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BLOOD CIRCULATION IN LARGE VESSELS AND IN THE ABDOMINAL ORGANS DURING THE EXPERIMENT

The purpose of this study was to study the blood circulation in large blood vessels and in the abdominal organs during inflammation of the abdominal cavity. Using the method of rheograph and laser ultrasonic dopplerography, the blood flow velocity in the abdominal aorta and inferior vena cava was studied. The circulatory system maintains the stability of the body in violation of internal organs and tissues.In large blood vessels and organs of the abdominal cavity, inflammation leads to disruption of blood supply in the microvasculature of the vessel. The rate of blood flow in the main vessel in acute inflammation of the abdominal cavity decreased compared to the control group. The resistance index in the main vessel RI decreased by 38.3%, which is associated with an increase in the diameter of the main vessel. With inflammation of the abdominal cavity, an increase in the velocity of blood flow in the portal vein and abdominal aorta was recorded.As a result of a decrease in the tone of blood vessels after a violation of liver function, the blood supply to the abdominal cavity decreased. The decrease in the functional properties of arteries and veins led to a decrease in blood flow in the abdominal cavity, which, in turn, manifests itself as a result of the preservation of microcirculatory disorders.

Key words: hemodynamics, abdominal cavity, blood circulation, blood vessels, blood flow, inflammation.

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Тәжірибе кезіндегі ірі тамырлар мен іш қуысындағы қан айналымы

Зерттеудің негізгі мақсаты – іш қуысының қабынуы кезіндегі ірі қан тамырлары мен құрсақ қуысындағы қан айналымын зерттеу. Реография және лазерлік ультрадыбыстық доплерография әдісімен іштің қолқа мен төменгі қуыс венадағы қан ағысының жылдамдығын зерттелді. Қанайналым жүйесі ішкі мүшелер мен ұлпалардың бұзылуы кезінде ағзаның тұрақтылығын сақтайды. Ірі қан тамырлары мен іш қуысындағы қабыну кезінде қан тамырлардың микроциркуляторлық арнасын қанмен қамтамасыз етудің бұзылуына әкеледі. Іштің жедел қабынуы кезінде магистральды тамырдағы қан ағысының жылдамдығы бақылау тобымен салыстырғанда төмендеді. Магистральды тамырлардағы кедергі индексі RI 38,3% – ға төмендеді, бұл өз кезегінде магистральды тамырлардың диаметрінің ұлғаюына байланысты. Іштің қабынуымен қақпа венасында және құрсақ қолқасында қан ағысының артқандығы байқалады. Бауыр қызметінің бұзылуынан кейін қан тамырларының тонусының баяулау нәтижесінде іш қуысының қанмен қамтамасыз етілуі төмендеді. Артерия мен вена тамырларының функционалдық қасиеттерінің төмендеуі нәтижесінде құрсақ қуысы аймағында қан ағысының төмендеуіне әкелді, бұл өз кезегінде микроциркуляторлық бұзылулардың болуынан көрінеді.

Түйін сөздер: гемоддинамика, қабыну, қан айналымы, қан ағысы, қан тамырлары, құрсақ қуысы.

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Кровообращение в крупных сосудах и органах брюшной полости при эксперименте

Цель данного исследования являлось изучить кровообращение в крупных кровеносных сосудах и в органах брюшной полости при воспалении брюшной полости. Методом реографы и лазерный ультразвуковой допплерографии исследовали скорость кровотока в брюшной аорте и нижней полой вене. Кровеносная система поддерживает устойчивость организма при нарушении внутренних органов и тканей. В крупных кровеносных сосудах и органах брюшной полости при воспалении приводит к нарушению кровоснабжения в микроциркуляторном русле сосуде. Скорость кровотока в магистральном сосуде при остром воспалении брюшной полости снижалась по сравнению с контрольной группой. Индекс сопротивления в магистральном сосуде RI снизился на 38,3%, что связано с увеличением диаметра магистрального сосуда. При воспалении брюшной полости зафиксировано увеличение скорости кровотока в воротной вене и брюшной аорте. В результате снижения тонуса кровеносных сосудов после нарушения функции печени уменьшилось кровоснабжение брюшной полости. Снижение функциональных свойств артерий и вен привело к снижению кровотока в области брюшной полости, что, в свою очередь, проявляется в результате сохранения микроциркуляторных нарушений.

Ключевая слова: гемоддинамика, воспаление, кровоброщения, кровоток, кровеносные сосуды, брюшная полость.

Introduction

Peritonitis is an inflammation of the peritoneum, which can cause pathology of various body functions, pronounced local changes and intoxication. Inflammation of the abdominal cavity remains one of the most urgent problems of modern medicine. At the same time, lethality from widespread peritonitis continues to be high, reaching 20-70% [1]. The urgency of this problem is determined by the reaction of the microvasculature to the influence of factors of the external and internal environment, ensuring the adaptation of local hemodynamics in accordance with the needs of the body. The septic state of the body is simultaneously stressful, characterized by impaired central hemodynamics and regional circulation disorders in the form of centralization of blood flow. When the level of tissue blood flow drops below the threshold values, the occurring metabolic, biochemical, and enzymatic cellular disorders lead to the development of multiple organ failure, and, without adequate treatment, to death [2]. The microcirculatory bed is a sphere where, ultimately, the transport function of the cardiovascular system is realized and transcapillary exchange is provided, which creates tissue homeostasis necessary for life [3]. As is known, microcirculation is not only a structural and functional unit of the circulatory system, in which the exchange between blood and tissues takes place, but also the most important source of information about the state of tissues, organs, and the body as a whole [4].

Inflammation of the abdominal cavity is a multicomponent complex of severe pathophysiological reactions with impaired functioning of all systems, which is based on a progressive infectious and inflammatory process, initially localized in the abdominal cavity [5]. One of the main pathogenetic factors of hemodynamic disorders are hypoxia and endotoxemia [6]. The severity of peritonitis, with rapidly advancing intoxication, is due not only to the action of microbial toxins, but also to a violation of local and systemic microcirculation [7]. Microcirculation disorders serve as a trigger for the development of central hemodynamic disorders in peritonitis, organically associated with the development of hypovolemia, hypoproteinemia, a decrease in circulating blood volume, loss of electrolytes and active enzymes [8].

The leading cause of the progression of peritonitis with subsequent adverse outcomes is enteral insufficiency – a violation of the excretory functions of the abdominal cavity [9]. Intoxication increases capillary permeability, toxic substances lead to the formation of inflammatory exudate [10]. With endotoxication of peritonitis in the toxic and terminal phases of its development, it is a complex multicomponent phenomenon in which factors

associated with unresolved sources of intoxication (damaged peritoneum and intestines in a state of deep paresis), factors associated with circulation in the internal environment of the body (blood, lymph, urine) toxic products of inflammatory destruction and factors arising from the effects of toxins on various organs and tissues [11].

The mesenteric blood flow plays a significant role in the general hemocirculation system. The amount of blood in the intestine is from 30 to 40% of all circulating blood; blood circulation of the intestine is provided by the vessels of the basin of the superior and inferior mesenteric arteries and veins [12]. Circulatory disorders in abdominal inflammation are among the most severe diseases and are accompanied by high mortality (up to 80% or more) [13].

It has been shown that in acute peritonitis against the background of the development of endotoxicosis, the functional activity of the liver is impaired [14]. The arterial blood supply of the stomach is carried out due to the branches of the celiac trunk, which, starting from the abdominal aorta at the level of the XII thoracic vertebra, with a short trunk of 1–1.5 cm, immediately splits into its three main branches – the left gastric artery, the splenic artery and the common hepatic artery involved in the blood supply of the stomach [15]. Liver dysfunction leads to an increase in systemic intoxication, damage to other body systems, changes in protein, lipid, enzyme, mineral, water metabolism, discoordination of protective, compensatory and reparative reactions [16].

There are various methods for studying microcirculation: reflected spectrophotometry, orthogonal polarization spectroscopy, dark-field spectroscopy, sublingual capnometry, laser Doppler flowmetry. The detection of pathology in the microcirculation is of great practical importance when choosing and evaluating the effectiveness of intensive care methods, especially in emergency cases [17]. However, one should not forget that not only changes in central hemodynamics characteristic of each variant (hypodynamic or hyperdynamic type of blood circulation) occur, but they also have their own characteristics and microcirculation disorders, which differ depending on the cause that led to this condition. The study of the nature of hemodynamic disorders in inflammation of the abdominal cavity will reduce their manifestations by acting on the leading pathogenetic factors. Purpose of the study: to study blood circulation in large vessels and organs during experimental inflammation of the abdominal cavity in animals.

Material and methods

The experiments were carried out on male Wistar rats weighing 250–270 g. The animals had a veterinary certificate. All animal experiments were carried out in accordance with the requirements of the directive. European Parliament (1986) and set out in the Guidelines for the protection of animals, for the care and use of laboratory animals used for scientific purposes, and approved by the local ethical commission of the Institute of Genetics and Physiology protocol No. 4 of 12/18/2021. All groups of animals were in the same conditions of feeding and keeping in vivarium conditions. The experiments were carried out on 35 white laboratory male rats weighing 250 ± 5 g. 2 groups of rats were formed, the 1st group – 15 control rats, the 2nd group with inflammation of the abdominal cavity (20 rats). We have chosen a method for modeling inflammation of the abdominal cavity by introducing fecal matter, which is similar in terms of peritonitis. Acute peritonitis in rats was caused by introducing fecal suspension into the abdominal cavity at the rate of 0.5 ml of a 10% solution per 100 g of animal body weight [18]. Animals for study were taken 44-48 hours after fecal injection. Anesthetization of animals was carried out by inhalation with ether through a mask into which a cotton wool with ether was placed. Animal thermometry was carried out with an Omron electronic thermometer.

The blood flow velocity in the abdominal aorta and inferior vena cava was studied by laser ultrasonic dopplerography against the background of inflammation of the abdominal cavity using the Sanomed-300 device (Russia). The study of the main arteries of the body was carried out with an ultrasonic probe (8 MHz) in the mode of constant wave radiation. Dopplerogram value, determination of the average systolic frequency, showing the weighted average blood flow velocity over the entire diameter of the vessel. The maximum (Vmax) blood flow velocity, the pulsation index (HR) were studied, the stress index or Purcelo circulation resistance (RI) was calculated [19, 20].

The blood flow velocity in the abdominal aorta and inferior vena cava was recorded by laser ultrasonic dopplerography against the background of acute peritonitis.

The quantitative assessment of blood flow in the arteries is based both on the direct changes in the Dopplerogram (amplitude, frequency, frequency distribution, impulse variations based on their various indices.

When calculating medical indices, the values of blood flow velocity curves at characteristic points are used. The parameters of blood flow are determined from the values of the curved characteristic points: V_{max} is the maximum blood flow velocity in systole, V_{min} is the final diastolic blood flow velocity, V_{av} is the average blood flow velocity over the cardiac cycle, V_{al} is the rate at which the systolic wave begins to rise. The resistance index will be:

$$RI = (V_{max} – V_{min}) / V_{max}$$

From there comes the index of circulatory resistance, i.e., resistivity, a group of indices includes: 1. Index of circulatory resistance (resistance) – RI (Purcelo index), by the ratio of the difference between the maximum systolic (A) and the final diastolic and systolic frequency (Dk):

$$RI = (A – Dk) / A$$

Pulsation index calculation formulas PI = (Vmax – Vmin) / Vav: from there comes the pulsation index – PI (Gosling index), is the ratio of the difference between the maximum systolic (A) and maximum diastolic frequencies (D_m) to the average frequency for the cardiac cycle (Fc):

$$PI = (A – D_m) / F_c$$

The digitization of data coming from the ultrasonic device was carried out using the computer program «Statistica 8».

To determine the parameters of hemodynamics in the abdominal organs, the method of tetrapolar rheography was used and the data of differential rheograms characterizing the rate of change in the blood filling of the studied area were used;registration of rheograms was carried out using the hardware software rheographic complex «Mizar-Reo» (Russia).

To study the blood filling of the vessels, impedancemetry of the carotid artery of animals was carried out; to study the blood filling of tissues, impedancemetry was carried out using a Mizar-Reo rheograph (Russia). To register the results of studies in the abdominal region, methods were used based on preventing the full effect of electrode polarization during tetrapolar testing by the method of rheohepatography and rheorenography.The rheogram was carried out according to the generally accepted method, directing ultrasonic electrodes to different parts of the body so that they do not diverge. Registration of the rheography index was recorded automatically via a computer [20, 21]. The data of the differential rheogram characterizing the rate of change in the blood filling of the study area were used.The following indicators were calculated: systolic wave amplitude (ASV, Om/s), rheographic index (RI, Om), average blood filling rate (SVR, Om/s), dicrotic index (DCI, %). The anesthetized animal was placed on a heated table to maintain normothermia throughout the experiment. Access to the abdominal cavity was carried out through a median laparotomy.After that, a section of the abdominal aorta was isolated, on which a bandage-type sensor was applied. Statistical processing of the results was carried out using the Excel program. The results were expressed as mean ± standard error of measurement. To assess the statistical significance of differences, a t-test was used at a significance level of $p < 0.05$.

Results and Discussion

Inflammation of the abdominal organs, this is due to the fact that the number of patients, including those with severe forms of this disease, is constantly increasing. It is observed with inflammation of the parietal and visceral layers of the peritoneum, which is accompanied by a severe general condition of the body. In animals with inflammation of the abdominal cavity after the introduction of fecal suspension, we observed a change in the behavior of the animals. Animals throughout the observation period were inactive, symptoms characteristic of acute diffuse peritonitis: lethargy, disheveled wool, increased respiration, shortness of breath, refusal to eat, stool retention and bloating. The rats concentrated in one of the corners of the cage. When modeling acute inflammation of the abdominal cavity in our experiments on rats, after 48 hours the lethality was 18% of the total number of animals. In the following days, the percentage of lethality of animals increased and by day 5 was 57%, accumulation of a large amount of fluid was observed in the abdominal cavity. The temperature of the animals increased to 40.6±1.20 C (control 38.5±0.40^{C}).

Using modern ultrasound dopplerography during the study of the abdominal cavity, it is possible to determine the blood flow velocity of the abdominal cavity and the extraperitoneal space. The influence of the inflammatory process on the parameters of systemic hemodynamics is shown in Table 1, and on the indicators of blood supply to the abdominal organs – in Table 2.

When opening the abdominal cavity, 2 to 5 ml of inflammatory exudate of a serous or purulent nature,

sometimes with a hemorrhagic component, were found. The rheography showed a slight increase in the blood accumulation of the muscles of the body. In animals with inflammation of the abdominal cavity, an increase in blood flow velocity in the abdominal aorta of 31.6±0.04 cm/s was found, in the control group it was 27.1±0.06 cm/s.The study of blood flow velocity in the main vessel (portal vein) against the background of acute inflammatory processes showed an increase in the linear blood flow velocity in the inferior vein, which amounted to 22.4±0.03 cm/s (in control -19.4±0.02 cm/s).

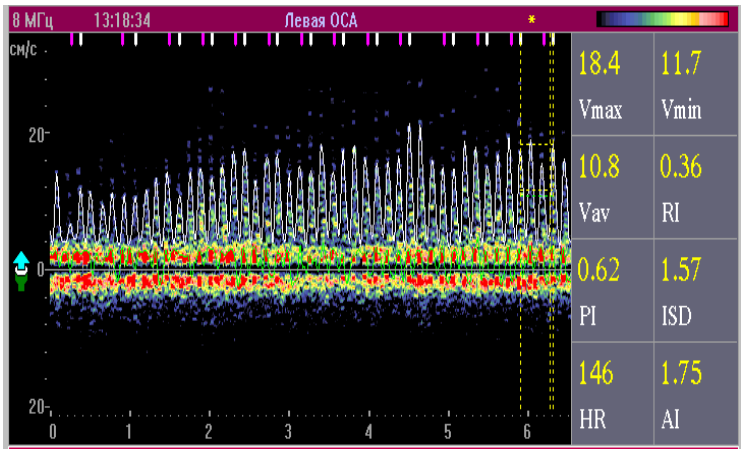
The study showed that in case of inflammation of the abdominal cavity, the blood flow velocity in the main vein by laser ultrasound Dopplerography showed an increase in the linear frequency of blood flow in the main vein by 22.4 ± 0.03 cm/s (normal – 19.4 ± 0.02 cm/s). As can be seen from Table 3, the resistance index in the main vessel RI decreased by 38.3%, which is associated with an increase in the diameter of the main vessel.In acute inflammation of the abdominal cavity, an increase in blood flow velocity in the maxillary artery was recorded, which amounted to 31.6±0.04 cm/s, and in inflammation of the abdominal cavity, the blood flow velocity was 27.1±0.06 cm/s. The rhythmic (pulse) index decreased by 16-21% both in the main vein and in the abdominal artery (Table 1).

Table 1 – Parameters of blood flow in the vessels of the portal system in rats with experimental inflammation in the abdominal cavity and gentle vena cava.

Groups	Blood flow velocity, cm/s	PI (pulsation index)	RI (resistance index)
parameters in the portal vein			
Control group	19,4±0,02	1,06±0,01	0,65±0,05
group with inflammation of the abdominal cavity	22,4±0,03	0,89±0,07 *	0,40±0,02*
indicators in the abdominal aorta			
Control group	27,1±0,06	4,56±0,03	0,84±0,003
group with inflammation of the abdominal cavity	31,6±0,04	3,68±0,07**	0,66±0,002**
Note: significantly compared with control, -p<0.05*, -p<0.001*			

Doppler studies were carried out, which showed that after the introduction of a fecal suspension of changes in the walls of the vessels of the abdominal aorta, in the surrounding tissues. On the organs of the abdominal cavity and on the mesentery of the intestine, there are separate small-focal hemorrhages. The loops of the intestines are swollen, filled with dark-colored masses, in some places the intestine is edematous, the vascular pattern of the intestinal wall is enhanced. An accelerated blood flow in the abdominal aorta was observed with inflammation of the abdominal cavity after the introduction of fecal suspension (Figure 1).

The study of the integral rheography of the body of rats in the control group, the amplitude of the systolic wave decreased compared to the control group of rats to 0.011±0.005 Ω/s, the rheographic index decreased by 0.36±0.02 Ω, which indicates a deterioration in the elastic-tonic properties of the wall of small arterial vessels and medium caliber. The rate of rapid blood filling decreased compared to the control group. The elasticity of the vessels decreased sharply, by 82% of the control. These indicators indicate changes in the blood supply to the tissues of the body of rats. At the same time, an increase in the speed of fast blood filling up to 0.11±0.004 Ohm/s, and the speed of slow blood filling up to 0.03±0.004 were observed. The modulus of elasticity of peripheral vessels decreased slightly. The dicrotic index (DCI) was 81%, indicating insignificant changes in the arterial system (Table 2). According to rheographic data, it can be seen that in rats with acute peritonitis, there is a decrease in slow and fast blood supply by 16% in the liver, in the stomach – by 11%, due to an increase in the diameter of the vessels compared to the control group of animals. The increase in DCI (dicrotic index) compared with the control is due to spasm of the arterial (up to the capillaries) bed of the splanchnic blood flow and, above all, the arteries of the mesenteric vascular basin.



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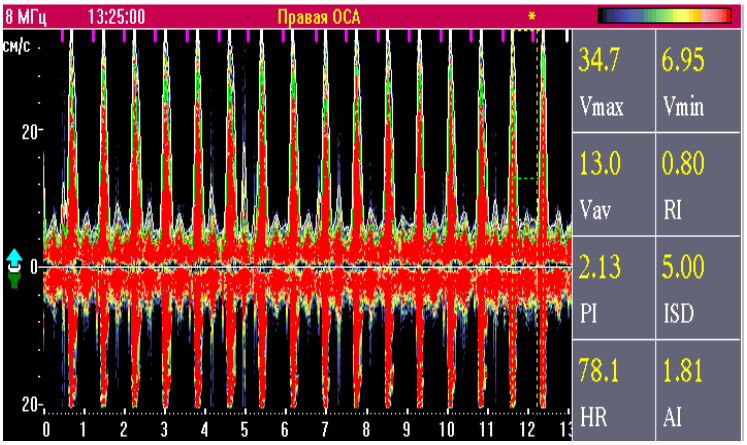

B

Designations: A – control, B – after inflammation of the abdominal cavity

Figure 1 – A fragment of the experiment with dopplerogram of the abdominal aorta in rats

Table 2 – Indicators of volumetric blood flow in the liver and stomach with inflammation in the abdominal cavity

Name	Controlg roup (liver)	Acute peritonitis (liver)	Control group (stomach)	Acute peritonitis (stomach)
Systolic wave amplitude, Ohm/s	0,013±0,001	0,011±0,005	0,017±0,001	0,015±0,005
Rheographicindex, Ohm	0,5±0,002	0,32±0,003	0,24±0,002	0,41±0,003
Average rate of blood filling, Ohm/s	0,20±0,003	0,14±0,003*	0,27±0,003	0,19±0,003*
Systolic wave amplitude, Ohm/s	0,09±0,0032	0,017±0,004*	0,11±0,0032	0,024±0,004*
Rheographicindex, Ohm	0,01±0,005	0,001±+0,0002*	0,01±0,005	0,007±0,0002*
Average rate of blood filling, Ohm/s	100	45,7**	100	57,2**
DCI, %	100	67,3**	100	78,3**
Note: significant compared to control, -*p<0.05, -**p<0.001*				

In the course of the study, we clarified that the liver and stomach have a number of additional sources of blood supply. According to the indicators characterizing the ratio of inflow and outflow, a decrease in dicrotic, diastolic indices and peripheral resistance index was revealed. The dicrotic index decreased significantly after acute peritonitis in animals. The decrease was 33.7% in the liver and 21.7% in the stomachs ($p<0.001$), which characterizes the decrease in peripheral resistance. Peripheral resistance index, i.e. the rheographic index also turned out to be statistically significantly lower in the liver by 64%, in the stomach of rheographic shifts there is a different-sized and multidirectional nature of vascular reactions, in comparison with the control group after acute peritonitis it increased by 70.8%. The amplitude of the systolic wave decreased by 15.2-12% respectively in the liver and stomach in animals. The data we obtained of monotonous rheographic shifts in the stomach testify to their gastric binding, as well as the phase nature of the functional vascular reactions in the stomach that we identified, and this can be assumed to be the nervous regulation of gastric circulation.

With peritonitis, rapidly advancing intoxication is caused not only by the action of microbial toxins, but also by a violation of local and systemic circulation [22].

The conducted studies have shown that the use of Doppler ultrasound examination of large vessels in animals with peritonitis makes it possible to identify significant circulatory disorders, which, along with disorders of systemic hemodynamics, microcirculation and metabolism, play an important role in the pathogenesis of a severe abdominal infectious and inflammatory process. With peritonitis, significant morphofunctional changes occur in the vessels. In the presence of an infection in the abdominal cavity and the development of a stressful state, there is a further deepening of macro and microcirculatory disorders, which leads to an increase in arterial blood flow. Circulatory disorders are most clearly seen in the portal vein system and consisted of an increase in linear blood flow velocities, a significant increase in blood flow velocity in the abdominal aorta, in comparison with the control group.

The study of methods for the integral assessment of blood circulation in organs and their areas showed that rheography is the most informative and safe of them [23]. A significant advantage of rheography is the ability to simultaneously study the circulation of various areas of the body, which makes it possible to evaluate the patterns of general hemodynamics in studies. Of particular value, rheography allows diagnosing early disorders in the circulatory system [24].

One of the pathogenetic factors of hemodynamic disorders in peritonitis, identified in the experiment, is the deterioration of rheographic parameters. As follows from Table 2, the rate of rapid blood filling decreased and changed significantly compared to the control group.

The study showed that the rate of rapid blood filling and the elasticity of peripheral vessels decreased compared to the control group. Studies have shown a decrease in slow and fast blood circulation in the liver and kidney, and thus a decrease in blood circulation in these organs.

Peritonitis is considered by many researchers as peritoneal sepsis, in which the focus of infection is the abdominal cavity. Any septic condition is simultaneously stressful, characterized by a typical violation of central hemodynamics and disorders of regional circulation in the form of centralization of blood flow and aggravation of the periphery, first of all, mesenteric blood flow and skin circulation suffer [25, 26] .

Thus, the rheographic study of the abdominal cavity blood circulation, based on the new principle of rheography, is a reliable, non-invasive, technically simple and unlimited in time method for recording relative pulse fluctuations in the blood filling of the arterial basin of the abdominal cavity, in the liver and stomach.

The data obtained show that significant changes in the circulatory system during experimental inflammation of the abdominal cavity caused by fecal matter in animals were observed centralization in the circulatory system of an increase in the blood flow of the abdominal cavity in the large vessels of the abdominal aorta and abdominal vein, a decrease in blood circulation in the abdominal organs.

In inflammatory processes in rats, after 48 hours from the start of the simulation, a significant decrease in vascular tone and blood supply to tissues and organs was observed in the blood circulation. That is, a decrease in the blood circulation of the abdominal organs and an increase. Increased blood flow in the abdominal artery and inferior vena cava is shown.

Conclusion

It has been established that in experimental inflammatory processes, after 48 hours from the beginning of peritonitis modeling, the total blood flow in the abdominal aorta increases, the diastolic

blood flow velocity. Also, an increase in the linear velocity of blood flow in the inferior vena cava, a decrease in the resistance index in the vessels. The resistance index RI in the abdominal artery to the portal vein also decreased in the portal vein by 38.3% and 19.2%, respectively, this is due to the fact that inflammation of the abdominal cavity increases the diameter of the vessels of the portal vein.

Using the method of tetrapolar rheography, hemodynamic parameters of the liver and stomach were evaluated. The formation of hypodynamic blood circulation in the abdominal organs is shown. With inflammation of the abdominal cavity, the blood supply to the abdominal organs decreased and the blood flow velocity in the main vessels increased, as well as the stroke index and cardiac index decreased, and the minute volume of blood circulation in the liver and stomach decreased.

Conflict of interest

The authors have worked together, have read and are familiar with the content of the article and have no conflict of interest.

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