Pesq. Vet. Bras. 46:e07839, 2026
DOI: 10.1590/1678-5150-PVB-7839

Original Article
Small Animal Diseases

Galectin-3 and cardiac biomarkers in cats with cardiomyopathy[1]

Özge Şahin[2], Öznur Aslan[3*]

Registros ORCID:
Özge Şahin – https://orcid.org/0009-0005-9946-4239
Öznur Aslan - https://orcid.org/0000-0001-5479-3737

ABSTRACT.- Şahin Ö., Aslan Ö. **Galectin-3 and cardiac biomarkers in cats with cardiomyopathy**. *Pesquisa Veterinária Brasileira 46:e07839, 2026.* Erciyes University, Faculty of Veterinary Medicine, Department of Internal Medicine, 38280 Talas, Kayseri, Türkiye. E mail: oznuratalay@gmail.com

Galectin-3 (GAL-3) is a serum-detectable biomarker involved in inflammatory and fibrotic processes and has been associated with the development of cardiovascular diseases in human medicine. Therefore, this study aimed to evaluate GAL-3 levels in cats with different types and stages of cardiomyopathy. A total of 48 cats were included in the study, comprising a healthy control group (Group I, n=12) and cats diagnosed with cardiomyopathy classified according to the American College of Veterinary Internal Medicine staging system [Class B2 cats to Group II (n=12), Class C cats to Group III (n=12), and Class D cats to Group IV (n=12)]. All cats underwent echocardiographic, electrocardiographic, and radiographic examinations, and serum NT-proBNP, cTn-I, and GAL-3 levels were evaluated. Serum NT-proBNP and cTn-I levels differed significantly among the groups. NT-proBNP concentrations in Group IV were significantly higher than those in Group I and Group II, while NT-proBNP levels in Group III were significantly higher than those in Group I and Group II. The cTn-I concentration in Group IV was significantly higher than in Group I, Group II, and Group III. Additionally, Group III exhibited significantly higher cTn-I levels compared with Group I. No statistically significant difference in galectin-3 concentrations was detected between the control group and cats with cardiomyopathy. NT-proBNP and cardiac troponin-I levels were associated with disease stage and demonstrated diagnostic importance in feline cardiomyopathies. Although no significant difference in GAL-3 levels was observed according to cardiomyopathy classification in this study, further large-scale studies using different classifications are warranted.

INDEX TERMS: Cardiomyopathy, Cat, cTn-I, Galectin-3, NT-proBNP

RESUMO.- [**Galectin-3 e biomarcadores cardíacos em gatos com cardiomiopatia.**] A galectina-3 (GAL-3) é um biomarcador detectável no soro, envolvido em processos inflamatórios e fibróticos, e tem sido associada ao desenvolvimento de doenças cardiovasculares em humanos. Portanto, este estudo teve como objetivo avaliar os níveis de GAL-3 em gatos com diferentes tipos e estágios de cardiomiopatia. Um total de 48 gatos foram incluídos no estudo, compreendendo um grupo controle saudável (Grupo I, n=12) e gatos diagnosticados com cardiomiopatia, classificados de acordo com o sistema de estadiamento do American College of Veterinary Internal Medicine [gatos da Classe B2 para o Grupo II (n=12), gatos da Classe C para o Grupo III (n=12) e gatos da Classe D para o Grupo IV (n=12)]. Todos os gatos foram submetidos a exames ecocardiográficos, eletrocardiográficos e radiográficos, e os níveis séricos de NT-proBNP, cTn-I e GAL-3 foram avaliados. Os níveis séricos de NT-proBNP e cTn-I diferiram significativamente entre os grupos. As concentrações de NT-proBNP no Grupo IV foram significativamente maiores do que nos Grupos I e II, enquanto os níveis de NT-proBNP no Grupo III foram significativamente maiores do que nos Grupos I e II. A concentração de cTn-I no Grupo IV foi significativamente maior do que nos Grupos I, II e III. Além disso, o Grupo III apresentou níveis de cTn-I significativamente maiores em comparação com o Grupo I. Não foi detectada diferença estatisticamente significativa nas concentrações de galectina-3 entre o grupo controle e os gatos com cardiomiopatia.

[1] Received on April 20, 2026.
Accepted for publication .

[2] Erciyes University, Institute of Health Science, Department of Veterinary Internal Medicine, 38280 Talas, Kayseri, Türkiye

[3] Erciyes University, Faculty of Veterinary Medicine, Department of Internal Medicine, 38280 Talas, Kayseri, Türkiye. *Corresponding author: oznuratalay@gmail.com
Os níveis de NT-proBNP e troponina I cardíaca estiveram associados ao estágio da doença e demonstraram importância diagnóstica em cardiomiopatias felinas. Embora nenhuma diferença significativa nos níveis de GAL-3 tenha sido observada de acordo com a classificação da cardiomiopatia neste estudo, estudos adicionais em larga escala utilizando diferentes classificações são necessários.

TERMOS DE INDEXAÇÃO: Cardiomiopatia, cTn-I, Galectina-3, Gato, NT-proBNP

INTRODUCTION

Heart disease is common in cats, affecting approximately 10-15% of the population (Romito et al. 2018). Cardiomyopathy is defined as an acquired heart disease characterized by myocardial damage and can lead to heart failure associated with cardiac morbidity and mortality in cats (Kittleson & Côté 2021a, Filipe et al. 2015, Fox et al. 2011). Structural and functional changes in the heart muscle result in reduced cardiac output and an inability to adequately meet the metabolic needs of tissues. While some affected cats remain asymptomatic, cases of congestive heart failure or sudden death may develop in others (Kiatsilapanan & Surachetpong 2020). In the 2020 guidelines published by the American College of Veterinary Internal Medicine (ACVIM), cardiomyopathies are classified as: hypertrophic (HCM), restrictive (RCM), dilated (DCM), arrhythmogenic right ventricular cardiomyopathy (ARVC), and unclassified cardiomyopathy (UCM) (Luis Fuentes et al. 2020). Of these, HCM and RCM are the most common types of cardiomyopathy in cats. HCM is characterized by concentric left ventricular hypertrophy and diastolic dysfunction and is the most common myocardial disorder (Kittleson & Côté 2021b, Jung & Kittleson 2011). RCM, on the other hand, is a heterogeneous myocardial disease characterized by impaired ventricular filling and reduced myocardial compliance (Chetboul et al. 2019). DCM is characterized by systolic dysfunction and left ventricular dilation. UCM is a cardiomyopathy that does not fit into other classifications based on echocardiographic and pathological criteria, presenting with severe biventricular enlargement, normal or mild left ventricular hypertrophy, and normal or mildly reduced systolic function. ARVC, on the other hand, is defined as a cardiac muscle disorder characterized by severe right atrial and ventricular dilation, frequent arrhythmias, and significant tricuspid regurgitation due to distortion of the tricuspid valve (Luis Fuentes et al. 2020).

Echocardiography is considered the gold standard for the diagnosis of cardiomyopathies (Harris et al. 2017). However, because echocardiography requires specialized equipment and expertise and is not always readily available in clinical practice, the need for alternative methods in diagnosis and follow-up has increased (Klein et al. 2022). In this context, cardiac biomarkers are used as important tools for determining the presence of heart disease, monitoring treatment, and assessing prognosis (Pierce et al. 2017, Boswood 2009).

N-terminal pro-B-type natriuretic peptide (NT-proBNP) and cardiac troponin-I (cTn-I) are biomarkers commonly used to assess cardiac stress and myocardial damage in cats. Various studies have demonstrated that these biomarkers reflect the presence and severity of heart disease (Gavazza et al. 2021, Oyama et al. 2013, Fox et al. 2009).

In recent years, it has been reported that Galectin-3 (GAL-3), a β-galactoside-binding lectin, is associated with cardiac fibroblast proliferation, collagen deposition, and ventricular dysfunction (Filipe et al. 2015, Lok et al. 2013). While GAL-3, which plays a role in inflammation and fibrosis processes, is noted to be associated with the development and progression of heart failure, it is also stated that it is not specific to cardiac diseases and may increase in various systemic diseases as well (Erdevir 2021, Merino et al. 2021, Kim et al. 2007). However, studies on the clinical significance of GAL-3 in cardiomyopathies in cats are limited.

The primary objective of this study is to evaluate serum GAL-3 levels in cats diagnosed with cardiomyopathy and to determine how GAL-3 levels change across different stages of the disease.

MATERIALS AND METHODS

Ethical approval. This study was approved by the Erciyes University Local Ethics Committee for Animal Experiments under project application no. 22/232 dated November 3, 2022, and all procedures were conducted in accordance with animal ethics and welfare guidelines. The number of cats to be included in the study and in each group was calculated with an effect size of 0.50, α=0.05, test power (1-β)=0.80 and group size=4, and was determined to be at least 48. The cats included in the study were divided into healthy control (Group I, n=12) and experimental group (n=36).

The study population consisted of cats brought to clinic for routine check-ups or presenting with signs of heart disease (such as dyspnea, tachypnea, fainting, aortic thromboembolism, rapid fatigue, or coughing), and in which a murmur or arrhythmia was detected during auscultation. In the study, the weight, age, breed, and sex of all

healthy and sick cats were recorded. After routine clinical examinations, all cats included in our present study underwent complete blood count, blood gas, and serum biochemical analyses, as well as radiographic, electrocardiographic, and echocardiographic examinations. Cats whose values were within the reference range were included in the study as healthy controls. Care was taken to ensure that the healthy control cats were of a similar age and breed to the cats in the patient group whenever possible. Echocardiographic examinations were performed according to established standard imaging protocols and techniques (Petric et al. 2012, Boon 2011, Fox et al. 2009). The cats included in the study were divided into a healthy control group (Group I, n=12) and an experimental group (n=36). Cats in the experimental group were classified according to the ACVIM classification following echocardiographic examinations: cats with cardiomyopathy showing heart muscle problems and cardiac remodeling, with a left atrial (LA) long-axis diameter >16 mm and/or an LA/AO ratio ≥1.6, and without clinical symptoms (asymptomatic) were classified as B2 (Group II = 12); cats with cardiomyopathy that had developed cardiac remodeling [Vertebral heart score (VHS) ≥8.1, LA/AO ≥ 2], exhibited clinical symptoms (respiratory distress, thromboembolism), and showed effusion/pulmonary edema and/or pleural effusion/pericardial effusion on radiographic and ultrasonographic examinations were classified as C (Group III=12), and cats with cardiomyopathy exhibiting the same symptoms as Group III patients but resistant to standard treatment (use of >6 mg/kg/day of furosemide) and experiencing recurrent symptoms were classified as Group IV (Group IV=12) (Fuentes et al. 2020). Patients with non-cardiac diseases such as lung diseases (bronchitis, neoplasia, asthma, etc.) that could cause respiratory problems other than cardiac disease, chronic diseases, infectious diseases, endocrinological, kidney, liver or spleen problems, and congenital heart diseases were excluded from the study. Additionally, cats using any heart disease medication or medications that could alter the values of the cardiac biomarkers being examined in the study (nonsteroids, steroids, antibiotics, etc.) were excluded.

Echocardiographic examination (2D, M-Mode, DDG). Without sedation, the animals included in the study underwent echocardiographic examinations using standard techniques, including 2D (B-mode), M-mode, color Doppler, Continuous Wave (CW), Pulsed Wave (PW), and DDG. Echocardiographic examinations were performed using a 4–12 MHz multi-frequency phased array probe (Philips Affiniti 50, Philips Healthcare, Andover, MA, USA). Measurements were repeated at least three times. Patients with an LA/Ao ratio greater than 1.5 were diagnosed with LA dilatation (Abbot & MacLean 2006). Clinical symptoms such as pain, cyanosis in the legs, paralysis, absent pulse, and decreased limb temperature that developed in patient groups (Levels C and D) were classified as cases of thromboembolism (Guillaumin 2024). Furthermore, thromboembolism was confirmed in patients during echocardiographic examination by the presence of clots and a smoke-like appearance inside the heart.

Radiographic examination. VHS measurements were performed on all cats included in the study using X-rays taken in the right lateral (LL) and dorsoventral (DV) positions (Browiner, Beatle 05 Vet HF; Mindray Vetipad M1 Plus DR). In the lateral radiograph, the lengths of the heart's long axis (from the apex of the heart to the base of the heart where it intersects the tracheal bifurcation) and short axis (perpendicular to the long axis measurement, at the point of maximum heart width, usually where the silhouette of the heart intersects the ventral border of the caudal vena cava) were measured in centimeters. The number of thoracic vertebrae was determined by placing each measurement from the cranial to the caudal aspect of T4. Vertebral heart score was obtained by summing the number of long-axis and short-axis thoracic vertebrae. The normal VHS range was accepted as 7.5 ± 0.32 (6.7-8.1) (Litster & Buchanan 2000). They were evaluated for pleural effusion, pulmonary edema, and left atrial (LA) enlargement, which can cause respiratory symptoms (Fuentes et al. 2020)

Electrocardiographic examination (ECG). ECG recordings were performed on all patients in the right lateral recumbent position. The ECG trace was recorded at 50 mm/sec, with each amplitude calibrated at 10 mm/mV. Bipolar I, II, and III limb leads, as well as unipolar aVR, aVL, and aVF limb leads, were automatically printed when the optimal analysis was displayed on the device screen. The electrocardiographic examination was evaluated using a 6-channel electrocardiography device (Carewell, 1103L Vet) operating with a three-lead system (I, II, III, aVR, aVL, aVF) and 25-50 mV settings.

Biochemical analyses. Blood samples (3 mL) were collected from the saphenous vein of the cats included in the study into gel-filled tubes without anticoagulant for biochemical analysis. The samples collected for biochemical analysis were centrifuged at 3,000 rpm for 5 minutes to separate the serum. Serum samples for GAL-3 analysis were stored in Eppendorf tubes at -20 °C until the time of analysis. Quantitative measurements of feline NT-proBNP (50-1500 pmol/L) and feline cTn-I (0.01-20 ng/mL) concentrations were performed immediately on the collected serum samples using the Vcheck V200 immunofluorescence model (Bionote®, Korea: ELK Diagnostics, Turkey). At the end of the study, serum GAL-3 levels (Grup I=8, Grup II=10, Grup III=10, Grup IV=12) were measured in duplicate using a feline GAL-3 (4.5-1000 pg/mL) ELISA kit (EF1RB-USA) in accordance with the manufacturer's procedures and read with an ELISA reader (Biotek uQuant Plate Reader; Winooski, VT, USA) set to 450 nm.

Statistical analyses. IBM SPSS Statistics 22 was used to perform statistical analyses when evaluating the findings obtained in the study. The normality of the data was assessed using the Kolmogorov-Smirnov and Shapiro-Wilks tests, and it was found that the data did not follow a normal distribution. In evaluating the study data, descriptive statistical methods (median, IQR) were used, along with the Kruskal-Wallis test for comparing quantitative data and conducting intergroup comparisons of parameters. Spearman's rho correlation analysis was used to examine the relationships between parameters. Statistical significance was assessed at the $P<0.05$ level.

RESULTS

Of the 48 cats included in the study, 3 were Scottish Folds, 32 were mixed-breed, 10 were British Shorthairs, 1 was a Siamese cat, and 2 were Persian cats; the median age of the cats was 8 (1-19), with 22 females and 26 males. Of these, Group I consisted of 8 Domestic Shorthair, 2 Persian cats, 1 British Shorthair, and 1 Scottish Fold cats; aged 1–12 years, with 8 females and 4 males; Group II consisted of 8 Domestic Shorthair, 2 British Shorthair, and 2 Scottish Fold cats, aged 2–14 years, 6 males and 6 females; Group III consisted of 8 Domestic Shorthair, 4 British Shorthair, aged 4–12, with 10 males and 2 females; and Group IV consisted of 8 Domestic Shorthair, 1 Siamese cat, and 3 British Shorthair, aged 4–19, with 6 males and 6 females.

During the clinical examination of the animals in Group II, symptoms such as exercise intolerance, respiratory distress, and thromboembolism were not observed, but a heart murmur was detected in 8 cats. All cats in which a murmur was detected were classified as having hypertrophic obstructive cardiomyopathy (HOCM). All cats in Group III were presented with symptoms of acute respiratory failure, and all exhibited exercise intolerance (n=12) and respiratory distress (n=12). Pleural effusion (n=6), pulmonary edema (n=12), and pericardial effusion (n=5) were observed. Thromboembolism was observed in only 1 of the Group III patients (n=1), while a "smoke" (spontaneous echocardiographic contrast) appearance was noted in the left atrium of some patients (n=9). Additionally, atrial fibrillation (AF, n=8) and premature ventricular complex (PVC, n=9) were observed in Group III patients. In all cats in Group IV, recurrent signs of respiratory distress (pericardial effusion n=8, pleural effusion n=10, pulmonary edema n=12) were observed, and thromboembolism was detected in 8 cats. In addition, recurrent ascites was observed in 5 patients. While AF and PVCs were observed in all patients, left bundle branch block was additionally identified in 3 patients. The types of heart muscle disease in the cats included in Groups II, III, and IV were found that based on echocardiographic findings. Among the 12 cats in Group II, 8 were diagnosed with HOCM, 1 with eRCM, and 3 with HCM. Of the 12 cats in Group III, 7 had HCM, 3 had DCM, and 2 had eRCM. Among the 12 cats in Group IV, 3 had mRCM, 2 had DCM, 1 had eRCM, 4 had HOCM, and 2 had HCM (Table 1).

Serum cardiac biomarker findings. The data on the significance of NT-proBNP, cTn-I, and GAL-3 biomarkers in healthy cats and cats with varying degrees of heart disease evaluated in this study are presented in Table 2. Although there was an increase in Group IV compared to Group I, no statistically significant difference was observed between the groups in terms of serum GAL-3 levels ($P=0.119$). When evaluated in terms of serum NT-proBNP levels, a significant difference was observed between Groups I and II and Groups III and IV ($P=0.001$), while in terms of serum cTn-I levels, significant differences were observed between Group I and Groups III and IV, and between Group II and Group IV ($P=0.001$). No correlation was found between serum Nt-proBNP, cTn-I and GAL-3 levels among the groups (Supplementary 1).

Vertebral heart score measurement findings. The vertebral heart scores of the cats included in the study were evaluated to determine heart size (Table 3). A statistically significant difference in VHS values was observed between the groups ($P=0.001$). The results of the Kruskal-Wallis test, conducted to determine which groups contributed to the significance, showed that Group I's VHS value was significantly lower than those of Group II ($P=0.026$), Group III ($P=0.001$), and Group IV ($P=0.001$). Group II's VHS value was found to be significantly lower than that of Group IV ($P=0.006$). There was no statistically significant difference among the other groups ($P>0.05$).

Electrocardiographic findings. Echocardiographic examinations were performed to assess waveform changes and rhythms. No abnormal rhythms or waveform changes were observed in healthy cats. In the patient groups, PVCs were observed in 3 patients in Group II, and left bundle branch block was identified in only one of these patients. In Group III, AF and PVCs were observed in 8 patients; in another patient, AF was not present, but PVCs were identified in only 1 patient. In all patients in Group IV, AF and PVC were observed, and left bundle branch block was additionally observed in 3 of these patients.

Echocardiographic findings. For all cats (both patients and healthy controls) included in the study, echocardiographic measurements were performed by a single operator using M-mode, 2D, pulsed-wave (PW), continuous-wave (CW), and tissue Doppler techniques through the right parasternal short-axis, right parasternal long-axis, left apical 4-chamber, and left apical 5-chamber views, and the statistical analyses of the data are presented in Supplementary 2 and 3.

A statistically significant difference in interventricular septal diastolic thickness (IVSd) was observed between the groups ($P=0.034$). According to the results of the Kruskal-Wallis test, the IVSd level in Group I was

found to be significantly lower than that in Group II (P=0.005) and Group III (P=0.031). No significant difference was observed between the other groups (P>0.05). A statistically significant difference was also found that between the groups in terms of left ventricular posterior wall diastolic thickness (LVPWd) (P=0.018). In the post hoc analysis, it was found Group I's LVPWd level was significantly lower than that of Group II (P=0.029) and Group IV (P=0.044). No statistically significant differences were found between the other groups (P>0.05). There was a significant difference among the groups in terms of left ventricular end-systolic diameter (LVIDs) (P=0.007). As a result of the Kruskal-Wallis test, it was found that Group I's LVIDs level was significantly lower than that of Group III (P=0.019) and Group IV (P=0.038). No significant differences were found among the other groups (P>0.05).

A statistically significant difference was observed between the groups in terms of left atrial diameter (LA Diam) (P=0.001). Accordingly, the LA Diam levels in Group III and Group IV were found to be significantly higher compared to Group I (P=0.001 for both) and Group II (P=0.039 and P=0.034, respectively). No significant differences were observed in other group comparisons (P>0.05). A statistically significant difference was detected between the groups in terms of the LA/Ao ratio (P=0.001). In the post hoc analysis, it was found that Group I's LA/Ao ratio was significantly lower than that of Group II (P=0.014), Group III (P=0.001), and Group IV (P=0.001); and that Group II's LA/Ao ratio was significantly lower than that of Group III (P=0.029) and Group IV (P=0.015). No significant difference was observed between Group III and Group IV (P>0.05).

A statistically significant difference in left ventricular ejection fraction (LV EF) was observed between the groups (P=0.005). According to the results of the Kruskal-Wallis test, the LV EF level in Group I was found to be significantly higher than that in Group III (P=0.002) and Group IV (P=0.014). No significant differences were observed between the other groups (P>0.05). Statistically significant differences were also present between the groups in terms of left ventricular fractional shortening (LV FS) values (P=0.006). In the further analysis, it was found that Group III's LV FS level was significantly lower compared to Group I (P=0.002) and Group II (P=0.014). No statistically significant difference was observed between the other groups (P>0.05). No statistically significant differences were observed in the other echocardiographic measurements evaluated across the groups (P>0.05).

DISCUSSION

Cardiomyopathies are among the most common heart diseases in cats and, according to the ACVIM consensus statement (2020), are classified as HCM, DCM, RCM, ARVC, and UCM based on structural and functional myocardial changes (Luis Fuentes et al. 2020). In the present study, HCM was the most common type of cardiomyopathy in the patient group, consistent with prevalence data reported in the literature. (Çolakoğlu et al. 2022, Kittleson & Côté 2021a).

According to the ACVIM classification, clinical findings such as congestive heart failure, effusion, and thromboembolism are expected to emerge in stages C and D (Fuentes et al. 2020). Similarly, in the present study, the higher incidence of dyspnea, pleural/pericardial effusion, and thromboembolism in symptomatic groups is consistent with the literature (Rohrbaugh et al. 2020, Ferasin & DeFrancesco 2015). Furthermore, the widespread observation of atrial fibrillation and ventricular premature complexes in advanced-stage groups is consistent with studies reporting a relationship between left atrial enlargement and the development of arrhythmias (Bartoszuk et al. 2019, Coté et al. 2004).

Studies involving electrocardiographic examinations have reported detecting PVCs in cats with HCM (Bartoszuk et al. 2019) and AF in cats with left atrial enlargement (Cote et al. 2004). The detection of AF in 20 patients and PVC in 21 patients in this study is consistent with previous reports.

The vertebral heart score is a reliable method used for the objective radiographic assessment of heart size (Litster & Buchanan 2000). In our present study, the fact that the mean VHS of the healthy group was consistent with reference values reported in the literature and that VHS was found to be significantly higher in patient groups supports the notion that VHS is an important parameter in the assessment of cardiomegaly and disease severity. In particular, the detection of higher VHS values in symptomatic groups demonstrates the relationship between disease progression and radiographic findings.

Although echocardiography is considered the gold standard for the diagnosis and monitoring of cardiac diseases, the use of cardiac biomarkers has become increasingly important in clinical practice because echocardiographic examination requires costly equipment and experienced operators (Laudhittirut et al. 2020). In feline medicine, N-terminal pro-B-type natriuretic peptide (NT-proBNP) and cardiac troponin I (cTnI) are the most widely used biomarkers for the diagnosis and assessment of cardiac diseases (Szarková et al. 2019, Oyama, 2013). NT-proBNP is a biomarker released in response to myocardial stress and is widely used in the diagnosis and staging of heart diseases (Fox et al. 2011, Connolly et al. 2008). Previous studies have reported that NT-proBNP levels are positively correlated with the presence and severity of cardiac disease (Machen et al. 2014, Oyama et al. 2013, Tominaga et al. 2011). This study demonstrated that NT-proBNP levels were lowest in the healthy group and significantly higher in stages C and D, supporting prior literature. However, the interpretation of the present

findings should take into account the potential influence of a ceiling effect. In particular, one possible explanation for the absence of statistically significant differences in NT-proBNP concentrations between C and D stages, representing cats with advanced cardiomyopathy, is the presence of a ceiling effect. As a substantial proportion of the measurements approached the assay's upper limit, the ability of NT-proBNP to discriminate between individuals with more advanced disease stages may have been diminished. Consequently, the observed lack of statistically significant differences may reflect limitations in the analytical measurement range rather than the absence of underlying biological differences.

cTn-I is considered a specific marker of myocardial cell damage, and elevated serum levels are associated with a poor prognosis (Gavazza et al. 2021, Langhorn & Willesen 2016). Numerous studies have demonstrated that cTn-I levels in cats with HCM are significantly higher than in healthy cats (Borgeat et al. 2014, Connolly et al. 2003, Herndon et al. 2002). In the present study, the marked increase in cTn-I levels, particularly in stage D, suggests that myocardial damage increases in advanced stages of the disease and is consistent with the literature.

Galectin-3 is a biomarker that plays a role in inflammatory and fibrotic processes and is associated with heart failure (Ding et al. 2020, Filipe et al. 2015). However, it has been reported that GAL-3 levels may also increase in various systemic diseases beyond cardiac pathologies (Merino et al. 2021). Therefore, cats with diseases such as infection, liver failure, lung disease, malignancy, and hyperthyroidism were excluded from this study. Although studies in the veterinary field are limited, Stack et al. (2023) reported that GAL-3 levels were elevated in cats with HCM compared to healthy cats, but no significant difference was found between disease stages. Similarly, Sakarin et al. (2016) detected elevated GAL-3 levels in dogs with mitral valve disease but noted no significant differences between disease stages. Another study by Klein et al. (2022) showed that GAL-3 levels were not associated with the presence or stage of degenerative mitral valve disease. In the present study, no statistically significant difference in GAL-3 levels was observed between patient groups with different stages of cardiomyopathy and the healthy control group, and no significant correlation was found between GAL-3 and NT-proBNP or cTn-I. These findings suggest that GAL-3 may have limited discriminatory power in reflecting disease severity in feline cardiomyopathies. However, the lack of statistically significant differences in GAL-3 concentrations among cats with different stages of cardiomyopathy may be attributable to the heterogeneity of the study groups, which may have obscured phenotype-specific effects. Furthermore, factors such as sample size, different cardiomyopathy phenotypes, and storage of serum samples at -20°C until testing should be considered as they may affect the results.

The present study has several limitations. First, the upper detection limit of the NT-proBNP assay was 1500 pmol/L, which may have introduced a ceiling effect and limited discrimination among cats with advanced disease. Second, the sample sizes differed between groups because the GAL-3 assay was performed in duplicate, resulting in the exclusion of some samples. Finally, serum samples used for GAL-3 analysis were stored at −20°C prior to testing, which may have influenced biomarker stability and should be considered when interpreting the results.

CONCLUSION

In conclusion, while the clinical usability of NT-proBNP and cTn-I in cardiomyopathy staging and disease severity assessment was confirmed, GAL-3 was evaluated to have limited diagnostic and prognostic value within the scope of this study. Further studies should be conducted using larger sample groups focused on specific subtypes of cardiomyopathy to gain a clearer understanding of the effects of new biomarkers, such as galectin-3, on diagnosis and staging.

Acknowledgments.- We would like to thank the Scientific Research Unit of Erciyes University for supporting this study with thesis project number TDK-2023-12757.

Conflict of interest.- The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Credit author statement. - Özge Şahin and Öznur Aslan – Conceptualization. Özge Şahin and Öznur Aslan – Methodology. Özge Şahin and Öznur Aslan – Investigation. Özge Şahin and Öznur Aslan - Writing original draft preparation. Özge Şahin and Öznur Aslan - Project administration. Öznur Aslan - Writing – review and editing. Öznur Aslan – Supervision. Öznur Aslan - Funding acquisition.

Data availability statement. - We will make pertinent data available after publication of the manuscript upon request.

Editor-in-Chief.- Fabiano José Ferreira de Sant'Ana.

REFERENCES

Abbott JA, Maclean HN. Two-dimensional echocardiographic assessment of the feline left atrium. J Vet Intern Med 2006;20(1):111–119.

Bartoszuk U, Keene BW, Baron Toaldo M, Pereira N, Summerfield N, Novo Matos J, Glaus TM. Holter monitoring demonstrates that ventricular arrhythmias are common in cats with decompensated and compensated hypertrophic cardiomyopathy. Vet J 2019;243:21–25.

Boon JA. Veterinary echocardiography. 2nd ed. USA: Wiley-Blackwell Press; 2011. p. 1–480.

Borgeat K, Sherwood K, Payne JR, Luis Fuentes V, Connolly DJ. Plasma cardiac troponin I concentration and cardiac death in cats with hypertrophic cardiomyopathy. J Vet Intern Med 2014;28(6):1731–1737.

Boswood A. Biomarkers in cardiovascular disease: beyond natriuretic peptides. J Vet Cardiol 2009;11:23–32.

Chetboul V, Passavin P, Trehiou-Sechi E, Gouni V, Poissonnier C, Pouchelon J, Desquilbet L. Clinical, epidemiological and echocardiographic features and prognostic factors in cats with restrictive cardiomyopathy: a retrospective study of 92 cases (2001–2015). J Vet Intern Med 2019;33(3):1222–1231.

Connolly DJ, Cannata J, Boswood A, Archer J, Groves EA, Neiger R. Cardiac troponin I in cats with hypertrophic cardiomyopathy. J Feline Med Surg 2003;5(4):209–216.

Connolly DJ, Magalhaes RJ, Syme HM, Boswood A, Luis Fuentes V, Chu L, Metcalf M. Circulating natriuretic peptides in cats with heart disease. J Vet Intern Med 2008;22(1):96–105.

Côté E, Harpster NK, Laste NJ. Atrial fibrillation in cats: 50 cases (1979–2002). J Am Vet Med Assoc 2004;225(2):256–260.

Çolakoğlu EÇ, Sevim K, Kalınbacak A, Kaya U. Retrospective evaluation of cardiopulmonary diseases in cats and dogs: 570 cases. Kocatepe Vet J 2022;15(2):182–188.

Ding Y, Wang Y, Zhang W, Jia Q, Wang X, Li Y, Lv S, Zhang J. Roles of biomarkers in myocardial fibrosis. Aging Dis 2020;11(5):1157–1174.

Erdevir M. The relationship between vitamin D status and the roles of galectin-3 and other cardiac markers in determining heart failure with preserved ejection fraction. Doctoral thesis, Hacettepe University, Türkiye, 2021.

Ferasin L, DeFrancesco T. Management of acute heart failure in cats. J Vet Cardiol 2015;17(1):173–189.

Filipe MD, Meijers WC, van der Velde AR, De Boer RA. Galectin-3 and heart failure: prognosis, prediction and clinical utility. Clin Chim Acta 2015;443:48–56.

Fox PR, Oyama MA, Reynolds C, Rush JE, DeFrancesco TC, Keene BW, Atkins CE, Macdonald KA, Schober KE, Bonagura JD, Stepien RL, Kellihan HB, Nguyenba TP, Lehmkuhl LB, Lefbom BK, Moise NS, Hogan DF. Utility of plasma N-terminal pro-brain natriuretic peptide (NT-proBNP) to distinguish between congestive heart failure and non-cardiac causes of acute dyspnea in cats. J Vet Cardiol 2009;11(Suppl 1):S51–S61.

Fox PR, Rush JE, Reynolds CA, DeFrancesco TC, Keene CE, Atkins CE, Gordon SG, Schober KE, Bonagura JD, Stepien RL, Kellihan HB, MacDonald KA, Lehmkuhl LB, Nguyenba TP, Moise NS, Lefbom BK, Hogan DF, Oyama MA. Multicenter evaluation of plasma N-terminal pro-brain natriuretic peptide (NT-proBNP) as a biochemical screening test for asymptomatic cardiomyopathy in cats. J Vet Intern Med 2011;25(5):1010–1016.

Gavazza A, Marchegiani A, Guerriero L, Turinelli V, Spaterna A, Mangiaterra S, Galosi L, Rossi G, Cerquetella M. Updates on laboratory evaluation of feline cardiac diseases. Vet Sci 2021;8:41.

Guillaumin J. Feline aortic thromboembolism: recent advances and future prospects. J Feline Med Surg 2024;26(6):1098612X241257878.

Harris AN, Estrada AH, Gallagher AE, Winter B, Lamb KE, Bohannon M, Hanscom J, Mainville CA. Biologic variability of N-terminal pro-brain natriuretic peptide in adult healthy cats. J Feline Med Surg 2017;19(2):216–223.

Herndon WE, Kittleson MD, Sanderson K, Drobatz KJ, Clifford CA, Gelzer A, Summerfield NJ, Linde A, Sleeper MM. Cardiac troponin I in feline hypertrophic cardiomyopathy. J Vet Intern Med 2002;16(5):558–564.

Jung SW, Kittleson MD. Effect of atenolol on NT-proBNP and troponin in asymptomatic cats with hypertrophic cardiomyopathy. J Vet Intern Med 2011;25(5):1044–1049.

Kiatsilapanan A, Surachetpong SD. Assessment of left atrial function in feline hypertrophic cardiomyopathy using speckle tracking echocardiography. BMC Vet Res 2020;16(1):344.

Kim H, Lee J, Hyun JW, Park JW, Joo HG, Shin T. Expression and localization of galectin-3 in mouse tissues. Cell Biol Int 2007;31(7):655–662.

Kittleson MD, Côté E. The feline cardiomyopathies: general concepts. J Feline Med Surg 2021;23(11):1009–1027.

Kittleson MD, Côté E. The feline cardiomyopathies: hypertrophic cardiomyopathy. J Feline Med Surg 2021;23(11):1028–1051.

Klein S, Nolte I, Granados Soler JS, Lietz P, Sehn M, Rau JF, Rohn K, Packeiser EM, Bach JP. Evaluation of new and old biomarkers in dogs with degenerative mitral valve disease. BMC Vet Res 2022;18(1):256.

Langhorn R, Willesen JL. Cardiac troponins in dogs and cats. J Vet Intern Med 2016;30(1):36–50.

Laudhittirut T, Rujivipat N, Saringkarisate K, Soponpattana P, Tunwichai T, Surachetpong SD. Accuracy of methods for diagnosing heart diseases in cats. Vet World 2020;3(5):872–878.
Litster AL, Buchanan JW. Vertebral scale system to measure heart size in radiographs of cats. J Am Vet Med Assoc 2000;216(2):210–214.
Lok DJ, Lok SI, Bruggink-André de la Porte PW, Badings E, Lipsic E, van Wijngaarden J, De Boer RA, van Veldhuisen DJ, van der Meer P. Galectin-3 is an independent marker for ventricular remodeling and mortality in patients with chronic heart failure. Clin Res Cardiol 2013;102(2):103–110.
Luis Fuentes V, Abbott J, Chetboul V, Côté E, Fox PR, Häggström J, Kittleson MD, Schober K, Stern JA. ACVIM consensus statement guidelines for the classification, diagnosis and management of cardiomyopathies in cats. J Vet Intern Med 2020;34(3):1062–1077.
Machen MC, Oyama MA, Gordon SG, Rush JE, Achen SE, Stepien RL, Fox PR, Saunders AB, Cunningham SM, Lee PM, Kellihan HB. Multi-centered investigation of a point-of-care NT-proBNP ELISA assay to detect occult feline heart disease. J Vet Cardiol 2014;16(4):245–255.
Merino-Merino A, Gonzalez-Bernal J, Fernandez-Zoppino D, Saez-Maleta R, Perez-Rivera JA. The role of galectin-3 and ST2 in cardiology: a short review. Biomolecules 2021;11(8):1167.
Oyama MA. Using cardiac biomarkers in veterinary practice. Vet Clin North Am Small Anim Pract 2013;43(6):1261–1272.
Oyama MA, Boswood A, Connolly DJ, Ettinger SJ, Fox PR, Gordon SG, Rush JE, Sisson DD, Stepien RL, Wess G, Zannad F. Clinical usefulness of an assay for measurement of circulating N-terminal pro-B-type natriuretic peptide concentration in dogs and cats with heart disease. J Am Vet Med Assoc 2013;243(1):71-82.
Petrič AD, Rishniw M, Thomas WP. Two-dimensionally-guided M-mode and pulsed wave Doppler echocardiographic evaluation of the ventricles of apparently healthy cats. J Vet Cardiol 2012;14(3):423–430.
Pierce KV, Rush JE, Freeman LM, Cunningham SM, Yang VK. Association between survival time and changes in NT-proBNP in cats treated for congestive heart failure. J Vet Intern Med 2017;31(3):678–684.
Rohrbaugh MN, Schober KE, Rhinehart JD, Bonagura JD, Habing A, Yıldız V. Detection of congestive heart failure by Doppler echocardiography in cats with hypertrophic cardiomyopathy. J Vet Intern Med 2020;34(3):1091–1101.
Romito G, Guglielmini C, Mazzarella MO, Cipone M, Diana A, Contiero B, Baron Toaldo M. Diagnostic and prognostic utility of surface electrocardiography in cats with left ventricular hypertrophy. J Vet Cardiol 2018;20(5):364–375.
Sakarin S, Rungsipipat A, Surachetpong SD. Galectin-3 in cardiac muscle and circulation of dogs with degenerative mitral valve disease. J Vet Cardiol 2016;18(1):34–46.
Stack JP, Fries RC, Kruckman L, Kadotani S, Wallace G. Galectin-3 as a novel biomarker in cats with hypertrophic cardiomyopathy. J Vet Cardiol 2023;48:54–62.
Szarková A, Lukáč B, Weissová T, Bjørnstad P, Turňa H, Martínez O. Feline hypertrophic cardiomyopathy (FHCM). Folia Vet 2022;66(1):83–90.
Tominaga Y, Miyagawa Y, Toda N, Takemura N. The diagnostic significance of plasma N-terminal pro-B-type natriuretic peptide concentration in asymptomatic cats with cardiac enlargement. J Vet Med Sci 2011;73(8):971–975.

Table 1. Types of heart muscle diseases observed in the group of cats under study

Patient Group	Total Number of Patients	Conditions	Number of Patients
Group II	12	HOCM	8
		eRCM	1
		HCM	3
Group III	12	HCM	7
		DCM	3
		eRCM	2
Group IV	12	mRCM	3
		DCM	2
		eRCM	1
		HOCM	4
		HCM	2

HOCM: Hypertrophic Obstructive Cardiomyopathy, eRCM: Endomyocardial Restrictive Cardiomyopathy, HCM: Hypertrophic Cardiomyopathy, DCM: Dilated Cardiomyopathy, mRCM: Myocardial Restrictive Cardiomyopathy

Table 2. Levels of significance of cardiac biomarkers between groups

	Group I	Group II	Group III	Group IV	
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	p
NT-proBNP (pmol/L)	n=12 45 (45-54.88)[a]	n=12 374.7 (183.5-494.88)[a]	n=12 1500 (999.1-1500)[b]	n=12 1500 (1500-1500)[b]	0.001 *
GAL-3 (pg/mL)	n=8 781.72 (635.71-913.69)	n=10 813.16 (612.71-906.26)	n=10 760.83 (507.58-825.28)	n=12 869.21 (812.49-958.22)	0.119
cTn-I (ng/mL)	n=12 0.01 (0.01-0.06)[a]	n=12 0.05 (0.01-0.4)[ab]	n=12 0.36 (0.06-2.24)[b]	n=12 4.36 (2.08-8.88)[c]	0.001 *

*P<0.05. Different letters in the same row indicate differences between groups.

Table 3. Comparison of VHS measurements by group

	Group I	Group II	Group III	Group IV	
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	p
VHS	(7.5) (7.2-7.98)[a]	(8.35) (8-8.88)[b]	(9.5) (8.78-9.65)[bc]	(9.9) (9.5-10.5)[c]	0.001*

VHS: Vertebral Heart Scores, *P<0.05 Different letters in the same row indicate differences between groups.

Supplementary 1: Correlation assessment of cardiac biomarkers across groups.

		NT-ProBNP (pmol/L)	GAL-3 (pg/mL)	cTn-I (ng/mL)
Group I				
NT-proBNP (pmol/L)	r	1.000		
	p	.		
GAL-3(pg/mL)	r	0.165	1.000	
	p	0.697	.	
cTn-I (ng/mL)	r	0.084	0.353	1.000
	p	0.796	0.391	.
Group II				
NT-proBNP (pmol/L)	r	1.000		
	p	.		
GAL-3 (pg/mL)	r	-0.067	1.000	
	p	0.855	.	
cTn-I (ng/mL)	r	0.321	-0.006	1.000
	p	0.309	0.986	.
Group III				
NT-proBNP (pmol/L)	r	1.000		
	p	.		
GAL-3 (pg/mL)	r	-0.102	1.000	
	p	0.778	.	
cTn-I (ng/mL)	r	0.402	0.128	1.000
	p	0.195	0.725	.
Group IV				
NT-proBNP (pmol/L)	r	1.000		
	p	.		
GAL-3 (pg/mL)	r	-0.131	1.000	
	p	0.685	.	
cTn-I (ng/mL)	r	0.394	0.270	1.000
	p	0.205	0.396	.

Supplementary 2. Evaluation of groups based on 2D-M mode echocardiographic measurements

	Group I	Group II	Group III	Group IV	
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	p
IVSd (cm)	0.51 (0.45-0.55 [a]	0.71 (0.55-0.98)[b]	0.68 (0.45-0.96)[b]	0.56 (0.51-0.73)[ab]	0.034*
LVIDd (cm)	1.3 (1.15-1.58)	1.67 (1.08-1.9)	1.87 (1.32-2.31)	1.59 (1.42-1.81)	0.077
LVPWd (cm)	0.43 (0.38-0.53)[a]	0.63 (0.51-0.69)[b]	0.53 (0.47-0.63)[ab]	0.61 (0.43-0.78 [b]	0.018*
IVSs (cm)	0.7 (0.61-0.72)	0.92 (0.68-1.14)	0.9 (0.61-1.05)	0.74 (0.63-0.88)	0.103
LVIDs (cm)	0.72 (0.61-0.97)[a]	0.83 (0.55-1.21)[ab]	1.29 (0.78-1.85)[b]	1.11 (0.95-1.48 [b]	0.007*
LVPWs (cm)	0.63 (0.56-0.68)	0.83 (0.68-0.89)	0.65 (0.58-0.81)	0.73 (0.48-0.86)	0.075
LA Diam (cm)	1.25 (1.05-1.4)[a]	1.75 (1.6-1.88) [a]	2.45 (1.9-2.78) [b]	2.35 (2.2-2.5)[b]	0.001*
Ao Diam (cm)	0.9 (0.8-0.98)	0.8 (0.8-0.9)	0.8 (0.73-1)	0.75 (0.7-0.9)	0.194
LVOT Diam (cm)	0.8 (0.63-0.8)	0.7 (0.6-0.7)	0.7 (0.6-0.8)	0.6 (0.53-0.7)	0.169
LA/Ao	1.41 (1.3-1.55)[a]	2 (1.89-2.35)[b]	2.84 (2.27-3.54)[c]	3.29 (2.69-3.92 [c]	0.001*
LV EF %	77.3 (69.13-86.53)[a]	77.95 (64.03-87.05)[ab]	54.75 (29.13-72.58)[b]	61.35 (40.68-70)[b]	0.005*
LV FS %	43.1 (35.3-51.78)[a]	42.75 (31.63-53.58)[a]	26.35 (13-37.7)[b]	30 (18.7-36.78)[ab]	0.006*

IVSd: Interventricular Septal thickness in diastole, LVIDd: Left Ventricular Internal Diameter in diastole, LVPWd: Left Ventricular Posterior Wall thickness in diastole, IVSs: Interventricular Septal thickness in systole, LVIDs: Left Ventricular Internal Diameter in systole, LVPWs: Left Ventricular Posterior Wall thickness in systole, LA Diam: Left Atrial Diameter, Ao Diam: Aortic Diameter, LVOT Diam: Left Ventricular Outflow Tract Diameter, LA/Ao: Left Atrium to Aorta ratio, LV EF %: Left Ventricular Ejection Fraction, LV FS %: Left Ventricular Fractional Shortening, *P<0.05. Different letters in the same row indicate differences between groups.

Supplementary 3. Evaluation of groups based on pulse wave doppler, transmitral flow, and mitral annulus doppler echocardiography measurements

	Group I	Group II	Group III	Group IV	
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	p
MV E vel (cm/sn)	61.55 (59.15-72.43)[a]	98.6 (79.1-111)[b]	105.5 (82.28-149.25)[b]	92.7 (74.58-111.5)[b]	0.001*
MV A vel (cm/sn)	40.9 (35.48-41.88)	40.1 (27.23-50.93)	38.65 (29.8-64.3)	31.85 (23.68-50.25)	0.613
E/A	1.55 (1.4-1.8[a]	2.65 (2.13-3)[b]	2.47 (1.98-3.25)[b]	3.25 (1.63-3.83)[b]	0.007*
MV Dec. Time	166.5 (160.25-173.75)[a]	111.5 (92-128)[b]	93 (80-124)[b]	97.5 (80.75-120)[b]	0.001*
E' medial	9.04 (8.24-9.3)[a]	6.91 (5.72-11.78)[ab]	5.07 (4.28-6.47)[b]	5.37 (4.23-6.75)[b]	0.001*
A'medial	9.6 (7.67-11.75)[a]	7.16 (5.57-8.26)[ab]	5.17 (4.36-6.47)[b]	4.48 (3.42-6.02)[b]	0.001*
E' lateral	7.36 (6.24-8.7)[a]	8.51 (5.22-11.64)[a]	6.66 (5.27-7.86)[ab]	4.19 (3.88-6.2)[b]	0.003*
A'lateral	6.72 (4.95-8.3)	6.47 (5.57-8.26)	5.72 (4.75-7.42)	5.57 (2.99-6.89)	0.261
E'/A' medial	1.1 (0.73-1.13)	1.4 (0.9-1.7)	0.9 (0.6-1.4)	1.35 (0.7-1.65)	0.291
E'/E' medial	7.2 (6.03-8.18)[a]	12.2 (9.38-16.33)[b]	17 (15.1-29.9)[b]	16.45 (12.95-23.48)[b]	0.001*
E'/A' lateral	1.4 (0.88-1.6)	1.5 (0.8-1.9)	0.95 (0.7-1.18)	0.73 (0.6-2.03)	0.301
E'/E' lateral	8.5 (7.75-8.85)[a]	11.75 (7.28-17.55)[ab]	15 (11.4-26.7)[bc]	20.55 (15.93-25.58)[c]	0.001*

MV E vel: Mitral Valve Early diastolic filling velocity (E wave velocity), MV A vel: Mitral Valve Late diastolic filling velocity (A wave velocity), E/A: Ratio of early to late ventricular filling velocities, MV Dec. Time: Mitral Valve Deceleration Time, E' medial: Medial (septal) mitral annular early diastolic velocity, A' medial: Medial (septal) mitral annular late diastolic velocity, E' lateral: Lateral mitral annular early diastolic velocity, A' lateral: Lateral mitral annular late diastolic velocity, E'/A' medial: Ratio of medial early to late diastolic velocities, E'/E' medial: Ratio of mitral inflow E velocity to medial E' velocity, E'/A' lateral: Ratio of lateral early to late diastolic velocities, E'/E' lateral: Ratio of mitral inflow E velocity to lateral E' velocity, *P<0.05. Different letters in the same row indicate differences between groups.