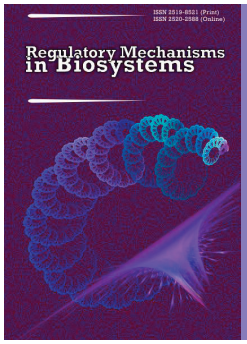

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Haemodynamic effects of hyperventilation on healthy men with different levels of autonomic tone

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The topicality of the research is stipulated by insufficient study of the correlation between the functional state of the cardiorespiratory system and autonomic tone. The goal of the research was to analyze the changes of central haemodynamics with 10-minute regulated breathing at the rate of 30 cycles per minute and within 40 minutes of recovery after the test in healthy young men with different levels of autonomic tone. Records of the chest rheoplethysmogram were recorded on a rheograph KhAI-medica standard (KhAI-medica, Kharkiv, Ukraine), a capnogram - in a lateral flow on a infrared capnograph (Datex, Finland), and the duration of R-R intervals was determined by a Polar WIND Link in the program of Polar Protrainer 5.0 (Polar Electro OY, Finland). Systolic and diastolic blood pressure were measured by Korotkov's auscultatory method by mercury tonometer (Riester, Germany). The indicator of the normalized power of the spectrum in the range of 0.15–0.40 Hz was evaluated by 5-minute records; three groups of persons were distinguished according to its distribution at rest by the method of signal deviation, namely, sympathicotonic, normotonic and parasympathicotonic. The initial level of autonomic tone was found to impact the dynamics of CO_2 level in alveolar air during hyperventilation and during recovery thereafter. Thus, $PetCO_2$ was higher (41.3 mm Hg) in parasympathicotonic than in sympathicotonic (39.3 mm Hg) and normotonic (39.5 mm Hg) persons. During the test, R-R interval duration decreased being more expressed in normotonic persons. At the same time, the heart index was found to increase in three groups, and general peripheral resistance – to decrease mostly in normo- and parasympathicotonic persons. In addition, the reliable increase of stroke index and heart index was found in these groups. In the recovery period after hyperventilation, the decrease of tension index and ejection speed was found in normo- and, particularly, parasympathicotonic compared with sympathicotonic men and the increase of tension phase and ejection phase duration.

Keywords: sympathicotonic persons; normothonic persons; vagotonic persons; central haemodynamics; hypocapnia.

Introduction

Studies of hyperventilation in the human body are quite numerous and stipulated by its presence in life activity, as well as by its application in diagnosis, correction and prediction of functional state (Eckberg et al., 2016; Burman et al., 2018; Mutch et al., 2018). Hyperventilation syndrome was described for the first time in a classic study of Da Costa (Morgan, 1983). The increase of respiratory frequency and minute volume is conditioned by the action of stress factors (military activity) on a person. With hyperventilation, there is hypocapnia, which leads to an increase in the tone of the brain vessels (Meng & Gelb, 2015; Madureira et al., 2017; Hoiland et al., 2019). Hypocapnia is a state of the reduced carbon dioxide in the arterial blood of less than 35 mm Hg resulting from hypodynamia (hypokinesia), stress, with deep rapid breathing (hyperventilation) caused by the increased stimulation of the central nervous system (hyperthermia, pain, fear, anxiety, hypoxemia/hypoxia, taking medication, or after intensive sport training). Its symptoms are delirium, numbness, tingling, arrhythmia, dry mouth (Bajmakanova, 2013; Ponimasov, 2016; Khiat et al., 2018). Hypocapnia can lead to mild dizziness or fainting. It has been found that after a test for hyperventilation, a decrease in the level of $PetCO_2$ results in the loss of consciousness and apnea with spindle activity on the EEG. However, after the test, when the carbon (IV) oxide is restored, there is a restoration of consciousness and self-breathing with the disappearance of spindle activity. Loss of consciousness is associated with the partial involvement of the ascending activating mesodiencephalic reticular formation. Hypocapnia causes microvascular spasm, oxygen deficiency, and energy starvation of the body cells. Under normal conditions, the deterioration of health resulting from hypodynamia and stress lasts for years and decades. It leads to the so-called "diseases of civilization": ischemic heart disease, hypertension, insomnia, migraine, constipation, vegetative-vascular dystonia, osteochondrosis. It has been found that the concentration of CO_2 in such patients is 20–40% below normal. To achieve real recovery, it is necessary to lead the gas composition to normal, to eliminate hypocapnia (Salinet et al., 2019). Normocapnia is a condition in which the concentration of carbon dioxide in the arterial blood corresponds to 35–45 mm Hg. It has been established (Kavanagh, 2002; Drogovoz et al., 2016) that the metabolic rate of carbon monoxide (IV) at rest under standard conditions (STPD) is 150 mL/min. The body's CO_2 reserves are known to be divided into several fractions. The central fraction is about 2.5 L and is quickly flushed with hyperventilation. The peripheral fraction is distributed in: tissues with low blood supply (fat and bone tissues), organs with moderate blood supply (muscles) and organs with intensive blood supply and low own mass (brain and kidneys) (Shurygin, 2000). The optimal concentration of carbon (IV) oxide in the arterial blood, in which the blood supply of vital organs being 100%, is in the range from 6.0% to 6.5% (Mishustin, 2007; Semenov, 2016), and 5.6% according to some sources (Lyzogub et al., 2015). A concentration of CO_2 from 4.5% to 4.0% is considered to be a risk zone and from 4.0% to 3.6% - a

zone of pathological conditions. Its further reduction from 3.6% to 3.0% indicates the possibility of life-threatening diseases. From this, it follows that the concentration of carbon dioxide in the arterial blood is the most important information and diagnostic indicator, and the development of effective ways of its normalization will contribute to maintaining good health (Shaov et al., 2009; Zav'jalova, 2011).

There are the following mechanisms to maintain normal CO_2 content. They are bronchial and vascular spasm, the increased cholesterol production in the liver as a biological insulator sealing cell membranes in the lungs and vessels, lowering blood pressure (hypotension) leading to the decreased removal of carbon (IV) oxide (Zav'jalova, 2011; Drogovoz, 2017).

Molecular carbon dioxide easily crosses the blood-brain barrier and acts on the central chemoreceptors of the medulla oblongata. It is known to contain the retrotopezoid nucleus and the rostral medullary raphe, which mediate adaptive changes in breathing. The nucleus consists of a bilateral accumulation of glutamatergic neurons that respond to the enhancement of local PCO_2 by cell-autonomous and paracrine (glial) mechanisms and receive additional sensory information from carotid bodies. These neurons also innervate the area of the brain stem responsible for the respiratory rhythm. The astrocytes that are the part of this nucleus affect the release of ATP depending on the change in CO_2/H^+ to enhance the activity of chemosensitive neurons. The increase in carbon dioxide contributes to the release of ATP from a cell, leading to its destruction in the extracellular space and the release of adenosine, which is a powerful neuromodulator and serves to limit the functions of chemoreceptors, inhibiting hyperventilation. The rostral-medullary raphe dominated by serotonergic neurons, is believed to play a leading role in the regulation of carbon dioxide. However, CO_2 affects the peripheral chemoreceptors of the aortic arch. It is estimated that 80% of carbon dioxide is perceived by central chemoreceptors, while 20% – by peripheral ones (Guyenet, 2012; Singh, 2017; Falquetto et al., 2018; Bhandare et al., 2019). The decrease in the concentration of carbon dioxide in the blood leads to an increase in oxygen affinity for haemoglobin, and therefore, in the development of hypoxia with all its consequences. The contradiction of these two haemo-stimuli presents complexity in quantifying haemodynamic reactivity, as hypoxia causes cerebral vasodilation, whereas breathing-induced hypocapnia causes vasoconstriction. However, Willie's study clearly shows the comparatively greater importance of CO_2 for the regulation of cerebral blood flow (Willie et al., 2015; Lafave et al., 2019).

The dependence of the concentration of carbon dioxide and haemoglobin affinity for O_2 is due to the Verigo-Bohr effect, according to which a decrease in the level of CO_2 in the blood increases the binding energy of oxygen for haemoglobin and complicates its diffusion into tissues. This physiological phenomenon was discovered by B. F. Verigo, a Russian physiologist, at the end of the 19th century, and it was confirmed by C. Bohr, a Danish physician, ten years later. In the body, CO_2 dissolves in the tissue fluid, forming carbonic acid, which changes the pH in the acidic direction: $CO_2 + H_2O = H_2CO_3$. The lower the pH of the blood, the lower the affinity of haemoglobin for oxygen. Under the influence of carbonic anhydrase, the acid dissociates into ions: H^+ and HCO_3^-. The HCO_3^- anion interacts with the K^+ and Na^+ cations, resulting in a change in the buffer equilibrium toward the alkaline reaction. It is worth noting that in plasma, CO_2 dissolves slowly, and in the erythrocyte, the rate of this reaction increases thousands of times due to the presence of the enzyme. A small amount of CO_2 is transferred in the compound with haemoglobin provided by nucleophilic N-centers. The physiological norm of blood pH ranges from 7.35–7.45, which is provided by the buffer capacity of the blood, lung and kidney function (Grishin et al., 2011; Bukov & Belousova, 2016; Drogovoz et al., 2017). The relationship between $PaCO_2$ and pH can be represented by the following rules:

– when $PaCO_2$ increases by 20 mm Hg, the pH decreases by 0.1;

– when $PaCO_2$ decreases by 10 mm Hg, the pH increases by 0.1;

– changes in pH beyond these limits are the result of metabolic disorders.

The kidneys (metabolic buffer) maintain a normal acid-base balance by dual mechanisms: reabsorption of bicarbonate (HCO_3^-) in the proximal tubules or excretion in the distal nephron. These mechanisms take from several hours to several days. When the lungs and kidneys work together, the pH of the blood is maintained by equilibrating 1 part of acid to 20 parts of base (Bajmakanova, 2013). Impact on the reabsorption of HCO_3^- provides the effective volume of arterial blood, glomerular filtration rate, serum chloride and potassium concentration. According to the studies by Leacy et al. (2018), gradual climbing of mountains is accompanied by hypoxic hypocapnia; normal arterial pH is maintained by means of renal compensation. In respiratory alkalosis, the kidneys contribute to a decrease in the reabsorption of bicarbonate, i.e. H^+ retention and an increase in potassium bicarbonate output are observed. This process helps to maintain the pH of the extracellular environment to neutralize the effect of low pCO_2, which is the primary disorder with respiratory alkalosis (Leacy et al., 2018). In the studies of Zouboules et al. (2018), the concept of renal reactivity index is introduced showing the dependence of bicarbonate and $PaCO_2$ concentration during gradual climbing to a height. Strong negative correlation is found between these indicators ($r < 0.71$; $P < 0.001$) from the baseline at all heights (Zouboules et al., 2018).

The revealed changes of EEG during the prolonged hyperventilation are found to depend directly on the level of carbon (IV) oxide. Hypocapnia with a CO_2 concentration of 15 mm Hg causes a more active intensification of both intracortical and deep limbic-reticular effects of the brain, which are manifested in the increase of all types of cerebral activity, and in more than 70% in the generalized paroxysmal activity. The recovery of the original EEG pattern after hyperventilation occurs long before the restoration of the carbon dioxide voltage (Djomin & Poskotinova, 2017).

Carbon dioxide in physiological concentrations affects the tone of smooth muscles, expands the small arteries and capillaries in the place of spasm, normalizes the tone of veins, relieves spasm, and tones the atonic smooth muscles of all organs. It also reduces the viscosity of colloidal solutions improving metabolism and the increased speed of biochemical processes (Lyzogub et al., 2015).

The increase in the tone of the cerebral arteries under the action of hypocapnia is considered to be a compensatory mechanism in response to a decrease in the heart rate and pulse blood flow. Carbonic acid in humoral and reflexive way from the chemoreceptors of the vascular zones has a stimulating effect on the reticular formation of the trunk and then on the cerebral cortex. Reducing the partial pressure of CO_2 in the blood is accompanied by a decrease in stimulating effects and leads to the increased thalamic-cortical synchronization, activation of the anterior parts of the hypothalamus and hypertension of the cortex. Under the influence of hypocapnia and gas alkalosis, there is a spasm of the brain vessels, which leads to a decrease in the supply of oxygen and glucose to the brain with transient hypoxia and ischemia accompanied by a decrease in frequency and an increase in alpha rhythm and delta activity. Changes in the form of an increase in alpha rhythm synchronization, the appearance of bilateral synchrony, the intensification of slow-wave outbreaks in the anterior parts may be explained by the indirect influence on the hypothalamic-diencephalic structures (Gnezdickij et al., 2010).

Gas alkalosis in hyperventilation has a specific effect on vascular tone and causes narrowing not only of the brain vessels but also coronary and peripheral ones, the vessels of intestines, liver, kidneys; at the same time, there is an expansion of skeletal muscle vessels. There is a redistribution of regional circulation and reduction of coronary and cerebral blood flow. It is proved that the majority of patients with acute stroke are hypocapnic (Curley et al., 2010; Grishin et al., 2012; Nagibovich et al., 2016; Salinet et al., 2019).

Hypocapnia is found to cause a decrease in the heart rate variability and an increase in the variability of QT interval on the electrocardiogram, an increase in the heart rate. At the same time, slow breathing with a low inhalation-exhalation rate, accompanied by hypercapnia, is associated with greater power in the high-frequency component of heart rate variability (Sullivan et al., 2004; Van Diest et al., 2014).

Numerous studies show that changes in the diameter of the internal carotid artery is positively associated with the reactivity of $PaCO_2$ (~ 25%), while the spinal artery cross-section does not respond to the change in CO_2 in the arterial blood, but with severe hypoxia, 9% in-

crease in its diameter is observed (Willie et al., 2012; Sato et al., 2012). At the same time, the blood flow rate is characterized with less reactivity in the anterior and posterior cerebral arteries than in the vertebral and carotid.

Arbitrary hyperventilation is accompanied by changes in autonomic nerve regulation with a predominance of sympathetic effects leading to anger and panic attacks. Changes in cardiac activity and haemodynamics, decrease in the functionality of distant analyzers, and the level of psychomotor performance deepened with the increase in hypocapnia, are observed. The decrease in the activity of the respiratory center during hyperventilation, leads to a change in the propagation of excitation from it to the cortex of the cerebral hemispheres and spinal motor centers. Hypocapnia-induced vasoconstriction significantly inhibits neural activity (Szabo et al., 2011; Nagibovich et al., 2016). It was confirmed that the reduction of carbon dioxide in the body stimulated the coagulation function of the blood, contributing to the development of thrombophlebitis in combination with the slow blood flow in the veins. Hypocapnia leads to increased mucus secretion in the bronchi, nasal passages, development of adenoids and polyps. There is a thickening of membranes due to the accumulation of cholesterol contributing to the development of tissue sclerosis. Endogenous catecholamine release is activated (Grishin et al., 2012; Lyzogub et al., 2015).

It is established that the decrease in PCO_2 in the lungs causes vasodilation; in the gastrointestinal system, there are changes in perfusion, treatment of electrolytes and motility: the tone of the colon increases and the phase contractility in the transverse and sigmoid region increases, which can be explained by the suppression of sympathetic innervation and the direct effect of hypocapnia on the smooth muscles of the intestine (Foster et al., 2001; Panina, 2003; Grishin et al., 2012; Sur & Shah, 2019).

The physiological concentration of carbon dioxide has a positive effect on the permeability of membranes, namely, it normalizes the excitability of nerve cells. It helps to withstand stress, to avoid nervous overstimulation and, as a consequence, to relieve insomnia and migraines. It also stimulates the release of vasoactive substances as histamine, acetylcholine, serotonin, and kinins by nerve endings; these substances expand coronary vessels and result in a decrease of the heart rate and blood pressure (Makarenkova et al., 2012). At the same time, the excitability of nerve fibers increases as with the hyperventilation. As Ca^{2+} and H^+ ions competitively bind to plasma proteins, a decrease in the H^+ concentration causes an increase in the number of the bound Ca^{2+} ions. Their content in plasma and intercellular fluid decreases, leading to a decrease in transmembrane potential and an increase in the permeability of the cell membrane for Na^+ ions. Besides, the reduction of Ca^{2+} in the extracellular fluid influences myocardial contraction force (Panina, 2003; Makarenkova et al., 2012).

Pregnant women are found to be also exposed to hypocapnia (30.7 ± 3.7 mm Hg), and especially women in the second stage of childbirth, in which even lower values of $PetCO_2$ (20.8 ± 5.9 mm Hg) are detected, which probably affects the optimal cerebral oxygenation of the fetus (Tomimatsu et al., 2012).

The CO_2 introduced into the body creates a state of hypercapnia accompanied with vasodilation being the result of its direct activity on the smooth muscle cells of arterioles, an increase in capillary blood flow and, as a consequence, an increase in tissue oxygenation. Carbon (IV) oxide stimulates the secretion of growth factors, such as vascular endothelial growth factor, which results in the formation of new blood vessels (neovascularization) and revascularization. The state of hypercapnia is not harmful to the body, since excess gas can simply be removed through the lungs. The introduction of carbon dioxide is often used to treat lymphatic stagnation, since its vasodilator effect enhances tissue perfusion and improves local blood flow, leading to a decrease in lymphedema (Khiat et al., 2018).

An increase in CO_2 concentration leads to an increase in the rate of cerebral blood flow, and its decrease – to a decrease; besides, with hyperventilation, intracranial pressure is reduced due to the induction of cerebral vasoconstriction with a further decrease in cerebral blood volume. The cross-sectional area of the middle cerebral artery is found to increase by approximately 8% during hypercapnia. The reaction of the rate of cerebral blood flow to the concentration of carbon dioxide is due to changes in the resistance of cerebral resistance vessels, the mechanism of which has not been fully studied. Vasodilation with the introduction of carbon (IV) oxide is possibly due to the accumulation of H^+ and activation of K^+ channels in vascular smooth muscle cells. Carbon dioxide also increases average blood pressure (BP, with reverse breathing for more than 2 min), which can lead to an increase in perfusion pressure against autoregulation failure and affect the speed of cerebral blood flow. Thus, a threshold of $PetCO_2$ (42 mm Hg) is found; to achieve it, the enhancement of cerebral blood flow reflects true cerebrovascular reactivity to carbon dioxide without the dependence on changes in systemic BP. It may be stipulated by not only the vasodilating effect of carbon (IV) oxide, but also by increasing the perfusion pressure with the growth of systemic BP (Stocchetti et al., 2005; Kulikov et al., 2017).

It has been investigated that raising CO_2 to 0.7–1.2% within 23 days contributes to a 35% increase in the rate of cerebral blood flow compared to the background during the first 1–3 days, after which this indicator gradually decreases to the previous level. Time-dependent changes in vascular reactivity may be stipulated by either a delay in bicarbonate in the extracellular brain fluid, or a progressive increase in ventilation, or both ones (Cassaglia et al., 2008; Miller et al., 2018).

Hypercapnia has been shown to increase the diameter of the inferior vena cava, leading to a decrease in venous return of the blood, resulting in a decrease in cardiac output. An increase in CO_2 concentration contributes to a decrease in peripheral vascular resistance, right ventricular hypertrophy, and arrhythmias. It also produces negative inotropic and chronotropic effects (the occurrence of bradycardia), due to changes in the sensitivity of the vagus nerve nuclei to the influence of CO_2, which slows the cardiac output. The action of carbon dioxide expands the peripheral arterioles, resulting in redistribution of blood in favour of an increase in peripheral volume, with the filtration equilibrium point in the capillaries shifting distally, causing fluid movement beyond the vascular bed and the loss of plasma volume. Accordingly, the effective volume of circulation decreases , which stimulates the sympathetic nervous system, the production of renin and vasopressin. In order to maintain intravascular volume, the kidneys respond by vasoconstriction and retain sodium (Shoemaker et al., 2001; Baković et al., 2006; Gavrisjuk, 2006). Hypercarbia has been shown to decrease blood flow in the hepatic, renal, and musculoskeletal flow, while gastrointestinal, myocardial, and cerebral blood flow increase. There is also a decrease in blood pressure (Solov'eva et al., 2013; Coverdale et al., 2016).

In their study Harrison et al. (2017), the observation of video-based surgery shows an increase in respiratory rate and a decrease in $etCO_2$ in women. At the same time, there are significant shifts in haemodynamics. A meta-analysis of the literature shows that stroke survivors have low levels of CO_2 in the blood and cerebral blood flow (Salinet et al., 2019). Several studies show that hypocapnia with hyperventilation affects not only the level of blood flow in the brain but also modulates its response to various stimuli (Boulet et al., 2016; Smielewski et al., 2018; Tsuji et al., 2018).

Hyperventilation and the shortness of breath coming after it significantly increase coronary blood flow. Thus, in experiments on anesthetized pigs, shortness of breath after hyperventilation led to a significant increase in coronary blood flow, which was determined with magnetic resonance (by 346% compared with 97% increase during shortness of breath). In coronary artery stenosis, the differences were leveled (Fischer et al., 2016). However, hyperventilation followed by shortness of breath was successfully used as a non-pharmacological vasoactive impulse to stimulate changes in the oxygenation of myocardium including in patients with coronary heart disease (Fischer et al., 2018). Allan's work (Allan et al., 2015) shows that hyperventilation leads to an increase in blood pressure variability in patients with ischemic attack.

The reactivity of the cardiovascular system to physiological stimuli in healthy people may vary significantly depending on the conditions (Lutsenko & Kovalenko, 2017) and be determined by individual and typological characteristics (Kovalenko & Kudii, 2006). One of these typological indicators is the level of autonomic tone (Spitsin et al., 2018). It is proved that its initial level can determine the nature of the body's response to stress (Wilder, 1957).

Therefore, the purpose of our research is to study changes in central haemodynamics with 10-minute regulated breathing at a rate of 30 cycles per minute and during recovery after the test in healthy men with different levels of autonomic tone.

Materials and methods

The study was conducted in compliance with the basic bioethical principles of the European Council Convention on Human Rights and Biomedicine (04.04.1997), Helsinki Declaration of the World Medical Association on Ethical Principles of Conducting Medical Research Involving Human Subjects (1994–2008), the Order of Ministry of Healthcare (Ukraine) No 690 dated 23.09.2009. All participants gave written permission for participation in the measurements and for publication of their results. The measurements were made on 77 healthy young men aged 18–23 years (an average age 20.23 ± 0.18) under conditions close to the state of basal metabolism. All persons participated in the study voluntarily, were found to be healthy according to the medical examination, did not have acute and chronic diseases. Before completing the tasks, they were informed of the purpose and objectives of the measurements, the sequence and the content of the test loads, and gave written permission for the research and the scientific use of their results. The day before the examination, the subjects did not drink alcohol, coffee, stimulants or sedatives, did not have great emotional and physical activity. Breath capnography, chest rheoplethysmogram, cardio intervals were recorded for 5 minutes while sitting quietly, for 10 minutes of the regulated breathing at a frequency of 30 cycles per minute and 40 minutes of the recovery period after the test.

The chest rheoplethysmogram was registered on the rheograph of XAI-medica standard (XAI-medica, Kharkiv, Ukraina) (Fig. 1), capnogram – in the lateral flow on the capnograph of DATEX NORMOCAP (Datex, Finland); the duration of R-R intervals was determined with the cardio sensor of Polar WIND Link, the receiver of Polar Windlink in the program of Polar Protrainer 5.0 (Polar Electro OY, Finland). Systolic (APs) and diastolic (APs) arterial blood pressure was measured with Korotkov's auscultative method by mercury tonometer (Riester, Germany).

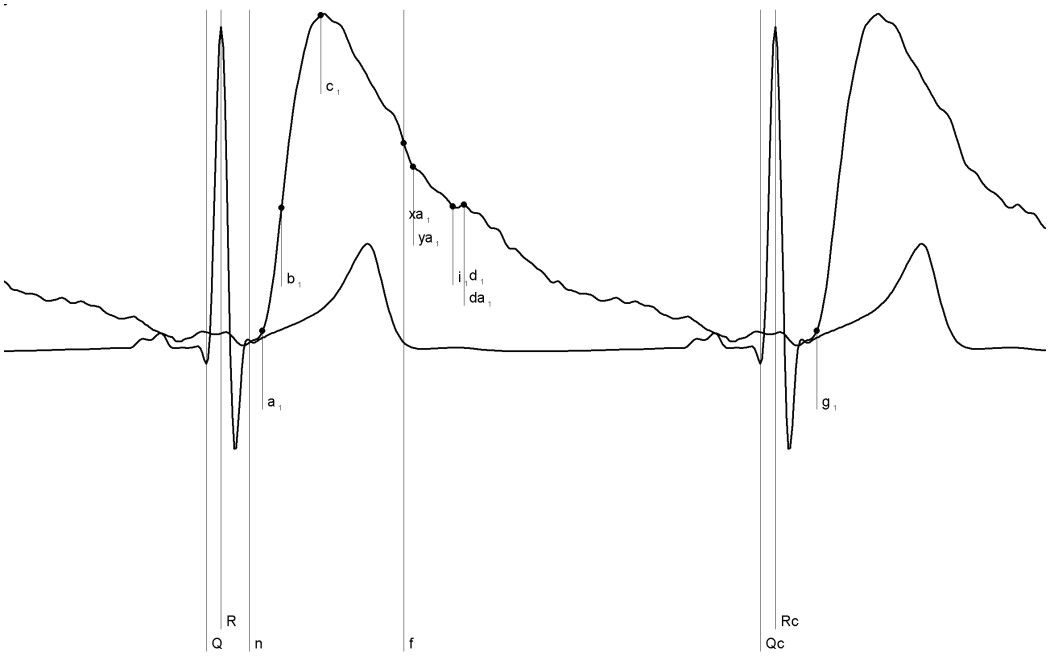

Fig. 1. Fragment of ECG and chest rheogram record with critical points for calculating central haemodynamics and cardiodynamics: on the abscissa axis – amplitudes of signals; on the ordinate axis – time of recording

CO_2 level at the end of exhalation ($PetCO_2$) was evaluated according to capnogram. The average blood pressure (APm) was calculated by the formula of Hickkam (Ramaat et al., 2003). Stroke volume indicator (SV) was given by the formula of W. G. Kubicek (Kubichek, 1970). The duration of tension phase (TPh), ejection phase (EPh), stroke index (SI), heart index (HI), general peripheral resistance (GPR), ejection speed (ES) were calculated according to generally accepted methods (Klabunde, 2012). Tension index (TI) was calculated as a ratio of TPh to EPh in percentage.

An indicator of the normalized power of the spectrum in the range of 0.15 - 0.4 Hz (HFnorm) reflecting the level of vagosympathetic balance was evaluated according to 5-minute records of cardiointervalogram at rest and under experimental influences (Malik et al., 2019). Three groups of persons were distinguished according to this indicator at rest by the method of signal deviations; they are sympathicotonic (I, n = 22) up to 40 conditional units (c.u.), normotonic (II, n = 30) from 40 to 60 c.u., and parasympathicotonic ones (III, n = 25) from 60 c.u.

The physiological indicators was evaluated as the difference between their level during the experimental influences and in the background. Statistical analysis due to the normality of sample distribution (by Shapiro-Wilk test) was made by parametric methods. The data in the tables and text are presented as mean ± standard error (x ± SE). The probability of differences was estimated Fisher's F-test by ANOVA method.

Results

There were differences in PetCO2 and central haemodynamics functioning at rest depending on the initial level of autonomic tone. Thus, in the parasympathicotonic persons, PetCO2 was higher (41.29 ± 0.50 mm Hg, $P < 0.01$) than in group I (39.28 ± 0.77 mm Hg, $P < 0.01$) and II (39.45 ± 0.61 mm Hg, $P < 0.01$). Immediately after the start of the regulated breathing at a rate of 30 cycles per minute, there was a significant decrease in $PetCO_2$ in all groups with its lowest values reached in the 5–7 minutes of the test (Fig. 1). During the test, the decrease in $PetCO_2$ was observed to be more expressed in normotonic persons (–23.07 ± 0.85 mm Hg) compared to group I (–20.19 ± 1.35 mm Hg, $P < 0.05$) and III (–20.10 ± 1.02 mm Hg, $P < 0.01$). After the test with hyperventilation, $PetCO_2$ was rapidly increased. This indicator was not restored to the initial values in any typological group up to 40 minutes of registration after the test.

Higher diastolic blood pressure (APd) was registered in sympathicotonic persons compared to group III (79.3 ± 1.7 mm Hg and 75.2 ± 1.3 mm Hg, $P < 0.05$ respectively) and APm (94.1 ± 1.9 mm Hg and 90.9 ± 1.3 mm Hg, $P < 0.05$ respectively). This trend was observed throughout the study. However, the normotonic persons were characterized with the highest reactivity at the end of recovery period APm (0.33 ± 0.43 mm Hg, $P < 0.05$).