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Clinical and biochemical markers of metabolic syndrome in cats with liver disease

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Early diagnosis of metabolic syndrome in cats with liver diseases is of critical importance for the timely implementation of therapeutic and preventive measures, prevention of disease progression, and avoidance of irreversible morphofunctional changes. The article presents the results of a comprehensive assessment of hematological and biochemical blood parameters, as well as urinalysis in cats with various forms of hepatic pathology. These indicators reflect the degree of metabolic disturbances, the functional state of the hepatobiliary system, and can be used as informative markers for early diagnosis and evaluation of disease severity. In this context, metabolic syndrome in cats is considered a multisystem regulatory disorder in which the liver acts as a key integrative organ of metabolic, endocrine, and detoxification processes. In cats with hepatic insufficiency, hematological changes were characterized by the development of an anemic syndrome, with a decrease in hemoglobin content by 49.3%, erythrocyte count by 1.9 times, and hematocrit by 63.2%. In cholangiohepatitis, leukocytosis with neutrophilia ($17.2 \pm 1.10\ 10^9$/L) was observed, whereas in hepatic lipidosis, hematological disorders were manifested by moderate anemia. The biochemical profile of affected cats was characterized by a combination of hepatocellular, cholestatic, and metabolic components of liver injury. In particular, in cholangiohepatitis, an increase in alanine aminotransferase activity by 4.2 times, aspartate aminotransferase by 3.8 times, gamma-glutamyl transpeptidase by 7.7 times, glutamate dehydrogenase by 3.4 times, and ammonia concentration by 3.2 times was observed, along with a decrease in total protein by 10.6%. In hepatic insufficiency, a decrease in total protein by 11.4% and hypoalbuminemia in 34.7% of cats were detected, with a maximum reduction in albumin concentration of 32.1%. In hepatic lipidosis, increased levels of cholesterol (2.9-fold), triglycerides (3.9-fold), fructosamine (1.8-fold), and phospholipids (2.9-fold), as well as an increase in fibroblast growth factor 21 (FGF21) concentration by 4.7 times were recorded. Urinalysis revealed proteinuria in 48.2% of affected cats, bilirubinuria in 42.6%, decreased urine specific gravity in 35.4%, and cylindruria in 28.4% of animals. In hepatic lipidosis, glucosuria (23.8%) and ketonuria (18.9%) were observed. The detected changes in urinary parameters indicate renal involvement in systemic metabolic and detoxification disorders associated with metabolic syndrome in cats. The obtained results confirm the feasibility of the integrated use of hematological and biochemical blood parameters, along with urinalysis, for the early detection of metabolic syndrome in cats with liver diseases and timely correction of the identified disorders.

Keywords: diagnostic markers; metabolism; hepatic insufficiency; hepatic lipidosis; cholangiohepatitis.

Introduction

Metabolic syndrome is a complex regulatory disorder characterized by a combination of metabolic, endocrine, and chronic inflammatory alterations, in which the liver plays a key role as an organ coordinating systemic energy, carbohydrate, and lipid metabolism (Zoran, 2010). Liver diseases in cats occupy a leading position in the structure of internal pathologies of small companion animals and are characterized by a wide variety of clinical forms, specific disease progression patterns, and challenges in early diagnosis (Lokes-Krupka, 2014; Loftus & Wakshlag, 2014; Rowe et al., 2015; Saavedra et al., 2024; Mospan & Shcherbatyi, 2025). An important aspect of their pathogenesis is the relationship with systemic metabolic disorders, which are increasingly considered within the framework of the metabolic syndrome concept (Verbrugghe et al., 2009; Mizorogi et al., 2020).

Despite the lack of a unified definition of metabolic syndrome in veterinary medicine, in cats it is typically characterized by a combination of obesity, insulin resistance, chronic low-grade inflammation, and lipid metabolism disturbances, all of which directly affect liver function (Hoenig et al., 2006; Lokes-Krupka & Tsvilikhovskyi, 2014; Valtolina & Favier, 2017). The liver plays a central role in the regulation of carbohydrate, lipid, and protein metabolism; therefore, under conditions of metabolic imbalance, it acts both as a target organ and as an active participant in pathogenetic processes (Hudyma & Slivinska, 2014; Arena et al., 2021). In cats with obesity and metabolic disorders, decreased tissue sensitivity to insulin, excessive influx of free fatty acids into hepatocytes, activation of lipogenesis, and impairment of β-oxidation create conditions for the development of hepatic lipidosis, cholangiohepatitis, and progressive hepatic dysfunction (German, 2006; Teng et al., 2020; Martins et al., 2023; Jørgensen et al., 2025). Moreover, liver dysfunction further exacerbates systemic metabolic disturbances, thereby promoting disease progression (Backus et al., 2007).

Early diagnosis of metabolic syndrome in cats with liver diseases is crucial for timely therapeutic intervention and prevention of irreversible morphofunctional changes (Okada et al., 2019). However, in the early stages of the pathological process, clinical signs are often nonspecific or mildly expressed, necessitating the use of sensitive clinical and biochemical markers (Wall et al., 2019; Godfrey et al., 2024). Modern diagnostic approaches are based not only on the assessment of body condition score and standard biochemical indicators of liver function but also on the evaluation of lipid and carbohydrate metabolism parameters, as well as adipokines such as leptin and adiponectin, which reflect adipose tissue function and the degree of insulin resistance (Xenoulis & Steiner, 2010; Martins et al., 2023; Godfrey et al., 2024). In addition, markers of systemic inflammation, including serum amyloid A and C-reactive protein, play an important role, as their levels correlate with inflammatory activity and the severity of metabolic disturbances (Shoveller et al., 2014; Mizorogi et al., 2020).

Metabolic syndrome in cats is considered a key pathogenetic factor which, when combined with liver diseases, is associated with a more severe clinical course, a guarded prognosis, and reduced treatment efficacy. Therefore, an in-depth study of clinical and biochemical markers of metabolic syndrome, their pathogenetic significance, and diagnostic value in cats with liver diseases represents an important task in modern small animal veterinary medicine. The aim of this study was to determine the regulatory mechanisms of metabolic syndrome in cats with hepatic insufficiency, cholangiohepatitis, and hepatic lipidosis by analyzing hematological and biochemical parameters, as well as changes in urinalysis indicators, and to evaluate their diagnostic significance.

Materials and methods

All the procedures with the animals were conducted according to the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (Strasbourg, 1986) and the General Ethic Principles of Experiments on Animals, adopted by the First National Congress of Bioethics (Kyiv, 2001). The experiments were performed with adherence to the principles of humanity, outlined in the Directive of the European Community (Directive 2010/63/EU, 2010).

In the clinic, patients underwent clinical examination and blood sampling for laboratory analyses. The study material consisted of 164 cats of various breeds, ages, and sexes diagnosed with metabolic syndrome. According to the study results, hepatic insufficiency was diagnosed in 95 cats, cholangiohepatitis in 48 cats, and hepatic lipidosis in 21 cats. Clinical and biochemical parameters were evaluated in groups of cats with hepatic insufficiency, cholangiohepatitis, and hepatic lipidosis (n = 10 in each group). The control group consisted of 10 clinically healthy cats selected to match the patients in terms of age and breed. The clinically healthy group was formed from animals undergoing routine outpatient examinations.

Blood samples were collected from the lateral saphenous vein of the forelimb using a 21G needle (40 mm length, 0.8 mm diameter; Alexpharm, China). For whole blood and plasma analysis, samples were collected into tubes containing ethylenediaminetetraacetic acid (EDTA) (Vacusel tubes with purple caps, Turkey). Serum was obtained by collecting blood into Vacusel tubes with yellow caps (Turkey) containing a coagulation activator and gel separator. Blood (plasma and serum) samples were analyzed on the day of admission.

Whole blood was analyzed using a Heka Element HT5+ hematology analyzer (Heska Corporation, USA, 2021). The following parameters were determined: erythrocyte and leukocyte counts, hemoglobin concentration, hematocrit, and red blood cell indices. Leukocyte differentiation (leukogram) was performed by preparing blood smears, staining them following Pappenheim's method, and counting cells in a specialized chamber under a microscope.

Biochemical analysis of blood serum was performed using an automatic analyzer Fujifilm NX600 (Fujifilm Holdings Corporation, Japan, 2021). The following parameters were measured in serum: alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma-glutamyl transpeptidase (GGT), glutamate dehydrogenase (GLDH), alkaline phosphatase (ALP), ammonia, total protein, albumin, and cholesterol.

Triglyceride and phospholipid levels were determined using enzymatic colorimetric methods, fructosamine by a colorimetric method using nitroblue tetrazolium (NBT), and fibroblast growth factor 21 (FGF-21) concentration by enzyme-linked immunosorbent assay (sandwich ELISA).

Urinalysis was performed using a URYXXON Relax Vet analyzer with Medi-Test Combi 10 Vet test strips. Physical and chemical parameters of urine, as well as sediment microscopy, were evaluated on the day of sample collection, no later than 24 hours after sampling.

The blood parameters were statistically analyzed using Statistica 7 (StatSoft Inc., USA). The graphs were developed in Statistica 7 using the generally accepted algorithms. The article presents the mean arithmetic values and standard deviation x ± SD (mean ± standard deviation), as shown in in the figures. To compare the differences between the mean parameters of the clinically healthy and ill animals, we used the Tukey Test, where the differences were considered statistically significant at $P < 0.05$.

Results

The analysis of hematological parameters demonstrated that animals with hepatic insufficiency developed anemia, characterized by a decrease in hemoglobin concentration by 49.3% ($P < 0.001$), erythrocyte count by 1.9-fold ($P < 0.001$), and hematocrit by 63.2% ($P < 0.001$) compared to clinically healthy cats. These findings indicate the development of an anemic syndrome associated with chronic hepatic dysfunction. In cats with cholangiohepatitis, leukocytosis with neutrophilia ($17.2 \pm 1.1 \times 10^9$/L) was diagnosed, reflecting the presence of systemic inflammation or secondary complications. In hepatic lipidosis, hematological changes were less pronounced; however, moderate anemia was observed in some animals (Table 1).

Biochemical analysis of blood in animals with different forms of hepatic pathology revealed specific features of metabolic disturbances. In cats with hepatic lipidosis, the most pronounced alterations in lipid metabolism were observed, with cholesterol levels increasing on average by 2.9-fold compared to the control group ($P < 0.001$) and triglycerides by 3.9-fold ($P < 0.001$, Fig. 1a, 1b).

Table 1

Hematological parameters of cats (x ± SD, n = 10)

Parameter	Clinically healthy	Cholangiohepatitis	Hepatic lipidosis	Hepatic insufficiency
Hemoglobin, g/L	132.0 ± 2.9^{c}	100.2 ± 3.4^{ab}	108.6 ± 2.8^{b}	88.4 ± 3.1^{a}
Hematocrit, L/L	0.38 ± 0.01^{c}	0.27 ± 0.01^{b}	0.29 ± 0.09^{b}	0.23 ± 0.01^{a}
Erythrocytes, $\times 10^{12}$/L	8.1 ± 0.2^{c}	5.1 ± 0.2^{ab}	5.7 ± 0.1^{b}	4.3 ± 0.2^{a}
Leukocytes, $\times 10^{9}$/L	8.2 ± 0.6^{a}	17.2 ± 1.1^{d}	10.1 ± 0.7^{b}	15.3 ± 1.0^{c}
MCV, fL	47.0 ± 1.3^{ab}	47.3 ± 1.2^{ab}	50.4 ± 1.3^{b}	45.6 ± 1.1^{a}
MCH, pg	14.8 ± 0.4^{ab}	15.1 ± 0.4^{ab}	16.2 ± 0.5^{b}	14.0 ± 0.4^{a}
MCHC, g/L	335.0 ± 7.0^{b}	325.4 ± 8.0^{ab}	340.4 ± 7.0^{b}	300.2 ± 9.0^{a}

Note: values with different superscript letters (^{a}, ^{b}, ^{c}, ^{d}) differ significantly ($P < 0.05$).

An increase in fructosamine levels in 76.2% of cats reflected chronic hyperglycemia and disturbances in carbohydrate metabolism associated with liver damage (Fig. 1c). The highest values were recorded in hepatic lipidosis, where fructosamine concentration was 1.8 times higher than in clinically healthy animals.

Phospholipids are important regulators of lipid metabolism and membrane stability in hepatocytes, and disturbances in their metabolism are considered one of the key mechanisms in the development of hepatic dysfunction. In cats with liver pathology, a significant increase in serum phospholipid levels was observed compared to healthy animals (Fig. 1d). In particular, in hepatic insufficiency, phospholipid levels were 1.9-fold higher, in cholangiohepatitis – 2.2-fold higher, whereas in hepatic lipidosis the maximum increase was recorded at 2.9-fold. This pattern indicates disruption of hepatocyte membrane homeostasis and increased strain on lipid metabolism mechanisms with increasing severity of liver pathology.

Cholangiohepatitis was characterized by the most pronounced inflammatory damage of the hepatobiliary system, accompanied by significant induction of cytolytic and cholestatic liver enzymes. Alanine aminotransferase (ALT) activity exceeded that of clinically healthy cats by an average of 4.2-fold ($P < 0.001$), aspartate aminotransferase (AST) by 3.8-fold ($P < 0.001$), and alkaline phosphatase (ALP) by 3.1-fold ($P < 0.001$, Fig. 2).

Gamma-glutamyl transpeptidase (GGT) is a marker of the cholestatic component of liver injury. In cats with metabolic syndrome, its activity was increased in 40% of cases, particularly in animals with jaundice and ascites (Fig. 2d). Elevated GGT activity reflects impaired bile transport, bilirubin accumulation, and the development of cholestasis, which often accompanies hepatic steatosis associated with obesity and diabetes mellitus.

In cats with hepatic lipidosis, GGT activity was 2.7-fold higher ($P < 0.001$), in hepatic insufficiency 3.7-fold higher ($P < 0.001$), and in cholangiohepatitis 7.7-fold higher ($P < 0.001$) compared to healthy animals, reflecting the cholestatic component of liver damage.

Glutamate dehydrogenase (GLDH) activity was increased in cats with liver diseases compared to clinically healthy animals (1.91 U/L).

The most pronounced increase was observed in cholangiohepatitis, where GLDH activity exceeded control values by 3.4-fold ($P < 0.001$) (Fig. 2c). Such hyperenzymemia reflects hepatocellular damage involving the mitochondrial apparatus of hepatocytes.

The most pronounced decrease in total protein levels was observed in cats with cholangiohepatitis and hepatic insufficiency (Fig. 3a). Specifically, in cholangiohepatitis, total protein concentration was 10.6% lower ($P < 0.05$), and in hepatic insufficiency 11.4% lower compared to clinically healthy animals (72.9 g/L), indicating significant suppression of the synthetic function of the liver. In hepatic lipidosis, the decrease in total protein was minimal, amounting to only 2.6%.

Ammonia levels were elevated in 89.5% of diseased cats, indicating impaired hepatic detoxification function (Fig. 3c). The most pronounced increase in ammonia concentration was observed in cholangiohepatitis, where levels exceeded those of clinically healthy animals by 3.2-fold. In hepatic insufficiency, ammonia levels were increased by 2.6-fold, and in hepatic lipidosis by 2.1-fold compared to the control group, reflecting a reduced capacity of hepatocytes to detoxify nitrogenous metabolites and the severity of hepatobiliary damage.

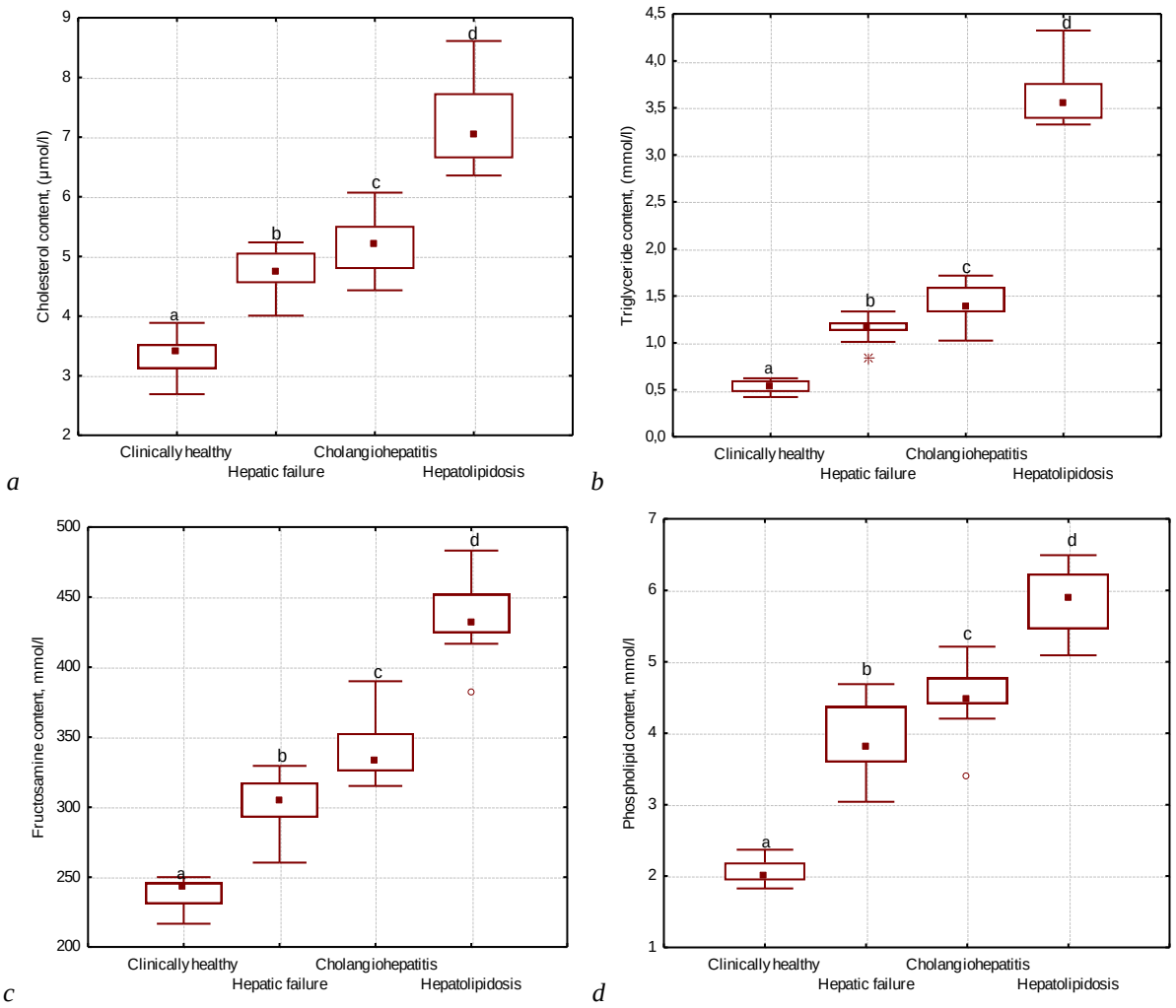

Fig. 1. Biochemical markers of lipid and carbohydrate homeostasis in cats: *a* – serum cholesterol concentration (µmol/L); *b* –serum triglyceride concentration (mmol/L); *c* – serum fructosamine concentration (mmol/L); *d* – serum phospholipid concentration (mmol/L); the x-axis represents animal groups, and the y-axis shows the measurement units of the parameters; the small square indicates the median; the upper and lower borders of the box represent the 25th and 75th quartiles, respectively; the vertical line indicates the minimum and maximum values; circles represent outliers; n = 10

Albumin concentration was decreased (<20 g/L) in 34.7% of diseased cats, indicating impaired protein-synthesizing function of the liver (Fig. 3b). The most pronounced decrease was observed in cholangiohepatitis, where albumin levels were 32.1% lower ($P < 0.001$) compared to clinically healthy animals (44.40 g/L). In hepatic lipidosis, albumin decreased by 30.3% ($P < 0.001$), whereas in hepatic insufficiency it decreased by 26.6% ($P < 0.01$), reflecting varying degrees of suppression of hepatocellular protein synthesis. Another important marker is fibroblast growth factor (FGF), particularly FGF21, which plays a role in the regulation of glucose and lipid metabolism and overall energy balance. In healthy cats, its mean concentration was 92.9 pg/mL, whereas in cats with hepatic insufficiency it increased 2.3-fold, in cholangiohepatitis 2.7-fold, and in hepatic lipidosis 4.7-fold (Fig. 3d).

Urinalysis in diseased cats revealed that the most pronounced abnormalities were observed in cholangiohepatitis. Specifically, proteinuria was detected in 48.2% of animals, an increased protein/creatinine ratio in 37.8%, decreased urine specific gravity in 35.4%, bilirubinuria in 42.6%, and cylindruria along with increased epithelial cell counts in 28.4% of cats. These findings indicate the development of cholestasis, endogenous intoxication, and renal involvement in the pathological process.

In contrast, hepatic lipidosis was characterized by metabolic disturbances, including glucosuria (23.8% of animals) and ketonuria (18.9%), reflecting impaired carbohydrate–lipid metabolism and a negative energy balance. The observed changes in urinary parameters indicate renal involvement in systemic metabolic and detoxification disorders associated with metabolic syndrome in cats.

Thus, the analysis of laboratory parameters in cats with metabolic syndrome revealed a combination of hepatocellular and cholestatic liver injury (GLDH, GGT), as well as adaptive metabolic changes (FGF21). These markers not only reflect the severity of liver damage

but may also be used to evaluate the effectiveness of therapeutic interventions and to predict the course of metabolic syndrome.

Different forms of liver damage in cats with metabolic syndrome may reflect distinct regulatory mechanisms. In particular, hepatic lipidosis can be considered a manifestation of metabolic dysregulation, whereas cholangiohepatitis may correspond to an inflammatory regulatory mechanism involving activation of immunometabolic signaling pathways.

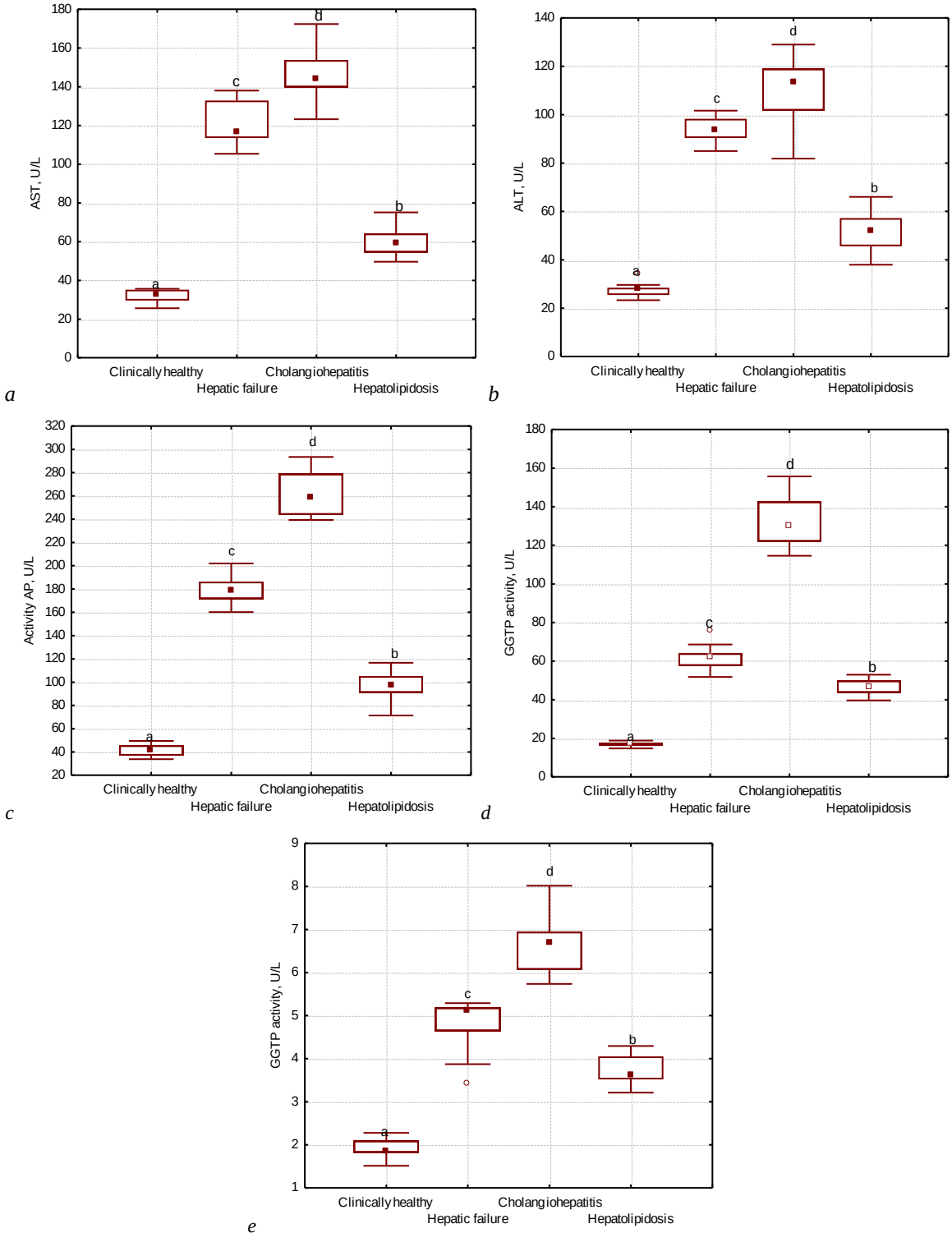

Fig. 2. Enzyme activities in the blood serum of cats (U/L): *a* – AST; *b* – ALT; *c* – alkaline phosphatase (ALP); *d* – gamma-glutamyl transpeptidase (GGT), *e* – glutamate dehydrogenase (GLDH); the x-axis represents animal groups, and the y-axis shows the measurement units of the parameters; the small square indicates the median; the upper and lower borders of the box represent the 25th and 75th quartiles, respectively; the vertical line indicates the minimum and maximum values; circles represent outliers

The obtained results confirm the polyetiological nature of metabolic syndrome in cats and the need for a comprehensive diagnostic approach that takes into account breed, age, and seasonal characteristics of disease occurrence. The combined use of hematological and biochemical blood parameters along with urinalysis allows early detection of metabolic syndrome in cats with liver pathology and timely correction of identified disorders. Overall, metabolic syndrome in cats should be considered a multisystem regulatory disorder in which the liver acts as a central integrative organ, and its dysfunction reflects systemic disturbances in metabolic and endocrine regulation.

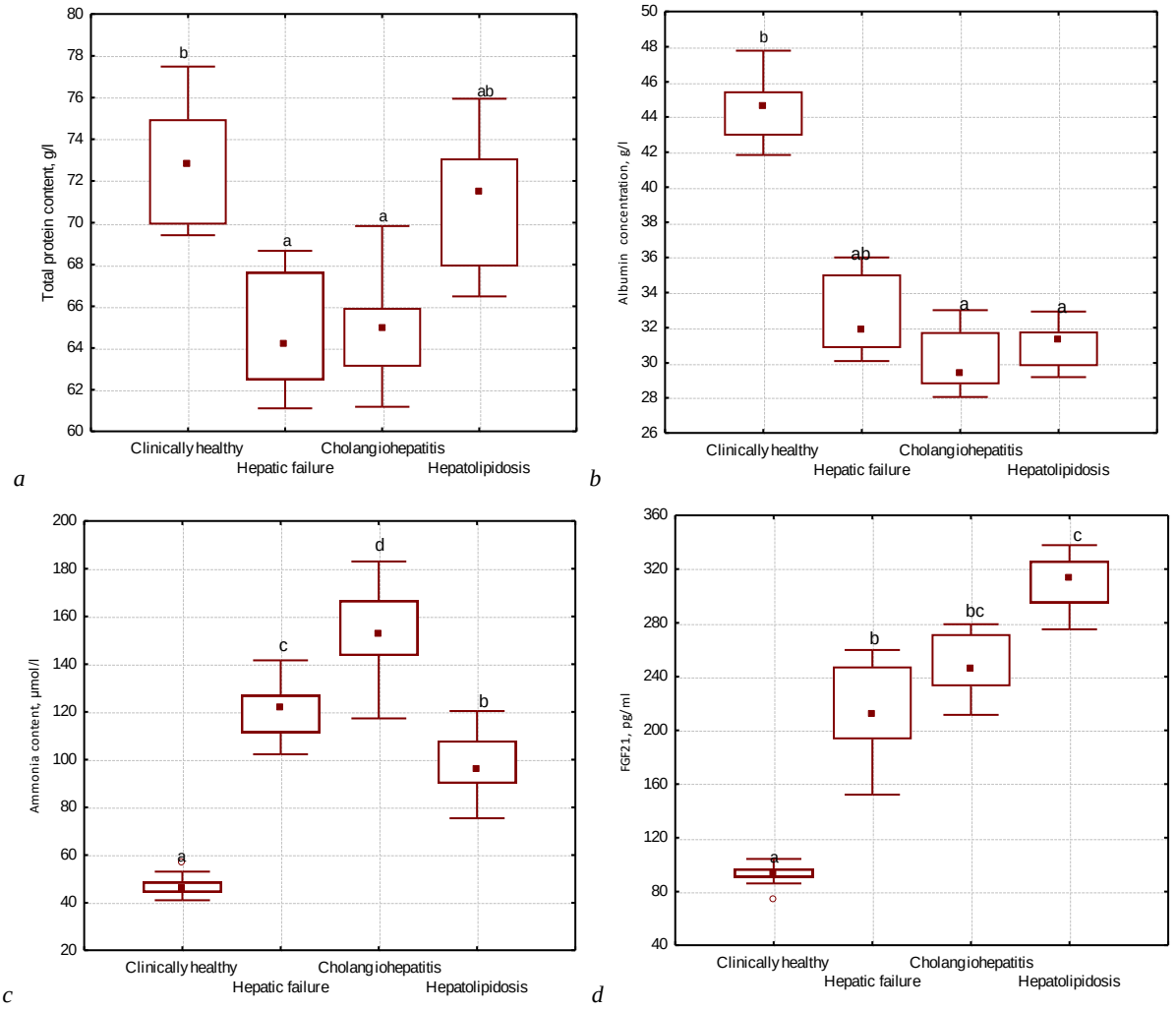

Fig. 3. Indicators of protein and nitrogen metabolism and regulatory markers of liver functional status in cats: *a* – total protein content (g/L); *b* – albumin concentration (g/L); *c* – ammonia content (µmol/L); *d* – FGF21 (pg/mL); the x-axis represents animal groups, and the y-axis shows the measurement units of the parameters; the small square indicates the median; the upper and lower borders of the box represent the 25th and 75th quartiles, respectively; the vertical line indicates the minimum and maximum values; circles represent outliers. n = 10

Discussion

Metabolic syndrome in cats should be considered a multisystem regulatory disorder in which disturbances in metabolic, endocrine, inflammatory, and detoxification mechanisms form a unified pathogenetically interconnected process, with the liver acting as the central integrative organ (Hoenig et al., 2006; Verbrugghe et al., 2009; Martins et al., 2023). The obtained results indicate that the combination of metabolic syndrome with liver diseases leads to the formation of characteristic complexes of laboratory changes reflecting the strain and decompensation of key regulatory mechanisms of the organism.

The hematological abnormalities identified in diseased cats have not only diagnostic but also regulatory significance, as they reflect systemic shifts in metabolism and inflammatory responses. The development of an anemic syndrome in hepatic insufficiency may result from suppression of erythropoiesis, impaired iron metabolism, and reduced synthetic liver function, which is typical of chronic hepatic insufficiency and corresponds to the stage of exhaustion of compensatory mechanisms (Teng et al., 2017; Martins et al., 2023).

In contrast, leukocytosis with neutrophilia observed in cholangiohepatitis reflects activation of immuno-inflammatory regulatory pathways, consistent with the concept of immunometabolic interaction in metabolic syndrome (Mizorogi et al., 2020; Sierawska & Niedźwiedzka-Rystwej, 2022).

The biochemical profile of cats with different forms of liver pathology indicates a combination of hepatocellular, cholestatic, and metabolic injury, reflecting multilevel regulatory dysfunction (Arena et al., 2021; Vlizlo et al., 2023). Increased activity of alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma-glutamyl transpeptidase (GGT), and glutamate dehydrogenase (GLDH) indicates disruption of hepatocyte membrane integrity and mitochondrial function, which is a typical feature of alterations in intracellular regulatory mechanisms of energy and protein metabolism (Arena et al., 2021).

Elevated ammonia concentrations in most diseased cats indicate reduced hepatic detoxification capacity and impaired regulation of nitrogen metabolism, contributing to the aggravation of systemic metabolic disturbances (Backus et al., 2007; Okada et al., 2019).

The most pronounced disturbances in lipid metabolism were observed in cats with hepatic lipidosis, as evidenced by significant increases in cholesterol, triglycerides, and phospholipids. These findings are consistent with current concepts of hepatic lipidosis pathogenesis in cats under conditions of insulin resistance, negative energy balance, and impaired β-oxidation of fatty acids (German, 2006; Xenoulis & Steiner, 2010; Valtolina & Favier, 2017).

Increased fructosamine levels in the majority of diseased cats reflect chronic hyperglycemia as a stable component of impaired carbohydrate regulation, which is a key feature of metabolic syndrome (Hoenig et al., 2006; Godfrey et al., 2024).

Particular attention should be given to the increase in fibroblast growth factor 21 (FGF21), which is considered not as a marker of damage but as an endocrine regulator of adaptation to metabolic stress. The most pronounced elevation of FGF21 levels in hepatic lipidosis likely reflects the activation of compensatory endocrine mechanisms aimed at stimulating fatty acid oxidation, reducing lipotoxicity, and

restoring energy homeostasis under conditions of metabolic stress (Hoenig et al., 2006; Martins et al., 2023). Thus, FGF21 may be regarded as an integral marker of metabolic regulatory stress in cats with metabolic syndrome.

From the perspective of systemic regulation, the observed changes can be interpreted as disturbances in three interrelated regulatory systems: metabolic-endocrine, immuno-inflammatory, and detoxification-excretory. The metabolic–endocrine system was manifested by alterations in lipid and carbohydrate metabolism, including hypertriglyceridemia, hypercholesterolemia, and increased fructosamine levels, reflecting persistent insulin resistance and disruption of energy homeostasis (Hoenig et al., 2006; Xenoulis & Steiner, 2010; Godfrey et al., 2024).

Immuno-inflammatory regulatory mechanisms were most pronounced in cholangiohepatitis, as evidenced by leukocytosis with neutrophilia and significant induction of cytolytic and cholestatic enzymes. These findings are consistent with current concepts of immunometabolic interaction, in which the inflammatory response is not only a consequence of metabolic imbalance but also a factor contributing to its progression through impairment of insulin-dependent regulatory mechanisms and hepatocellular function (Mizorogi et al., 2020; Sierawska & Niedźwiedzka-Rystwej, 2022; Araujo et al., 2024).

The obtained results support the consideration of metabolic syndrome in cats not as a set of isolated clinical signs, but as a dynamic regulatory process in which different forms of liver damage reflect stages of compensation, strain, and decompensation of homeostatic mechanisms. Changes in urinary parameters, including proteinuria, bilirubinuria, decreased specific gravity, and the presence of casts, indicate renal involvement in systemic metabolic and detoxification disturbances, further confirming the multisystem nature of metabolic syndrome (Ostrovskyi & Slivinska, 2023).

The detection of glucosuria and ketonuria in hepatic lipidosis reflects disturbances in energy regulation and a negative energy balance (Valtolina & Favier, 2017).

Summarizing the obtained results, different forms of liver damage in cats with metabolic syndrome can be considered as distinct regulatory phenotypes. In particular, hepatic lipidosis corresponds to a phenotype of impaired metabolic–endocrine regulation, cholangiohepatitis represents an immuno-inflammatory regulatory phenotype, whereas hepatic insufficiency reflects the stage of exhaustion of compensatory regulatory mechanisms.

Such an approach expands the understanding of the pathogenesis of metabolic syndrome in cats and substantiates the feasibility of a comprehensive interpretation of laboratory markers within the framework of systemic regulation of homeostasis.

Conclusions

In cats with hepatic insufficiency, a pronounced anemic syndrome was observed, characterized by a decrease in hemoglobin concentration by 49.3%, erythrocyte count by 1.9-fold, and hematocrit by 63.2% ($P < 0.001$). In contrast, cholangiohepatitis was predominantly associated with leukocytosis accompanied by neutrophilia ($17.2 \pm 1.1 \times 10^9$/L), reflecting the presence of an active systemic inflammatory process, whereas in hepatic lipidosis, hematological alterations were less pronounced and manifested as moderate anemia. The biochemical profile of diseased cats was characterized by a combination of hepatocellular, cholestatic, and metabolic liver injury, as evidenced by increased activity of gamma-glutamyl transpeptidase (GGT) by 7.7-fold, glutamate dehydrogenase (GLDH) by 3.4-fold, alanine aminotransferase (ALT) by 4.2-fold, and aspartate aminotransferase (AST) by 3.8-fold. Additionally, ammonia concentration was elevated in 89.5% of animals (up to 3.2-fold in cholangiohepatitis), while fructosamine levels were increased in 76.2% of cats and FGF21 levels increased up to 4.7-fold in hepatic lipidosis. In cholangiohepatitis, proteinuria (48.2%), bilirubinuria (42.6%), decreased urine specific gravity (35.4%), and cylindruria (28.4%) were detected, indicating impaired hepatic detoxification function and renal involvement in the pathological process. In contrast, hepatic lipidosis was characterized by glucosuria (23.8%) and ketonuria (18.9%), reflecting metabolic imbalance. The identified biomarkers reflect systemic regulatory disturbances linking metabolic syndrome with liver pathology in cats.

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