Photoplethysmographic study of age-related dynamics of peripheral circulation

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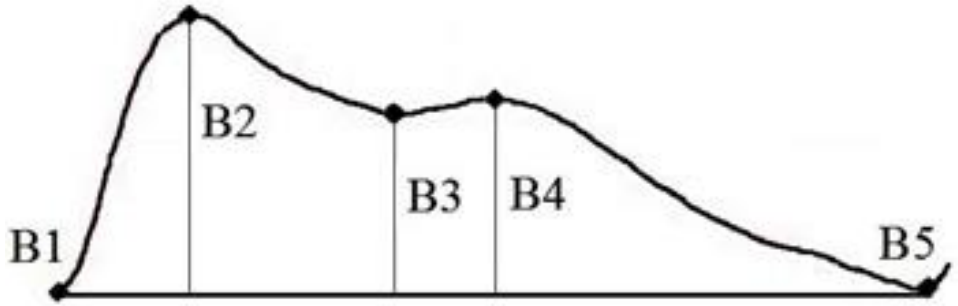
The relevance of the work is determined

- Regulation of peripheral blood circulation in humans is carried out as a result of a complex interaction of neurogenic, myogenic and metabolic mechanisms. These mechanisms provide continuous changes in the tone of small-diameter resistive arteries over a wide range at rest and during adaptation to various life conditions..
- Young people are often diagnosed with functional disorders of regional blood flow caused by neurocirculatory dystonia. In the process of natural aging of a person, not only functional but also morphological changes in the vascular bed naturally occur..
- High variability of the tone of regional resistive arteries in young people and age-related changes in the morphology of the vascular wall significantly complicate the interpretation of the results of functional diagnostic studies of peripheral circulation..
- In this regard, a thorough analysis of the range of changes in the parameters of the tone of resistive arteries is necessary depending on individual characteristics associated with the balance of the parasympathetic and sympathetic divisions of the autonomic nervous system and age-related changes in the regulation of the human cardiovascular system. This will allow us to specify the standards for photoplethysmographic indices of the functional state of the peripheral arterial bed.
- The present studies are devoted to a comprehensive analysis of the variability of the indices of finger photoplethysmography of the index finger of young people, middle-aged people and old people in order to specify and correct individual and age-related standards for photoplethysmograms.

Photoplethysmographic indicators



dicrotic wave index $DWI = \frac{B_3}{B_2}$

The PPG indicator characterizing the tone of the resistive arteries of the hand region is the dicrotic wave index - DWI PPG.

The dicrotic wave index of PPG of the index finger was calculated from photoplethysmograms. DWI PPG of the index finger mainly characterizes the tone of small arteries and arterioles of the limbs.

MATERIALS AND RESEARCH METHODS

The results of the analysis of photoplethysmograms (PPG) of the vascular region of the index finger of practically healthy individuals of three age groups are presented:

1. Young age (20.5±1.3 years, n=10).
2. Middle age (55.7±1.8 years, n=10).
3. Old age (85.2±1.1 years, n=5).

Conditions for recording PPG:

1. Free, involuntary breathing of subjects.
2. Voluntary (controlled) breathing with a frequency of 0.1 Hz.

For objective monitoring of the respiratory rate, expiratory spirograms were recorded simultaneously with PPG.

The duration of continuous PPG recording was 5 minutes (300 sec).

The DWI PPG values were subjected to the following types of analysis:

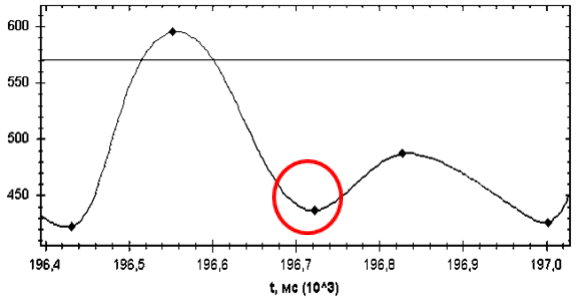
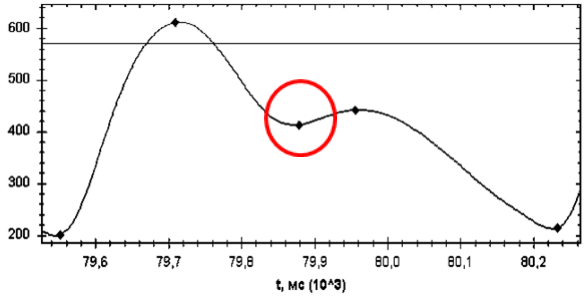
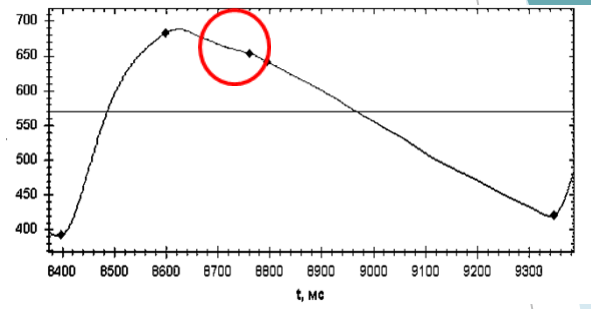
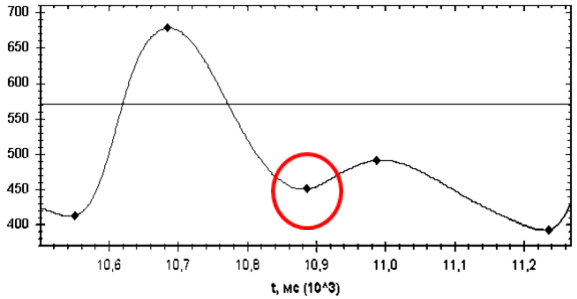
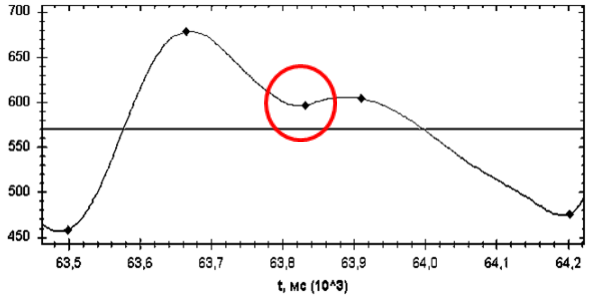
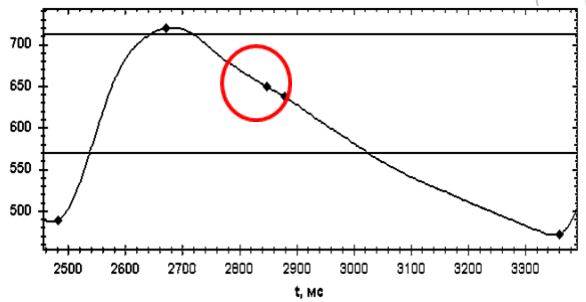
1. Contour analysis. Contour analysis is necessary for a qualitative, visual assessment of the position of the incisura and diastolic wave on the pulse curve.

2. Variational-statistical - the mode (Mo DWI), arithmetic mean (DWIam), variation range (VR DWI) of PPG were determined.

3. Spectral - the amplitude of the respiratory (parasympathetic) HF, low-frequency (sympathetic) LF and very low-frequency harmonics (VLF) were calculated.

Contour analysis of PPG

Typical contour of pulse curves in young people

	Hypotonic type	Normotonic type	Hypertonic type
involuntary breathing			
voluntary breathing			

The dicrotic notch is highlighted by a circle

In the hypotonic type, under conditions of involuntary breathing, the incisura on the index finger PPG is located at the base of the anacrota. In the hypertonic type, the incisura is shifted to the top of the anacrota. The incisura of the PPG in the normotonic type is in the middle of the anacrota height.During voluntary breathing, the location of the incisura does not change.A low location of the incisura in the hypotonic type indicates a decreased tone of the resistive arteries of the index finger; a high location of the incisura in the hypertonic type indicates an increased tone of the resistive arteries. These signs are stable, since they do not change at different respiratory rates and its control by the subject (involuntary and voluntary).

Contour analysis of PPG

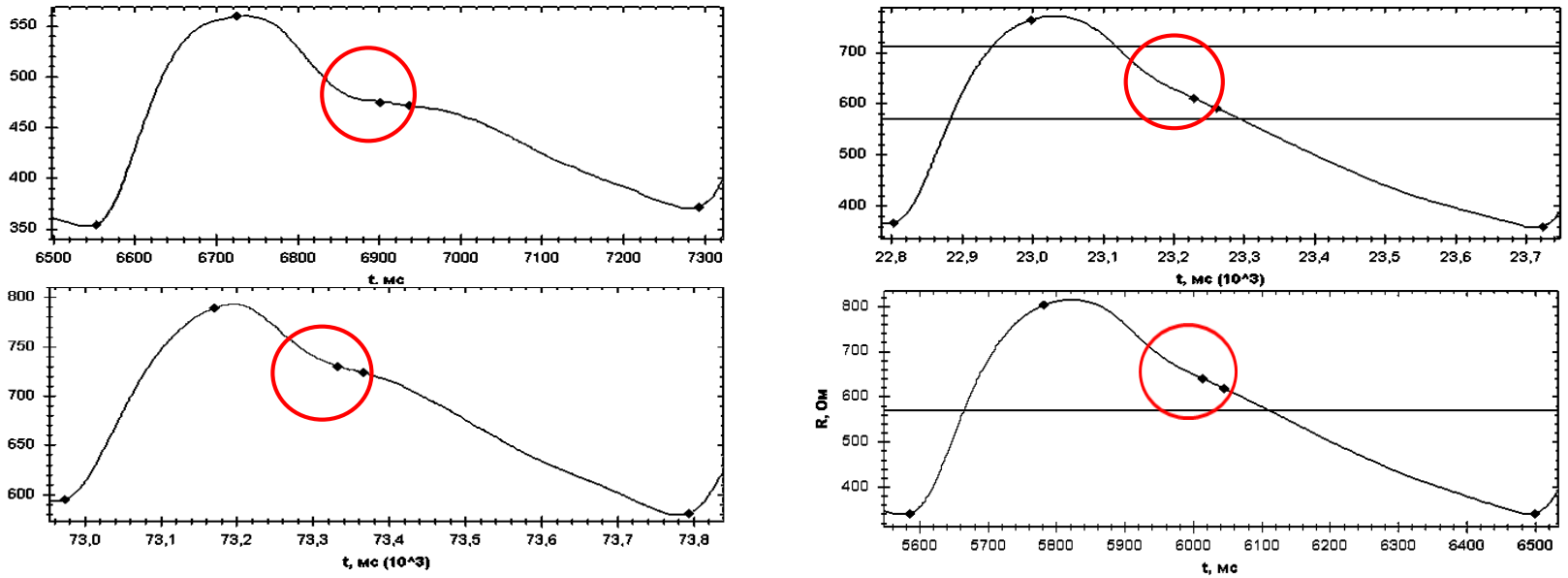
Typical pulse contour in middle-aged and old-aged people

Middle age

Old age

involuntary breathing

voluntary breathing



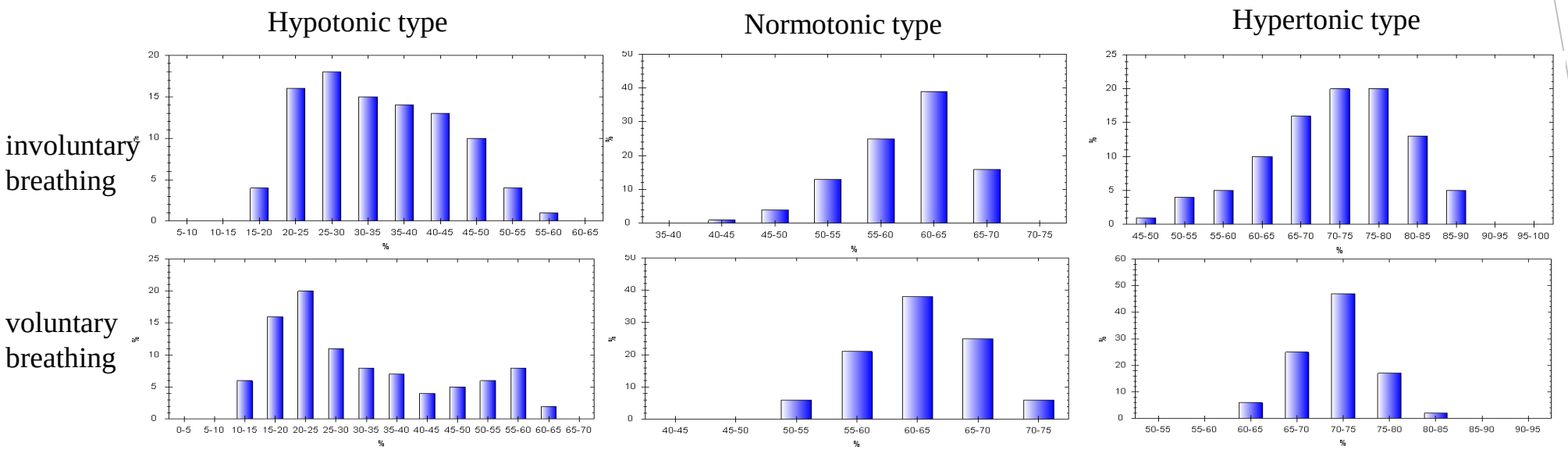
The dicrotic notch is highlighted by a circle.

In middle-aged and elderly subjects, during involuntary breathing, the dicrotic notch on the index finger PPG is located closer to the anacrotic apex. There is no diastolic wave. These signs of PPG are preserved during controlled breathing of the subjects. Hypotonic and normotonic types of PPG, which are found in young subjects, were not found in middle-aged and elderly subjects.

The high location of the dicrotic notch in middle-aged and elderly people indicates an increased tone of the resistive arteries of the index finger. The absence of a diastolic wave is a sign of morphological changes in the vascular wall (decreased elasticity). These signs are not accidental, since they do not change at different respiratory rates and control of the respiratory rate of the subject.

Variation-statistical analysis of DWI PPG in young people

DWI PPG distribution of index finger



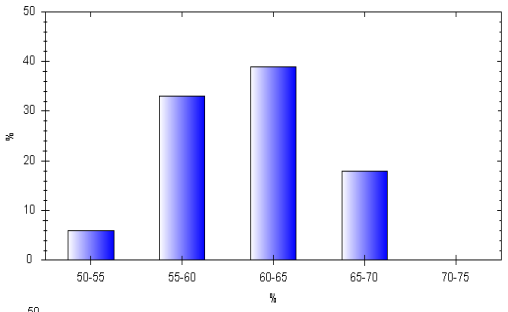
With involuntary breathing, the average and modal values of DWI PPG of the index finger of young individuals with the hypotonic type are 25-35%, which is at the lower limit of the norm. In the hypertonic type, the average and modal values of DWI PPG are 65-75%, which is the upper limit of the norm. With voluntary breathing, the average and modal values of DWI do not change in all types. However, in the hypotonic type, DWI has a significant variation range (45-55%) with natural breathing. The variation range of DWI increases with controlled breathing. In the hypertonic type, the variation range of DWI with involuntary breathing is 55-60%, but with voluntary breathing, on the contrary, it decreases significantly (to 25-30%). The hypotonic type is characterized by the greatest range of changes in the tone of the resistance arteries with different types of breathing. This may be due to the predominance of indirect parasympathetic influences on regional blood flow over sympathetic influences. The range of regulation of regional arterial tone in the hypertensive type is large, but it is significantly reduced during controlled breathing, probably due to increased activity of the sympathetic division of the autonomic nervous system.

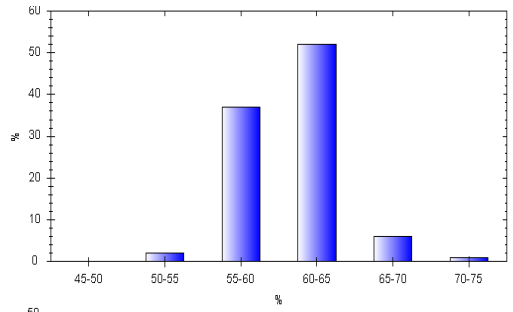
Variation-statistical analysis of DWI PPG in middle-aged and old-aged people

DWI PPG distribution of index finger

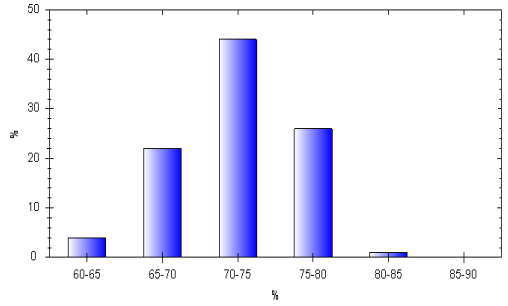
middle-age | old-aged

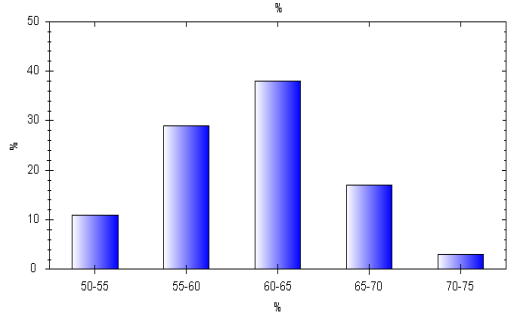
involuntary breathing





voluntary breathing

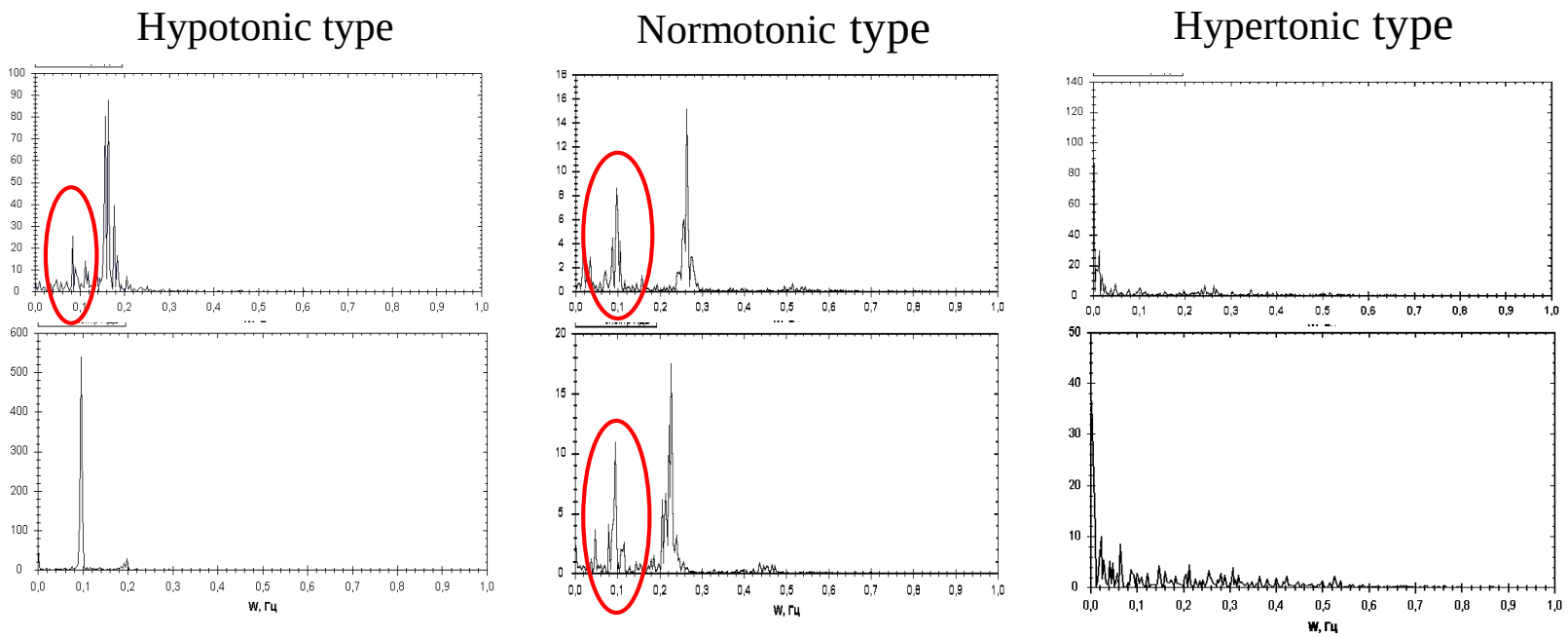




In middle-aged people, during involuntary breathing, the average and modal values of DWI PPG of the index finger correspond to age standards (40-70%). Normal values of DWI PPG are maintained during controlled breathing, performed at a frequency of 0.1 Hz. However, the variation range of DWI PPG during involuntary and voluntary breathing is insignificant. In most cases, the variation range of DWI PPG of the index finger is 25-30%. A small value of the variation range indicates a decrease in the efficiency of the mechanisms regulating the tone of resistive arteries as the human body ages. Perhaps this is due to an increase in the activity of the sympathetic division of the autonomic nervous system in middle-aged people and morphological changes in the vascular wall.

Spectral analysis of DWI PPG

Spectra DWI PPG of the index finger in young people



Sympathetic harmonic (Mayer) is highlighted by a circle.

In the DWI PPG spectra of the index finger of young people with hypotonic and normotonic types, the respiratory parasympathetic harmonic (HF) prevails during involuntary and voluntary breathing. In the hypotonic type, during controlled breathing, the amplitude of the respiratory harmonic increases by 3-5 times.

The amplitude of the respiratory harmonic in the DWI PPG spectrum in the hypertonic type during involuntary and voluntary breathing is small. The DWI PPG spectrum in the hypotonic and normotonic types contains the Mayer sympathetic harmonic (LF). In the hypertonic type, the amplitude of the parasympathetic harmonic in the DWI PPG spectrum of the index finger is small, very low frequency harmonics (VLF) prevail.

In the hypotonic type, the parasympathetic effect on regional hemodynamics prevails, in the normotonic type, the parasympathetic and sympathetic effects are balanced. The absence of respiratory harmonics in the hypertensive type indicates a stable predominance of sympathetic influences on regional arterial tone.

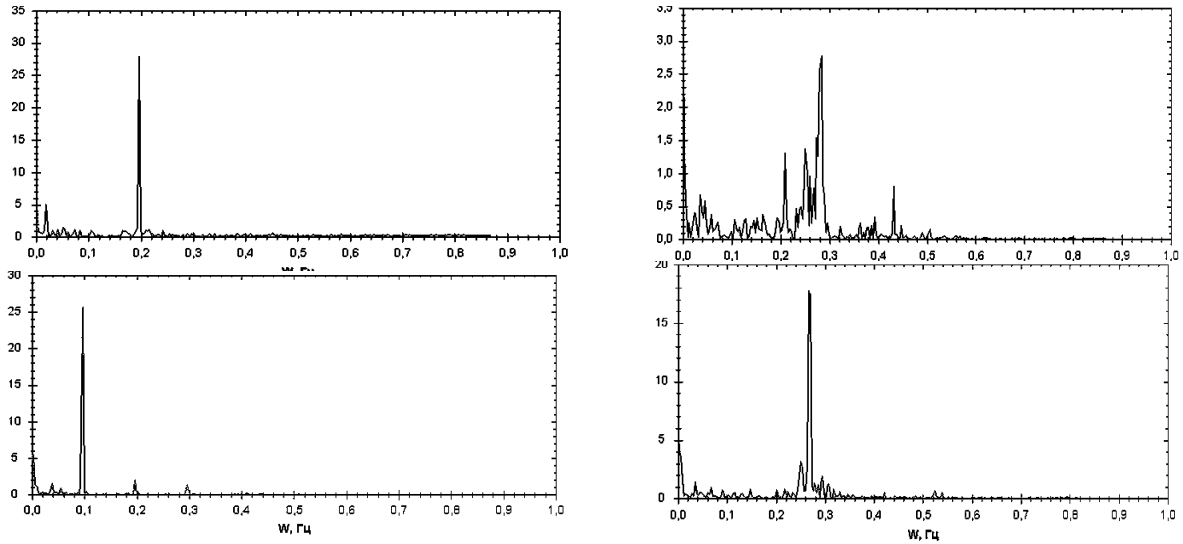
Spectral analysis of DWI PPG

Spectra DWI PPG of the index finger in middle-aged and old-aged people

middle-age | old-age

involuntary breathing

voluntary breathing



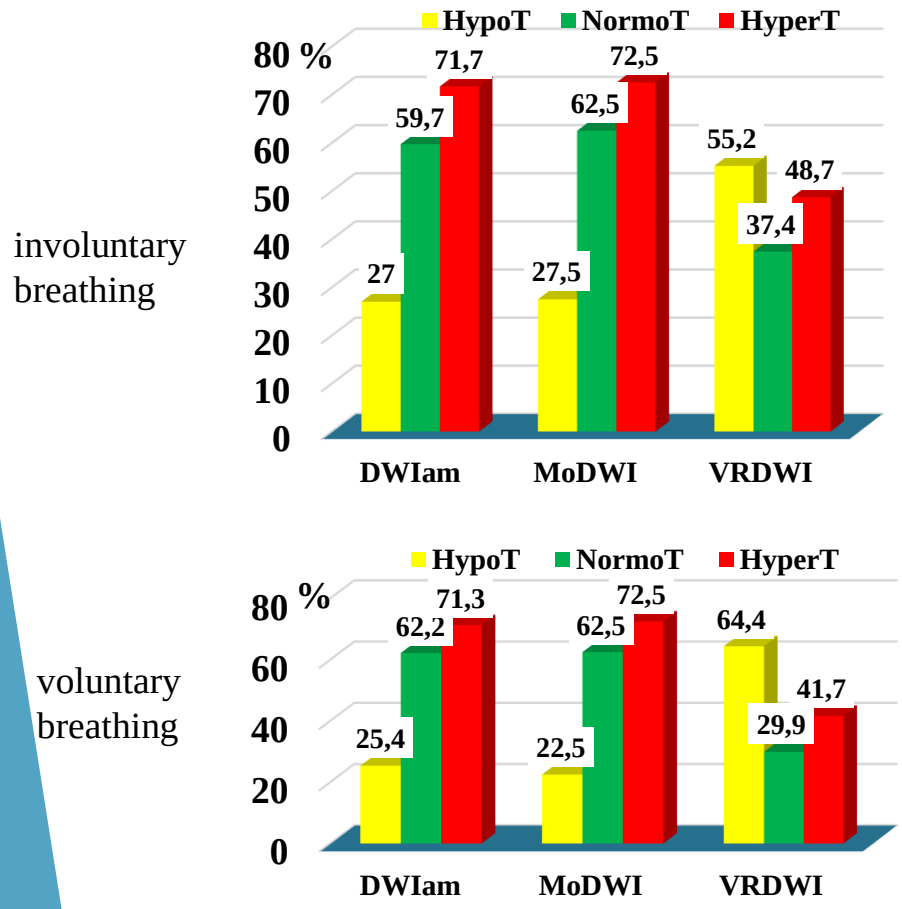
During natural breathing in middle-aged and elderly people, the respiratory harmonic (HF) has the highest amplitude in the DWI PPG spectrum of the index finger. The Mayer harmonic (LF) was not detected, and harmonics at very high frequencies (VLF) have a low amplitude. During controlled breathing with a frequency of 0.1 Hz in middle-aged people, the amplitude of the respiratory harmonic does not change. In elderly subjects, the amplitude of the respiratory harmonic during controlled breathing increases.

In middle age, the typological differences in DWI PPG characteristic of young subjects disappear. By the age of 55-60, the contour of finger photoplethysmograms acquires an "elderly", hypertensive appearance with a high incisura and an absent diastolic wave. The low amplitude of the parasympathetic harmonic (HF) in the DWI PPG spectrum indicates a decrease in indirect parasympathetic effects on the tone of regional resistance arteries. This decrease is accompanied by pronounced sympathicotonia, increasing with aging and the appearance of structural (atherosclerotic) changes in the wall of large arteries.

However, the presence in the DWI spectrum of elderly subjects (80-85 years) of respiratory harmonics, increasing with voluntary breathing control, proves the preservation of the effects of regulation of arterial and arteriolar tone, the absence of morphological changes in the structure of the muscular layer of the wall of small arteries.

Variation-statistical analysis of DWI PPG in young people

Arithmetic means, mode, and variation range of DWI PPG



In young people, in all three types of regional hemodynamics, the DWIam and Mo DWI do not go beyond the normal values. Thus, the hypotonic and hypertonic types are physiological types that characterize the variability of the tone of the resistance arteries in healthy young men.

Typological differences are resistant to functional loads. In a functional test with voluntary breathing, the reliability of differences in the arithmetic mean and modal values between the hypotonic, normotonic, and hypertonic types is preserved.

The types have significant differences in the VR DWI. The largest VR DWI is in the hypotonic type. The value of the VR DWI in the hypotonic type exceeds the average and modal values of this photoplethysmography indicator more than twice with involuntary and controlled breathing. In normotonic and, especially, hypertonic types, the average and Mo DWI , on the contrary, are greater than their variation range.

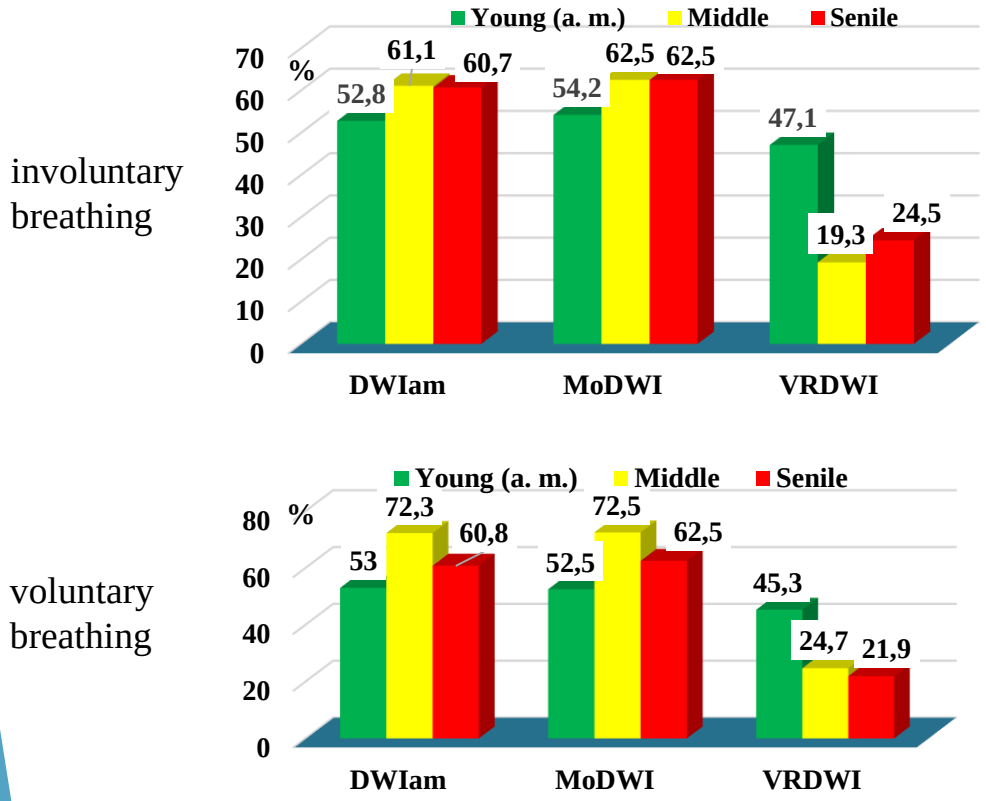
Thus, the greatest variability of the tone of small-diameter arteries is characteristic of the hypotonic type, the least variability of this parameter is characteristic of the normotonic type.

It can be assumed that the formation of the hypotonic type has a physiological origin and is due to the pronounced predominance of parasympathetic influences on the activity of the heart and, indirectly, through the venous-arterial mechanisms of regulation of the tone of small arteries, on the hemodynamics of the hand.

In normotonic and hypertonic types of hemodynamics, sympathetic influences predominate.

Variation-statistical analysis of DWI PPG: age-related features

Arithmetic means, mode, and variation range of DWI PPG



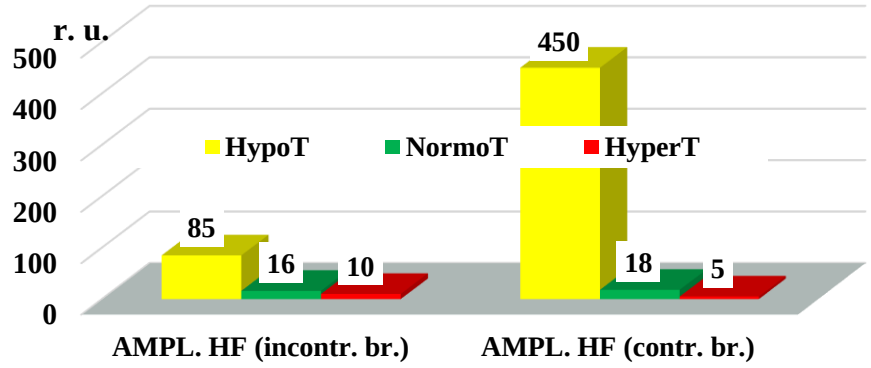
As a person ages naturally, an increase in DWI PPG is observed. This increase slows down after 55-60 years. In middle-aged and old people, the DWIam and Mo DWI do not differ. The VR DWI decrease significantly by the age of 50-55 years. As a person ages further, they do not change significantly. At the same time, in old people, the VR DWI are about 30-40% of its average values. Consequently, the gradual increase in the tone of regional small-diameter arteries observed with normal aging is of functional, not morphological origin.

During voluntary breathing in young and old people, the DWIam and Mo DWI not change compared to the values of this parameter during spontaneous, uncontrolled breathing. In middle-aged people, the DWIam during controlled breathing increase and begin to exceed the values of this parameter in both young and old people under similar conditions of lung ventilation.

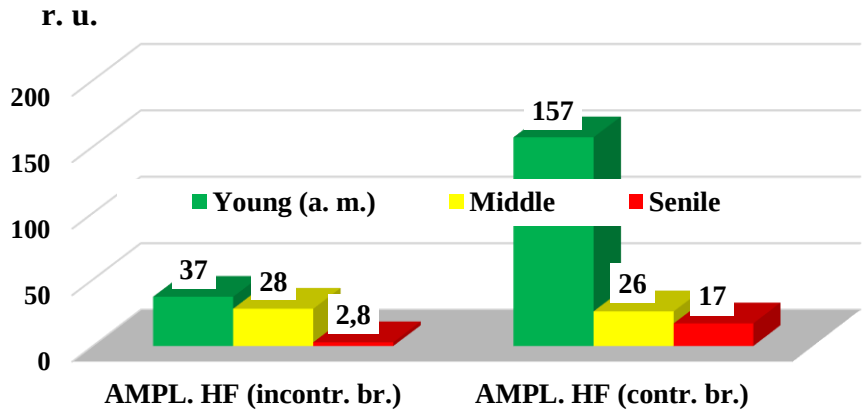
The VR DWI during the transition from uncontrolled to voluntary breathing changes insignificantly in all age groups. At the same time, a significant difference in the values of the variation range of DWI PPG VR DWI remains between the group of young people and the groups of middle-aged and old subjects.

Thus, aging is primarily accompanied by a stable decrease in the range of regulation of the tone of resistive arteries. This indicates a violation of the vegetative balance: a decrease in parasympathetic and an increase in sympathetic influences.

Spectral analysis of DWI PPG: age-related features



The amplitude of the parasympathetic harmonic (HF) in the DWI PPG spectrum in young people with hypotonic, normotonic, hypertonic types of regional hemodynamics during uncontrolled and controlled breathing.



Age-related changes in the amplitude of the parasympathetic harmonic (HF) in the DWI PPG spectrum during uncontrolled and controlled breathing

In young people in all types of regional hemodynamics in the DWI PPG spectrum, the parasympathetic harmonic (HF) has the highest amplitude (compared to the LF and VLF harmonics). In the hypotonic type, the amplitude of the respiratory harmonic is the highest, in the hypertonic type - the lowest. This is due to pronounced periodic changes in the activity of the parasympathetic division of the autonomic nervous system, mainly in young people with low tone of resistive arteries. In the hypotonic type, with voluntary breathing, the amplitude of the HF harmonic in the DWI spectrum increases many times. In the normotonic type, with the transition from uncontrolled to controlled breathing, the amplitude of the HF harmonic changes insignificantly. In the hypertonic type, with controlled breathing, the amplitude of the HF harmonic decreases. Consequently, in the hypotonic type, neurogenic mechanisms of regulation of regional tone, implemented by the parasympathetic division of the autonomic nervous system, steadily dominate.

With natural aging, in middle-aged and old people, the amplitude of the parasympathetic harmonic HF in the DWI PPG spectrum decreases. This is due to the age-related decrease in the activity of the parasympathetic division of the autonomic nervous system. In middle-aged subjects, when switching to controlled breathing, the amplitude of the parasympathetic harmonic in the DWI PPG spectrum does not change or decreases slightly. In old subjects, with controlled breathing, the amplitude of the parasympathetic harmonic in the DWI spectrum increases significantly, although in absolute values the HF amplitude is significantly lower than in young and middle-aged people. Consequently, in old people, the mechanisms of parasympathetic regulation of hand hemodynamics retain a certain efficiency.

CONCLUSION

- In young people, the peculiarity of peripheral hemodynamics is high individual variability of the tone of small-diameter arteries, caused by pronounced periodic changes in the activity of the parasympathetic and sympathetic divisions of the autonomic nervous system. This regulation effectively changes vascular tone in the dynamics of the respiratory cycle, since the elasticity of the arterial walls in young people is high. Age-related morphological changes in the arterial walls are absent.
- The balance of the mechanisms of parasympathetic and sympathetic regulation varies in specific young people. These differences allow us to formulate ideas about the types of peripheral hemodynamics: hypotonic, normotonic, hypertonic.
- Apparently, the hypotonic type of PPG is due to the stable predominance of parasympathetic influences on central hemodynamics and, indirectly, (through local myogenic mechanisms) on peripheral blood flow. The activity of the sympathetic division is low.
- The normotonic type is characterized by a periodic increase in the activity of the sympathetic division of the autonomic nervous system, which is indirectly confirmed by the appearance of a sympathetic harmonic (Mayer harmonic) in the spectrum of PPG parameters reflecting the tone of the small-diameter arteries of the hand region.
- The hypertonic type illustrates a persistently increased activity of the sympathetic division of the autonomic nervous system, which leads to a long-term, stable increase in the tone of the resistive arteries of the hand and a decrease in vascular reactivity. The hypertensive type can be considered to a certain extent a type of premature "progeric" (accelerated) aging of the cardiovascular system.
- By middle age, in the dynamics of natural aging, typological differences in regional blood circulation decrease. In middle-aged people, the PPG contour usually acquires a "hypertonic" appearance - the tone of the resistive arteries increases due to a steady increase in sympathetic influences on the cardiovascular system.
- By old age, functional disorders of hemodynamic regulation are superimposed by morphological changes in the walls of large arteries, a decrease in their elasticity, which, on the one hand, leads to an even more pronounced leveling of typological differences in regional hemodynamics. On the other hand, this limits the reactivity of the vascular wall in response to activation of the parasympathetic or sympathetic circuits of blood circulation regulation.

THANK YOU FOR ATTENTION!