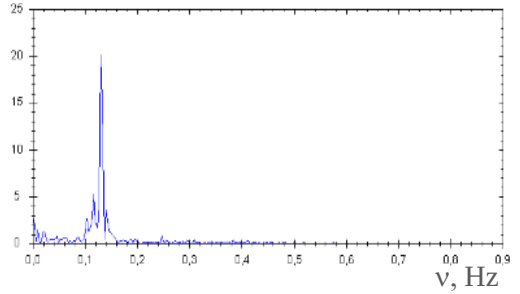
before taking nitroglycerin





2-7 minutes after taking nitroglycerin



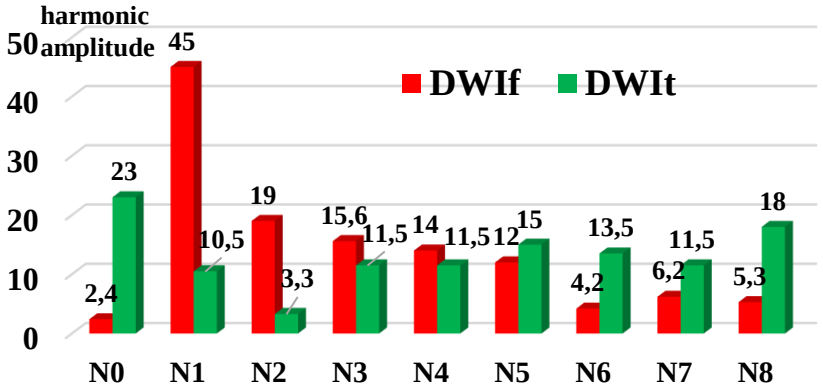


57-62 minutes after taking nitroglycerin

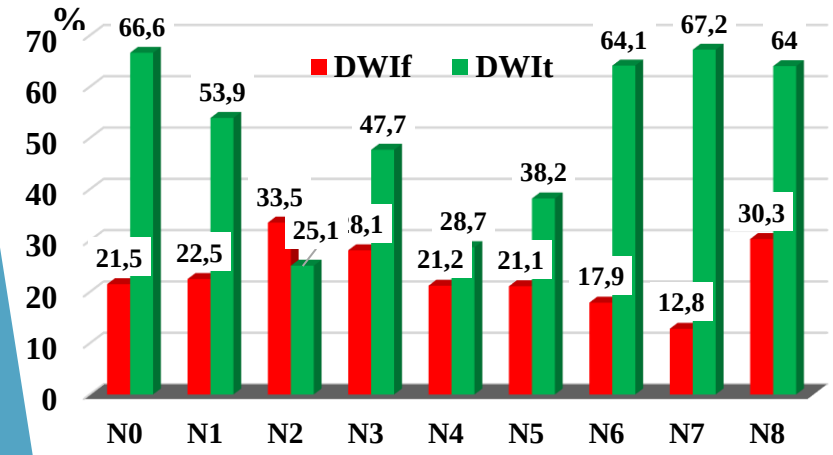
In the initial state, the amplitude of the respiratory harmonic (0.15 Hz) in the DWI PPG spectrum of the index finger is insignificant. Its amplitude increases significantly by 2-7 minutes after taking nitroglycerin and gradually decreases by 30-35 minutes after taking nitroglycerin. In the DWI spectrum of the second toe, the amplitude of the respiratory harmonic in the initial state is significantly higher than in the DWI spectrum of the PPG of the toe. Taking the drug causes a decrease in the amplitude of this harmonic by 2-7 minutes of the pharmacological test and a gradual return of its values to the initial level at 30-35 minutes after taking the drug.

Spectral analysis of DWI PPG

Amplitude of respiratory harmonics in the DWI PPG spectrum of the index finger and second toe in the dynamics of the test with nitroglycerin



Relative spectrum power in the low frequency range



Before taking nitroglycerin, the tone of the arteries of the hand was increased, which indicated an autonomic imbalance - the predominance of sympathetic influences on the blood flow of the upper extremities. Due to drug-induced normalization of the tone of the resistive arteries of the index finger of the hand, the amplitude of the respiratory harmonics in the DWI PPG spectrum of the upper extremity region increases significantly while taking the drug. This increase in respiratory harmonics indicates an increase in parasympathetic influences on vascular tone in the upper extremities.

Before taking nitroglycerin, the tone of the arteries of the foot is reduced. Accordingly, the amplitude of the respiratory harmonic in the DWI PPG spectrum of the second toe in the initial state is significantly higher than in the DWI PPG spectrum of the toe. Taking the drug causes a decrease in the amplitude of this harmonic by 9-14 minutes of the pharmacological test and a gradual return of its values to the initial level at 30-35 minutes of the test. The decrease in the amplitude of this harmonic is due to the fact that with drug-induced hypotension and vascular atony of the lower extremities, the influence of autonomic, mainly parasympathetic, regulatory mechanisms on the tone of the resistive arteries of this region is reduced.

In the initial state, the relative power of the LF* spectrum in the low-frequency range of the DWI PPG spectrum of the second finger of the hand is significantly lower than for the DWI PPG spectrum of the toe. However, after taking the drug, the relative power of the LF spectrum in the DWI PPG spectrum of the toe decreases significantly at 9-14 minutes, and increases by 30-35 minutes, while the relative power of the LF spectrum DWI PPG of the toe in the dynamics of the pharmacological test changes less significant: tends to increase 2-7 minutes after taking the drug and then gradually decreases.It is traditionally believed that low-frequency fluctuations in arterial tone are caused primarily by sympathetic influences on the cardiovascular system. However, the direction of changes in low-frequency oscillations in the dynamics of the test with nitroglycerin is similar to the direction of changes in the respiratory (parasympathetic) harmonics. Apparently, this is due to the fact that the breathing frequency of the subject during the test was in the range of 0.12 – 16 Hz - on the border with the high-frequency range* (0.15 – 0.4 Hz). This fact was confirmed by analysis of spirography results. Consequently, in this case, with the subject breathing infrequently, the relative power of the spectrum in the low-frequency range reflects predominantly parasympathetic influences on regional vascular tone.

* Баевский М.Р. и др. // Вестник аритмологии, 2001, Т. 24, с. 65-87.

Conclusion

- The initial value of the tone of small arteries is a factor influencing the formation of its respiratory period in the dynamics of a pharmacological test with short-acting nitrates:

- - if the initial tone of the resistive arteries is high (region of the upper extremities), nitroglycerin vasodilation contributes to an increase in the variation range of the PPG dicrotic wave index of the index finger and an increase in the amplitude of the respiratory harmonic in its spectrum. Nitroglycerin eliminates the autonomic imbalance existing before taking the drug, increases the elasticity of the walls of the resistive arteries of the hand and enhances parasympathetic endothelium-dependent effects on vascular tone in this region;

- - if the initial tone of the resistive arteries is low (region of the foot), then pronounced dilatation of small-diameter vessels while taking nitroglycerin helps to reduce the amplitude of the respiratory harmonic in the spectrum of the tone of the resistive arteries; in this case, the variation range of the dicrotic wave index of the PPG of the toe changes insignificantly. These phenomena are explained by the fact that nitroglycerin causes significant hypotension, atony, and paresis of resistive vessels of the lower extremities. In this regard, the physiological (mainly parasympathetic) regulatory influences on the tone of small-diameter vessels are significantly weakened for some time.

- According to the results of the spectral analysis of the DWI PPG of the studied vascular regions, it can be assumed that nitroglycerin also helps to reduce the effectiveness of local, myogenic mechanisms of blood circulation regulation, mainly under conditions of initial hypotension of the vascular wall. Apparently, this effect of the drug is due to the fact that, due to pronounced drug relaxation of the smooth muscle cells of the walls of resistive vessels that have low tone, the effectiveness of the indirect venous-arterial influence of the suction action of the chest cavity during the respiratory cycle on arterial blood flow is temporarily weakened or eliminated.