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Biochemical parameters of blood in cats with cardiogenic arterial thromboembolism and acute heart failure

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Abstract. Investigating the impact of vascular blockage on blood biochemical parameters, particularly in the context of acute heart failure, is crucial for understanding the underlying mechanisms of arterial thromboembolism in animals. The purpose of the study is to investigate the effect of vascular occlusion on the biochemical parameters of blood in cats with cardiogenic arterial thromboembolism. The study involved 12 cats and formed two groups: the first – animals with acute heart failure and the second – animals with arterial thromboembolism. Anamnesis data were collected for experimental animals, clinical examination, echocardiography, and biochemical examination of blood samples were performed. The activity of alanine aminotransferase, aspartate aminotransferase and gamma-glutamyl transpeptidase, the concentration of glucose, creatinine, urea, potassium, calcium, total and inorganic phosphorus were determined spectrophotometrically in blood serum. It was found that in cats with acute heart failure, the average value of serum aspartate aminotransferase activity increased by 2.8 times, and the creatinine concentration by 1.9 times compared to the upper limit of reference values. This indicates functional changes in the myocardium and kidneys in this pathology. In cats affected by arterial thromboembolism, the blood serum shows a significant elevation in various biochemical parameters compared to the upper limit of the corresponding reference intervals. Specifically, there is a 4.4-fold increase in alanine aminotransferase activity, a 4.3-fold increase in aspartate aminotransferase activity, a 1.4-fold increase in glucose concentration, a 1.8-fold increase in creatinine levels, a 2.0-fold increase in urea levels, and a 1.3-fold increase in inorganic phosphorus levels. The changes in biochemical parameters for feline thromboembolism may be a consequence of functional renal failure, ischemia, and muscle necrosis. Moreover, it was established that in most cats with acute heart failure, the urinary system is primarily affected, and with arterial thromboembolism, changes in muscle tissue also occur. The results obtained are of practical value for veterinary doctors when choosing a therapeutic strategy and prescribing additional diagnostic examinations

Keywords: hypertrophic cardiomyopathy; diagnosis; ischemia; pulmonary oedema; renal failure

Introduction

Among the considerable variety of heart diseases, cats are more likely to develop cardiomyopathies. Hypertrophic cardiomyopathy (HCM) ranks first in terms of prevalence, followed by dilated (DCM) and restrictive (RCM), less often arrhythmogenic (ACM) or unclassified cardiomyopathy (UCM) (Fuentes *et al.*, 2020; Tishkina *et al.*, 2022). Based on statistical data on the incidence and risk of non-cardiovascular death in clinically healthy cats and in cats with preclinical hypertrophic cardiomyopathy, Fox *et al.* (2019) found that mortality from various causes was notably higher in the group of animals with hypertrophic cardiomyopathy.

In the study by Fox *et al.* (2019), complications of cardiomyopathies include the development of heart failure (HF), arterial thromboembolism (ATE), and sudden cardiac death. The latter is not sufficiently studied among cats and is obviously more common than is possible to register. The most common structural cause of sudden death is HCM (Brugada-Terradellas *et al.*, 2021).

Acute heart failure is often the first manifestation of heart disease in cats, characterised by a rapid and severe course. Most often, hypothermia, tachycardia, auscultatory – gallop sound, and respiratory symptoms: dyspnea and tachypnea are registered. Notably, Liu *et al.*

(2020) established that animals with congestive heart failure have a substantially higher respiratory rate, a larger left atrium diameter, and a higher left atrium-to-aorta ratio compared to cats with preclinical cardiomyopathy. Kostiuk *et al.*, (2020) found that the mortality rate of cats with acute heart failure is most affected by the presence of systolic dysfunction, increased size of the left atrium, and the degree of radiological changes. According to Liu *et al.* (2020), in animals with congestive heart failure, serum concentrations of symmetric dimethylarginine (SDMA) and creatinine were elevated compared to preclinical and healthy cats.

Romito *et al.* (2022) provided a study of two cats with acute heart failure that was associated with *Toxoplasma gondii*. In one of the animals an increase in the activity of alanine aminotransferase, creatinine kinase, concentration of urea, serum amyloid A and troponin I was noted in the blood serum, while in the other – an increase in the activity of creatinine kinase and troponin I level. Studies of electrolyte abnormalities and markers of kidney damage in animals with heart failure are of great interest. A change in electrolyte balance is associated with neurohumoral activation of the renin-angiotensin-aldosterone and arginine-vasopressin systems, the use of diuretics (Roche-Catholy *et al.*, 2021; Lean *et al.*, 2022). Serum creatinine and potassium concentrations also change in both cats and dogs in response to furosemide administration (Ohad *et al.*, 2018).

The development of HF is associated with the occurrence of cardiogenic arterial thromboembolism – an acute blockage of a blood vessel that leads to ischemia of a certain area (Fox *et al.*, 2018). The prevalence of pathology is about 15% (Busato *et al.*, 2022).

The formation of a blood clot is a complex process that can have a different course, but the main elements will always be the components of Virchow's triad. The resulting embolus

moves with the flow of blood and clogs a vessel smaller in diameter. Occasionally, occlusion of blood vessels of internal organs or the brain is diagnosed. The most common location for a blood clot is in the terminal branches of the aorta when both pelvic limbs are affected. With this location, the pathology is manifested by paresis or paralysis of the limbs, hypothermia, anaemia or cyanosis of non-pigmented areas of the skin of the affected limbs and vocalisation of pain (Hassan *et al.*, 2020).

Abnormally high levels of laboratory indicators are often registered in cats with ATE. Thus, in a retrospective study by Mitropoulou *et al.* (2022), in animals hospitalised for arterial thromboembolism, hyperglycemia and high serum creatine phosphokinase activity were noted as the most common abnormalities.

The purpose of this study is to determine the effect of vascular blockage on the quantitative characteristics of biochemical parameters of blood serum. Cardiomyopathy and congestive heart failure have a considerable number of similar elements. This allows separating the influence of heart pathology and investigating the effect of vascular occlusion on the body separately.

Task: to compare the values of biochemical blood parameters in cats with cardiogenic arterial thromboembolism and acute heart failure with cardiomyopathy.

Literature Review

The investigation of pathologies of the heart of cats is of great interest to researchers from all over the world. In addition to veterinary medicine research, humane doctors attach great importance to studying cardiomyopathies. Thus, the HCM phenotype in cats is very similar to the HCM phenotype in humans, but the pathology has a faster course and is a very valuable model to study (Stern *et al.*, 2019).

Today, the scientific community places significant emphasis on research areas pertaining

to arterial thromboembolism in cats, focusing on enhancing diagnostic techniques and advancing therapeutic and preventive strategies. Thus, French researchers (Eberle *et al.*, 2022) described the ultrasound characteristics of arterial thromboembolism in cats and identified a potential relationship between ultrasound results and predicting the development of the disease. The link between cardiogenic pleural effusion and a reduced risk of arterial thromboembolism in cats was found in a study by Italian researchers (Busato *et al.*, 2022). One of the latest publications on the treatment and prevention of thromboembolism in cats is a study on the effectiveness of dual therapy with clopidogrel and rivaroxaban (Lo *et al.*, 2022).

For this study, it is of interest to examine biochemical abnormalities in cats with arterial thromboembolism and acute heart failure. These pathologies are commonly mentioned in studies dealing with a broader subject – feline cardiomyopathy (Fuentes *et al.*, 2020; Kittelson *et al.*, 2021), and the highly specific studies on them are not often published. A large number of large-scale and fundamental studies on this subject with a description of clinical and laboratory indicators were published in the late 1990s and early 2000s. From modern sources, the most complete is the study of 250 cats with arterial thromboembolism in general practice (Borgeat *et al.*, 2013). However, of the biochemical parameters, only the concentrations of urea, creatinine, phosphates, and potassium are highlighted in this paper. Therefore, there was a need to refer to the study that was conducted earlier (Smith *et al.*, 2003). The features of biochemical blood analysis in cats with ATE are thoroughly described by Moise (2007).

Studies on acute heart failure in cats face a similar situation. While the topic is often discussed within broader subjects like cardiomyopathy, there is a limited amount of research specifically dedicated to this pathology as an

independent focus. More often, researchers examined the effect of pathology on the concentration of electrolytes in the blood serum (Roche-Catholy *et al.*, 2021), interaction of biomarkers of kidney damage, myocardium, and inflammatory proteins (Liu *et al.*, 2020). Ohad *et al.* (2018) described changes in sodium, chloride, creatinine, and calcium concentrations in response to furosemide administration. The most extensive features of biochemical analysis of blood serum in cats with acute heart failure are described by Gountal *et al.* (2010).

Currently, cardiological pathologies of small animals have gained popularity among Ukrainian researchers. The subject of cardiogenic pulmonary oedema is covered by Zamorska *et al.* (2021). The prevalence of cardiomyopathy and arterial thromboembolism phenotypes in cats was investigated by Petrushko & Grushanska (2022). Kostiuk *et al.* (2020) devoted their study to echocardiographic parameters in cats with hypertrophic cardiomyopathy; a description of the aetiology and classification of feline cardiomyopathy are provided by Plysiuk & Tsvilikhovski (2016); report of clinical cases of hypertrophic cardiomyopathy in cats is presented by Tishkina *et al.* (2022), which expand the knowledge about this pathology.

Materials and Methods

The study was conducted based on the VetHouse veterinary centre in Vinnytsia (hereinafter VC). In the database for 2021-2022, a search for animals was conducted using keywords in the diagnoses: “pulmonary oedema”, “heart failure”, “cardiomyopathy”, and “arterial thromboembolism”. Records were analyzed, and those animals were selected that had a complete history, clinical examination, echocardiographic examination of the heart, and in which biochemical indicators of blood were examined. Cats who were first admitted with symptoms of acute congestive heart failure and

arterial thromboembolism were selected. Animals with information about previously diagnosed chronic heart failure were excluded from the study. Previous administration of drugs to stabilize the condition was not an exclusion criterion if this was the first case of heart failure.

To confirm the cardiological pathology, the animals underwent an echocardiographic examination using Esaote MyLab Gamma (Italy) or General Electric Vivid S6 ultrasound devices (USA). A 7.5 MHz phased array sensor was used. In already stable animals, the examination was performed on the right and left sides using B-mode, M-mode, and Doppler echocardiography. The right parasternal (short and long axis) and left apical positions were assessed. If it was necessary to conduct an examination before the condition stabilizes, echocardiography was performed only from the right parasternal position. Signs of left-sided congestive heart failure were considered (assessment in the right parasternal access): the size of the left atrium in the 4-chamber projection is more than 14 mm, the ratio of the left atrium to the aorta is more than 1.7 in the short projection.

Biochemical examination of cat blood serum samples was performed using a BS-3000m Sinnowa biochemical analyser (China) and SpainLab reagents (Kharkiv). Indicators studied: alanine aminotransferase (ALT; EC 2.6.1.2), aspartate aminotransferase (AST; EC 2.6.1.1), gamma-glutamyl transpeptidase (GGTP; ES 2.3.2.2), creatinine, urea, glucose, phosphorus, potassium, calcium.

The cats were divided into two groups. The group of animals with “acute heart failure” included cats admitted to the veterinary centre with respiratory signs (tachypnea, dyspnea), hypothermia, tachycardia, and echocardiographic signs of left-sided congestive heart failure. One cat had a restrictive cardiomyopathy phenotype, and five had a hypertrophic

cardiomyopathy phenotype. All were males aged 1 to 9 years. They belonged to the Bengal, Himalayan, European shorthair, Sphinx, Scottish fold, and Scottish longhair breeds.

The group of cats with “cardiogenic arterial thromboembolism” included animals that were admitted to the veterinary centre in an urgent state. Owners noted a sudden deterioration in the animal’s condition, vocalisation, aggression, shortness of breath, and lack of functioning of the pelvic limbs. During the clinical examination, paresis or paralysis of the pelvic limbs, anaemia or cyanosis, hypothermia, tachypnea, dyspnea, tachycardia, pain and aggression were noted. Echocardiographic examination revealed congestive heart failure. Five cats had the hypertrophic cardiomyopathy phenotype, and one had the restrictive cardiomyopathy phenotype. Two animals each belonged to the European shorthair and Mestizo breeds; one each belonged to the European long-haired and British shorthair breeds. Four of the six animals belonged to males. The animals ranged in age from 4 to 13 years.

Statistical analysis was performed using a personal computer and Microsoft Office Excel 2007 program. From the obtained data (concentration of indicators), variational series were developed. The normality of continuous data was proved according to the empirical rule: if a random variable is distributed normally, the absolute value of its deviation from the mathematical expectation does not exceed three times the mean square deviation. The statistical significance of differences between groups of cats was checked using the student’s t-test and expressed using the probability of error (P). The difference between the groups was considered significant at $P < 0.05$. For descriptive analysis, the data were presented as the arithmetic mean (M ; \bar{x} – the sum of all fixed values of the set divided by the number of terms) and the standard error of the mean

Results and Discussion

($\pm m$ is an indicator of the accuracy of the average value of the sample).

Information on compliance with bioethical standards. The study complied with the ARRIVE guidelines and was conducted without violating the guidelines of the EU Directive 2010/63/EU on the protection of animals used for scientific purposes (Percie du Sert *et al.*, 2020; Direktive 2010/63/EU..., 2010).

Among the studied and analysed parameters of blood serum in cats with arterial thromboembolism, the average value of alanine aminotransferase, aspartate aminotransferase activity, creatinine, glucose, urea, and phosphorus concentrations are higher than the reference range and the values obtained from cats with acute heart failure (Table 1). However, the difference was not always significant.

Table 1. Biochemical parameters of cat blood serum with acute heart failure and arterial thromboembolism, $M \pm m$

Biochemical parameters	Animals with acute heart failure		Animals with arterial thromboembolism		Reference values
	$M \pm m$	Number of cats with a value outside the reference range (n)	$M \pm m$	Number of cats with a value outside the reference range (n)	
ALT, U/L	51.7 \pm 15.6	1	329.0 \pm 59.5**	6	5.0-5.0
AST, U/L	140.9 \pm 43.9	5	215.5 \pm 47.7	6	5.0-50.0
GGTP, U/L	5.0 \pm 1.5	0	9.5 \pm 1.8	3	0.0-10.0
Creatinine, mmol/L	162.9 \pm 19.0	5	251.0 \pm 23.2*	6	50.0-140.0
Potassium, mmol/L	4.2 \pm 0.5	1	4.8 \pm 0.1	0	3.7-6.1
Calcium, mmol/L	2.2 \pm 0.1	4	1.9 \pm 0.1	5	2.2-2.9
Glucose, mmol/L	7.2 \pm 1.8	2	9.0 \pm 1.5	5	3.6-6.5
Urea, mmol/L	13.4 \pm 1.9	4	22.0 \pm 5.1	6	5.5-11.0
Phosphorus, mmol/L	1.6 \pm 0.1	1	2.3 \pm 0.4	5	0.9-1.7

Note: * $P < 0.01$, ** $P < 0.001$ compared to the group of cats with acute heart failure

In the blood serum of all animals with arterial thromboembolism, an increase in alt activity was found by 4.4 times compared to the upper limit of reference values. This intracellular enzyme is found mainly in liver and kidney cells, and in smaller amounts in heart muscle and skeletal muscle. Similar results were published earlier: out of 127 cats with arterial thromboembolism, an increase in ALT activity was observed in 72.8% of animals and a decrease in 1.2% (Smith *et al.*, 2003). This is probably due to large-scale necrosis of muscle tissue (Moise, 2007). Moreover, among cats with acute

heart failure, the activity of the aforementioned enzyme increased only in one animal out of six. This is consistent with the results of a retrospective study in which 45 cats with heart failure were examined, and only 7 of them had increased activity of this indicator (Goutal *et al.*, 2010). In this study, in the group of animals with arterial thromboembolism, the average value of the indicator's activity increased in the blood by 6.4 times compared to the group of cats with acute heart failure. The difference in indicators in the two groups is significant, so it can be argued that a high probability of an

increase in ALT activity in the blood serum is associated with muscle damage and, to a lesser extent, with myocardial damage. In addition, there is a high probability of an increase in the value of the indicator due to renal ischemia, because the concentration of urea and creatinine was also higher in cats with arterial thromboembolism. The probability of an increase in ALT activity in the liver in this case seems less likely.

Aspartate aminotransferase is one of the first cardiac biomarkers in history. It is used for the diagnosis of heart diseases, but it is of limited importance due to low sensitivity and lack of cardiac specificity. An increase in serum AST activity in animals with heart failure is expected, but it is not clear whether the development of thromboembolism will affect the activity of the indicator. In the blood serum of most of the studied animals ($n = 11$), except for the cat with acute heart failure, AST activity increased. The average activity value in animals with thromboembolism was higher, although the difference in AST activity between the two groups was insignificant ($P < 0.2$). A larger study of animals with acute heart failure showed an increase in AST activity in a smaller number of cats – in 17 out of 45 (Goutal *et al.*, 2010).

Gamma-glutamyltranspeptidase is classified as an enzyme involved in the metabolism of amino acids. This enzyme is found in the cells of the liver, bile ducts, and kidneys. All animals with acute heart failure had GGTP activity within physiological parameters, but cats with arterial thromboembolism ($n = 3$) had increased GGTP activity. The difference between the groups is defined as insignificant ($P < 0.1$). The most likely cause of the increased activity of this indicator is kidney injury.

Increased activity of AST, ALT, and GGTP is more common in liver, kidney, and heart diseases. Goutal *et al.* (2010) call increased activity of liver enzymes (alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase)

in cats with acute heart failure one of the most common abnormalities, and suggest that this is the result of low cardiac output or passive stagnation. In this study, acute heart failure was associated with the development of hypertrophic and restrictive cardiomyopathies. With these pathologies, the structure of the myocardium changes, relaxation slows down, and left ventricular stiffness increases. In this case, there is a violation of diastolic function. The chamber stretches worse, so blood enters the left ventricle under greater pressure, and its blood supply decreases. Increased diastolic pressure in the left ventricle is accompanied by increased pressure in the left atrium, pulmonary veins, and capillaries. As a result, there is stagnation of blood in the small circle of blood circulation. In the acute state, afferent vasoconstriction occurs when the neurohormonal system is activated. Because of this, liver perfusion may decrease, and systemic hypotension may occur. Such heart failure is classified as left-sided retrograde. Stagnation of blood can also be transmitted to a large circle of blood circulation, however, this is more typical for people. In cats, this is rarely recorded in the end stages of the disease. Concerning stagnation of blood, which can cause complications in the liver, it is reasonable to discuss right-sided retrograde heart failure, which is characteristic of the development of other heart pathologies and is more common in dogs (dilated cardiomyopathy, end-stage endocarditis of the mitral valve, etc.).

It is more likely that during the development of acute left-sided heart failure in cats, perfusion of organs (including kidneys and liver) was reduced, and the obtained deviations in biochemical parameters are primarily associated with renal ischemia, to a lesser extent, with damage to the myocardium and liver, and in the case of cats diagnosed with arterial thromboembolism, with muscle necrosis.

Serum creatinine concentration is considered a marker of glomerular filtration rate and is used in animals with heart failure to monitor renal function. In the blood serum of 92% of the studied cats ($n = 11$), the creatinine content increased and the difference in the concentration of this indicator between the groups was significant. In cats with arterial thromboembolism, the average value of the indicator increased by 1.5 times compared to animals with acute heart failure. Analyzing cases of acute heart failure in cats, Goutal *et al.* (2010) recorded an increase in creatinine concentrations relative to reference values in a smaller percentage of animals (11 out of 45 cats). The authors do not indicate that this deviation is common in cats with AHF. However, compared to healthy animals, creatinine concentrations in cats with congestive heart failure are usually higher. This is proved by the study on the cardiovascular-renal axis by Liu *et al.* (2020), during which an increase and correlation of creatinine and other renal biomarkers were observed in animals with congestive heart failure compared to healthy cats and animals with preclinical cardiomyopathy.

Borgeat *et al.* (2013) examined creatinine concentrations in only 30 of the 250 cats diagnosed with arterial thromboembolism. An increase in the value of the indicator relative to the reference intervals was found only in 26.7% of cats. In a study conducted based on the VetHouse veterinary centre (Vinnytsia), an increase in the concentration of this indicator was observed in all cats with a significant difference compared to the group of cats with AHF. The differences between the results obtained and the mentioned literature data may be explained by the smaller number of animals in the study.

The content of urea in the blood serum of all the studied animals with arterial thromboembolism increased (more than the physiological limit), and its average value is higher compared to the second group (22,05). Among

animals with AHF (13,4), the urea concentration index was within the reference interval in two animals. The difference between the groups was statistically insignificant ($P < 0.1$). In most of the studied cats with AHF, the urea content in the blood increased (Goutal *et al.*, 2010), and in 68.6% of cats with arterial thromboembolism (Borgeat *et al.*, 2013). It can be stated that the concentration of urea often increases both in the blood of cats with AHF and with arterial thromboembolism.

Serum potassium concentrations in 11 cats were within physiological parameters and almost did not differ between the groups. Other authors indicate that 27.3% of 22 cats with arterial thromboembolism developed hyperkalemia (Borgeat *et al.*, 2013). Probably, such results are due to the fact that the study was conducted in the first hours after the occurrence of vascular occlusion, and hyperkalemia as a marker of reperfusion syndrome can develop at any time within three weeks after the incident of arterial thromboembolism.

In the blood serum of a cat with hypertension, a reduced potassium content was found. In a study conducted on 34 cats with AHF, 79% of the potassium content was within physiological parameters, and 21% had hypokalemia. Blood potassium concentrations did not affect the survival of cats (Roche-Catholy *et al.*, 2021). American researchers proved that the potassium content in the blood of 33 animals was within physiological limits, hypokalemia was observed in 10 and hyperkalemia in 2 (Goutal *et al.*, 2010). Hypokalemia in the blood of cats during the study was caused by the use of furosemide before blood sampling.

An increase in serum creatinine and urea concentrations in sick cats indicates changes in renal function, possibly as a result of hypoperfusion and activation of neurohumoral systems in patients with heart failure. In a study conducted by Plysiuk *et al.* (2017) on cats with

hypertrophic cardiomyopathy and symptoms of pulmonary oedema (AHF), they observed a significant increase in serum urea concentration by 2.5 times and creatinine by 2.2 times compared to clinically healthy cats. There is a strong link between the renal and cardiovascular systems. In humans, renal dysfunction is considered an important prognostic factor for heart failure Liu *et al.* (2020). In most cats with congestive heart failure, azotemia is observed and the number of cases of detection of this anomaly increases with the progression of heart pathology. According to the findings from Liu *et al.*'s (2020) study on cats with primary cardiomyopathy and cardiovascular-renal axis dysfunction, all cardiorenal biomarkers, including creatinine, exhibited a positive correlation and were higher in cats with heart failure. Additionally, elevated levels of the natriuretic hormone (B-type) N-terminal polypeptide (NT-proBNP) and symmetric dimethylarginine (SDMA) were associated with an unfavourable prognosis. Such results indicate a close functional relationship between the heart and kidneys in heart failure. In addition, congestive heart failure is an inflammatory disorder, and the prognosis, in this case, can be determined by the degree of inflammation and, possibly, the level of residual kidney function.

A systematic study of morbidity and mortality risk in cats by Fox *et al.* (2018) showed that cats with preclinical hypertrophic cardiomyopathy were slightly more likely to die from chronic kidney disease (CKD). If among clinically healthy animals the mortality rate from CKD was 6.4%, in animals with HCM, this indicator was 7.5%. This indicator is actually higher, but it differs slightly from clinically healthy animals in the control group. For comparison, the mortality rate from cardiovascular pathology in the group of cats with cardiomyopathy was 27.9%, and in the control group, only 1%. The authors note that mortality from non-cardiovascular

diseases was similar between the study groups. Therefore, abnormalities in kidney function are often recorded in cats for cardiomyopathy, but such animals die from CKD no more often than animals that do not have HCM.

Some cats have arterial thromboembolism, as Borgeat *et al.*, (2013) noted, who also reported severe azotemia or hyperkalemia. Still, the incidence of acute metabolic disorders may have been underestimated due to periodic monitoring. As indicated by the authors, azotemia and hyperkalemia can be caused by reperfusion injury or acute kidney damage.

In the study, all animals involved were diagnosed with left-sided congestive heart failure, which is classified as "wet and cold" from a hemodynamic perspective. Pouchelon *et al.* (2015) established that cardiovascular and renal disorders in such cats are associated with increased venous renal pressure, decreased renal blood flow, and impaired autoregulation. As noted by Haase *et al.* (2013), in the acute state, with a significant decrease in the effective volume of circulating fluid, the neurohormonal system is activated, which leads to afferent vasoconstriction. This causes a decrease in renal blood flow and renal perfusion pressure. In such patients, low values of cardiac output and effective volume of circulating fluid may be associated with reduced systemic blood pressure. Therefore, it reduces renal perfusion pressure, even if venous renal pressure corresponded to relatively normal values since autoregulation does not always compensate for low blood pressure with a decrease in the effective circulating volume.

An additional risk factor for animals with heart failure is kidney infarction. As Hikey *et al.* (2014) established, cats with kidney infarction were 4.5 times more likely to have hypertrophic cardiomyopathy and 8 times more likely to be diagnosed with distal aortic thromboembolism compared to cats without kidney infarction.

Since ATE was cardiogenic in cats of the second group, the likelihood of developing acute kidney damage due to reduced cardiac output, activation of the neurohormonal system, and kidney infarcts in these animals is also present. In addition, cats with ATE may experience reperfusion syndrome. One of the elements of the pathogenesis of this condition is the release of a large amount of toxic substances from the area that was cut off from the blood flow. This condition occurs if the blood supply is restored more than four hours after occlusion. In this study, all cats were examined more than 6 hours after the onset of symptoms of thromboembolism, so they are likely to develop reperfusion injury.

The results of this study and the detection of a statistically significant difference in creatinine concentration in animals with acute heart failure compared to animals with arterial thromboembolism indicate more severe kidney damage in cats diagnosed with thromboembolism. Acute kidney damage in this animal species can be caused by toxic, ischemic, inflammatory, or infectious lesions. As heart failure progresses, there is inadequate perfusion of the kidneys.

The content of calcium in the blood serum of the vast majority of the studied animals ($n=9$) is reduced. In two animals with AHF and one with arterial thromboembolism, the value of serum calcium content corresponded to physiological limits. The quantitative indicator of calcium content in the blood serum of animals with arterial thromboembolism decreased, but the difference between the groups was insignificant ($P < 0.1$). Such changes in the concentration of calcium in the blood serum of cats may be due to hyperphosphatemia because excess phosphorus binds to calcium (Moise, 2007).

Hyperglycemia was reported in two cats with AHF and in five with arterial thromboembolism. As is known, hyperglycemia or normoglycemia is usually recorded in the blood

serum of animals with arterial thromboembolism, and with damage to the extremities, the glucose concentration decreases (Klainbart *et al.*, 2014). Hyperglycemia was observed in most cats with acute heart failure (66.6%) (Goutal *et al.*, 2010). Stress-induced hyperglycemia causes an intense release of adrenergic hormones that inhibit insulin secretion. Cortisol and glucagon levels also increase in the blood. In addition, in cats with arterial thromboembolism, lactate production increases due to muscle anaerobic glycolysis, which leads to an intense increase in blood glucose concentrations (Moise, 2007). Therefore, it was expected to detect an increase in the concentration of glucose in the blood serum of cats for AHF in accordance with the norm. In fact, the average value was higher, however, the difference with the group of cats with acute heart failure was classified as insignificant ($P < 0.2$).

In a study by English researchers, an increased concentration of phosphorus in the blood is noted as the least frequent deviation among other biochemical parameters, which occurred only in 5.3% of cats (Borgeat *et al.*, 2013). However, American researcher Moise (2007) diagnosed hyperphosphatemia along with the most common biochemical abnormalities in cats with arterial thromboembolism, which may indicate kidney hypoperfusion and massive muscle necrosis. In turn, the serum phosphorus content in five of the six cats that belonged to the group with arterial thromboembolism is higher than normal. In cats with AHF, an increase in the indicator was recorded in one animal out of six. The difference in quantitative indicators between animal groups was statistically insignificant ($P < 0.1$).

Conclusions

In the blood serum of five out of the six cats with acute heart failure, an increase in aspartate aminotransferase activity and creatinine

concentration was observed (the average value was increased relative to the upper limit of the reference range by 2.8 and 1.9 times, respectively). This indicates the development of complications in the urinary system due to the progression of this cardiopathology.

In the blood serum of cats with arterial thromboembolism, the average values increased compared to the reference intervals as follows: alanine aminotransferase activity – by 4.4 times, aspartate aminotransferase – by 4.3 times, creatinine concentrations – by 1.8 times, and urea – by 2 times. Quantitative changes in these indicators compared to the reference values were recorded in all the studied animals. It was found that the difference in alanine aminotransferase activity ($P < 0.001$) and creatinine content ($P < 0.01$) was statistically significant between animals of both experimental groups.

In the blood serum of cats of the experimental groups, an increase in urea content and the development of hypocalcemia were also noted, compared with the values of the reference intervals. This indicates not only the negative impact of acute heart failure on the functional state of cats' urinary system but also structural changes in the myocardium. Moreover, an increase in gamma-glutamyltranspeptidase activity and glucose and phosphorus content was observed in animals with arterial thromboembolism compared to the values of reference intervals. The obtained regularities regarding changes in blood biochemical param-

eters complement the established picture of changes in the internal organs of sick animals and indicate structural and functional disorders in the kidneys, as well as ischemia and necrosis in skeletal muscles.

The observed variations in the biochemical parameters of blood serum among the experimental groups of cats can be attributed to distinct differences in the pathogenesis of the respective pathologies. However, a certain similarity in the manifestation of pathologies (cardiomyopathy, congestive heart failure) allows determining the features of the effect of blockage of a vessel on a whole organism.

In the future, studies comparing other indicators (troponin, clotting factors, etc.) in the blood of cats with acute heart failure and arterial thromboembolism will be useful.

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Conflict of Interest

The authors declare having no conflict of interest regarding the research described in this paper, including financial, authorship, or other nature that could affect its results.

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Біохімічні показники крові у котів за кардіогенної артеріальної тромбоемболії та гострої серцевої недостатності

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Анотація. З'ясування особливостей впливу закупорки судини на біохімічні показники крові, у тому числі на тлі гострої серцевої недостатності, важливі для визначення патогенезу артеріальної тромбоемболії в тварин. Мета роботи – дослідити вплив оклюзії судин на параметри біохімічних показників крові в котів за кардіогенної артеріальної тромбоемболії. У дослідження включено 12 котів і сформовано дві групи: перша – тварини за гострої серцевої недостатності а друга – тварини з артеріальною тромбоемболією. У відношенні піддослідних тварин зібрано дані анамнезу, проведено клінічний огляд, ехокардіографію та біохімічне дослідження зразків крові. В сироватці крові спектрофотометрично визначали активність аланінамінотрансферази, аспартатамінотрансферази і гамма-глутамілтранспептидази, концентрацію глюкози, креатиніну, сечовини, калію, кальцію загального і неорганічного фосфору. Встановлено, що в котів за гострої серцевої недостатності середнє значення активності аспартатамінотрансферази у сироватці крові підвищувалося в 2,8 рази, а концентрація

креатиніну в 1,9 раза порівняно з верхньою межею референтних значень. Це вказує на функціональні зміни міокарду і нирок за даної патології. За артеріальної тромбоемболії в сироватці крові хворих котів відмічали підвищення активності аланінамінотрансферази в 4,4 раза, аспаргатамінотрансферази в 4,3 раза, концентрації глюкози в 1,4 раза, креатиніну – в 1,8 раза, сечовини – в 2,0 рази, неорганічного фосфору в 1,3 раза, відносно верхньої межі відповідних референтних інтервалів. Встановлені зміни біохімічних показників за тромбоемболії котів можуть бути наслідком функціонального порушення нирок, ішемії і некрозу м'язів. При цьому виявлено, що у більшості котів за гострої серцевої недостатності, насамперед, зазнає ураження сечова система, а за артеріальної тромбоемболії також відбуваються зміни у м'язовій тканині. Отримані результати становлять практичну цінність для лікарів ветеринарної медицини під час вибору терапевтичної стратегії та призначення додаткових діагностичних досліджень

Ключові слова: гіпертрофічна кардіоміопатія; діагностика; ішемія; набряк легень; ниркова недостатність
