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Research Article

Association of Galectin-3, Lipid Profile, Creatine Kinase-MB in Heart Failure Patients with Preserved Ejection Fraction and Reduced Ejection Fraction

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Abstract

Background: Heart failure (HF) is a progressive condition frequently associated with hypertension, type 2 diabetes mellitus, and obesity, contributing to myocardial stress and remodeling. The interaction among galectin-3, lipid profile, and creatine kinase-MB (CK-MB) plays a pivotal role in assessing both preserved and reduced ejection fraction (EF). These biomarkers are essential for diagnosis, prognosis, and risk stratification in HF. Measurement of galectin-3, lipid profile, and CK-MB levels may enhance the predictive capacity for HF.

Methods: A case-control study included a total of 90 individuals aged 45–70 years who were involved: 60 HF patients (30 with preserved ejection fraction and 30 with reduced ejection fraction) and 30 age- and sex-matched healthy controls. Five milliliters of venous blood were collected from each participant to measure galectin-3, lipid profile, and CK-MB. Statistical analyses were performed using SPSS for Windows 10 (IBM SPSS 26.0, Chicago, IL, USA).

Results: Galectin-3 levels were significantly higher in HF patients ($p < 0.001$): preserved EF (2201 ± 261), reduced EF (1329 ± 183), and controls (574 ± 120). The lipid profile showed significant increases ($p < 0.01$) in total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), and very low-density lipoprotein cholesterol (VLDL-C), with a notable decrease in high-density lipoprotein cholesterol (HDL-C) ($p < 0.01$). CK-MB levels showed no significant difference ($p = 0.724$). These findings suggest galectin-3 may be a more reliable HF biomarker than CK-MB.

Conclusions: Galectin-3 is markedly elevated in HF. Dyslipidemia contributes to HF progression. CK-MB lacks diagnostic significance in this context.

Keywords: Galectin-3; Lipid profile; Creatine Kinase-MB; Preserved ejection; Reduced ejection fraction.

Introduction

Heart failure (HF), which is caused by the heart's inability to pump enough blood to meet the body's needs for oxygen and nutrition, leaves patients with severe disabilities and a high death rate. One condition that significantly affects the clinical and economic well-being of people worldwide is HF [1]. Low cardiac output and/or high intracardiac pressures at rest or during stress are clinical symptoms of chronic heart failure (CHF), which is caused by structural and/or functional cardiac abnormalities. HF is more common as people age, rising from about 1% in people under 55 to >10% in people 70 years of age or older [2]. It is classified in several ways, the most popular being based on ejection fraction (EF) and clinical presentation. The main classifications include: Heart Failure with Preserved Ejection Fraction (HFpEF): EF ≥ 50%. Heart Failure with Mildly Reduced Ejection Fraction (HFmrEF): EF 41-49%. Heart Failure with Reduced Ejection Fraction (HFrEF): EF ≤ 40%. These categorizations help guide the diagnostic and treatment strategies [3]. An analysis of the results of the most recent HF registries in Middle East Arab countries (MEACs) revealed that the average age of affected individuals is at least 10 years younger than their Western counterparts; however, data on the prevalence of HF in this region is generally lacking [4]. The cardiovascular disease continuum was first presented by Dzau and Braunwald thirty years ago. They described cardiovascular disease as a series of events that are started by a wide range of related and unrelated risk

factors and progress through a number of physiological pathways and processes before ending in end-stage heart disease. Advanced HF and cardiovascular death are the outcomes of cardiovascular disease, which starts with diabetes mellitus (DM), hypertension, and dyslipidemia, among other conditions [5]. It hypothesized that in most elderly individuals with heart failure, independent of the left ventricular ejection fraction (LVEF), it is the result of accelerated cardiovascular aging caused by particular risk factors (often hypertension, obesity, type 2 diabetes mellitus (T2DM), coronary artery disease (CAD), and valvular heart disease (VHD)), which primarily impact the heart and vasculature. These risk factors act singly or, more typically, in combination, directly or indirectly (hypertension, obesity, and T2DM can cause HF through an intervening myocardial infarction) [6]. Galectins play an important role as both therapeutic agents and biomarkers of the inflammatory stage that occurs in a number of diseases, such as cancer, cardiovascular disease, type 2 diabetes, musculoskeletal disorders, and neurodegenerative diseases. As a result, galectin biosensing becomes essential for both assessing a pathological state and monitoring the effectiveness of a therapeutic treatment. This is why interest in this protein family is increasing [7].

Hyperlipidemia is characterized by unusually high levels of lipids or lipoproteins in the blood. Patients with hyperlipidemia are twice as likely to develop cardiovascular disease (CVD), and high levels of non-fasting triglycerides have been linked to an increased risk of HF. However, low serum total cholesterol (TC) levels were linked independently to a poor prognosis for patients with end-stage heart failure and raised the death rate for both ischemic and non-ischemic heart failure [8]. The current study aims to evaluate the association of galectin-3 (Gal-3) with creatine kinase-MB with lipid profile levels in HF patients and healthy controls. Understanding these interrelationships is essential for refining cardiovascular risk assessment and developing targeted interventions for high-risk heart failure populations. The study seeks to answer the following question: can a combination of Gal-3, lipid profile, and creatine kinase-MB improve the early detection and risk stratification in HF subtypes HFpEF vs HFrEF? The research objective is to evaluate Gal-3 as an HF diagnostic biomarker.

Materials and Methods

Patients

This case-control study with a prospective design was conducted at the Department of Chemistry and Biochemistry, College of Medicine, University of Karbala, in collaboration with the Karbala Center for Cardiac Diseases and Surgery and the Iraqi Center for Heart Disease in Medical City in Baghdad. A total of 60 individuals were enrolled in the study, with ages ranging from 45 to 70 years, divided into two groups: 30 patients with HFpEF and 30 patients with HFrEF. Another group is 30 samples of healthy controls that are age- and sex-matched.

The HF was divided into three classes based on the percentage of the ejection fraction (EF): heart failure with reduced EF (HFrEF), heart failure with midrange, also termed mildly reduced EF (HFmrEF), and heart failure with intact EF (HFpEF). HFpEF is a complicated cardiovascular illness characterized by an ejection fraction (EF) of above 50%. HFrEF is defined as an EF of less than 40%. Echo parameters: a left ventricle (LV) ejection fraction of about 50% to 70% is categorized as normal. A mildly reduced LV ejection fraction is usually between 41% and 49%. A reduced LV ejection fraction is usually 40% or less

Inclusion criteria: Includes patients with heart failure diagnosed by clinical signs, symptoms, echo, and specialist doctor approval. Healthy individuals were also included as a control.

Exclusion criteria: excluded patients were those with any condition that affects the biomarker in the study, such as chronic kidney disease, coronary heart disease, chronic liver disease, active cancer, and severe pulmonary conditions.

Assay

Diagnosis of HF was based on American Heart Association (AHA) criteria, supported by clinical presentation and electrocardiogram (ECG) findings. The biochemical tests included galectin-3 (Gal-3) levels, which were determined using a quantitative sandwich ELISA kit supplied by Bioassay Technology Laboratory (Shanghai, China). The assay detection range was 5–2000 pg/mL, with a sensitivity of 2.49 pg/mL, as per the manufacturer's datasheet. Serum samples were collected in gel tubes, allowed to clot at room temperature for 30 minutes, and then centrifuged at 3000 rpm for 10 minutes. The resulting sera were stored at –20 °C until analysis. All procedures strictly followed the manufacturer’s protocol. Absorbance was measured at 450 nm using a

microplate reader (BT LAB, China). A standard curve was generated using provided calibrators, and sample concentrations were calculated accordingly. The upper reference limit (URL) was considered 1200 pg/mL. Lipid profile parameters: serum total cholesterol (normal range: 40 mg/dL for males and >50 mg/dL for females), triglycerides (normal: <150 mg/dL), and low-density lipoprotein (LDL), calculated using the Friedewald equation. The analyses were conducted using the Dimension-RXL fully automated chemistry autoanalyzer (Siemens Healthcare Diagnostics Inc., USA).

Creatine kinase levels were determined using a coupled enzymatic reaction where creatine kinase (CK) using Creatine Kinase Kit supplied by Radiometer Laboratory (Denmark), The assay detection range was 0.1–100 ng/mL, with a sensitivity of <0.05 ng/mL, as per the manufacturer's datasheet. Serum samples were collected in gel tubes, allowed to clot at room temperature for 30 minutes, and then centrifuged at 3000 rpm for 10 minutes. The resulting sera were stored at –20 °C until analysis. All procedures strictly followed the manufacturer's protocol. Absorbance is measured spectrophotometrically at 340 nm (Radiometer, Denmark). A standard curve was generated using provided calibrators, and sample concentrations were calculated accordingly. The upper reference limit (URL) was considered <5.2 µg/L, consistent with current clinical guidelines for creatine kinase interpretation.

Ethical Approval

The study protocol was approved by the Ethical Committee of the College of Medicine and Karbala Health Directorate by document number 3559 on 20 October 2024. All research participants were informed and allowed to give their consent before sample collection. A local college and hospital ethics committee reviewed and approved the protocol, subject information, and consent form, which contains the study type and purpose.

Statistical analysis

The statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS, IBM, version 26.0). The data distribution's normality was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. Mean ±SD is a representation of continuous data having a normal distribution. A one-way ANOVA test was used to compare the means of each group. Spearman correlation was used to perform correlations between variables. A value of ($P \leq 0.05$) is deemed significant.

Results

The percentage of males is 60%, and the percentage of females is 40% (Figure 1). There was no statistically significant difference in mean age and BMI between patients and healthy control groups. The level of galectin-3 is significantly elevated in patients compared to the control group (Table 1). The results also showed an increase of HF incidence in the elderly, as shown in table (2).

A statistically significant increase in triglycerides (TG) ($p < 0.01$), low-density lipoprotein cholesterol (LDL-C) ($p < 0.01$), and very low-density lipoprotein cholesterol (VLDL-C) ($p < 0.01$) was observed in the HF group. In contrast, the high-density lipoprotein cholesterol (HDL-C) level was significantly decreased ($p < 0.001$) in patients with HF compared to the healthy control group. Notably, total cholesterol (TC) levels were lower in patients than in controls, with the difference being statistically significant ($p < 0.01$) (Table 3). A positive correlation was observed between galectin-3 and CK-MB levels, while galectin-3 showed a negative correlation with HDL-C (Table 2). Similarly, CK-MB levels are higher in the HF group than in controls ($p = 0.724$), but there is no statistically significant difference (Table 4).

Discussion

In the current study, the percentage of males was higher than the percentage of females. Several differences between women and men have been observed in HF, including the epidemiology, etiology, pathogenesis, risk factors, and prognosis. The incidence of HF also differs between men and women, depending on the study population analyzed. For example, women had a lower risk of incident HF than men in middle-aged to older individuals, but women had a higher HF risk than men in the oldest age groups. Men tended to be at higher risk of developing HF with reduced ejection fraction (HFrEF), and conversely, women were more likely to develop HFpEF [9]. Sex is a potential risk factor in aging adults, as older ladies have a higher risk of cardiovascular disease (CVD) compared to men of the same age. Nevertheless, in both males and females, the likelihood of developing CVD rises as they become older, which is linked to a general decrease in sex hormones, particularly estrogen and testosterone [10]. In the current study the HF incidence increases with age. Aging influences various physiological processes and contributes to structural and functional decline in cardiac tissue.

These alterations include an increased incidence of left ventricular hypertrophy, a decline in left ventricular diastolic function, left atrial dilation, atrial fibrillation, myocardial fibrosis, and cardiac amyloidosis, elevating susceptibility to chronic heart failure (CHF) in the elderly. Concurrently, age-related structural and functional changes in the vascular system, attributed to endothelial dysfunction, arterial stiffness, impaired angiogenesis, oxidative stress, and inflammation, impose additional strain on the heart [11].

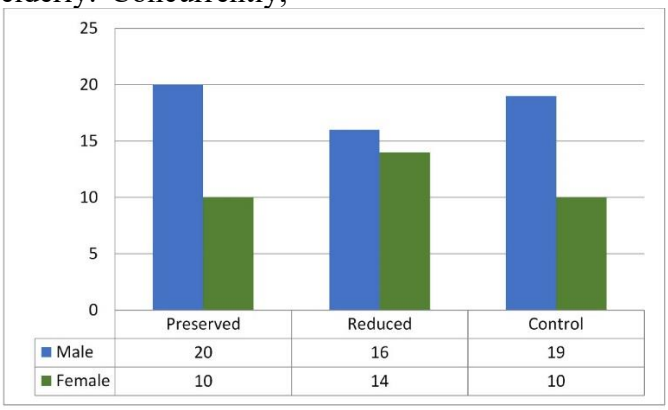

Figure 1: Sex distributions of study groups in comparison with study groups.

Table 1: Mean with standard deviation of serum galectin-3 in patient subgroups and control group.

Parameter	Study groups	N = 90	Mean ± SD	P-value
Serum galectin-3 (pg/mL)	Patients with Preserved EF%	30	2201 ± 261	<0.001
	Patients with Reduced EF%	30	1329 ± 183	
	Controls	30	574 ± 120	

N: number, EF: Ejection fraction

Table 2: Mean with standard deviation of serum galectin-3 in patient subgroups according to duration of disease.

Parameter	HF Duration	N = 60	Mean ± SD	P-value
Serum galectin-3 (pg/mL)	1-3 years	27	1668.3± 481.3	0.191
	4-6 years	17	1892.55 ± 456.7	
	≥ 7 years	16	1953.5 ± 706.17	

N: number, SD: Standard deviation, HF: Heart failure

Table 3: Mean with standard deviation of lipid profiles in patient subgroups and control group.

Parameter	Groups	N = 90	Mean ± SD	p-value
Cholesterol (mg/dl)	Patients with Preserved EF%	30	220 ± 49.5	<0.01
	Patients with Reduced EF%	30	180 ± 36	
	Controls	30	167 ± 13.6	
TG (mg/dl)	Patients with Preserved EF%	30	183 ± 52	<0.01
	Patients with Reduced EF%	30	152 ± 35.5	
	Controls	30	136 ± 13.6	
LDL (mg/dl)	Patients with Preserved EF%	30	149 ± 23.6	<0.01
	Patients with Reduced EF%	30	126 ± 22.3	
	Controls	30	121 ± 11.0	
HDL (mg/dl)	Patients with Preserved EF%	30	39.4 ± 3.7	0.001
	Patients with Reduced EF%	30	45.1 ± 4.6	
	Controls	30	55.3 ± 4.2	
VLDL (mg/dl)	Patients with Preserved EF%	30	36.6 ± 10.3	<0.001
	Patients with Reduced EF%	30	26.3 ± 7.1	
	Controls	30	27.3 ± 2.6	

*TG: Triglycerides, LDL: Low Density Lipoprotein, HDL: High Density Lipoprotein, VLDL: Very Low Density Lipoprotein, N: number, EF: Ejection fraction

Table 4: Mean with standard deviation of creatine kinase-MB in patient subgroups and control group.

Parameter	Study Groups	N = 90	Mean ± SD	P-value
Creatine Kinase-MB (µg/L)	Patients with Preserved EF%	30	3.17 ± 0.82	0.724
	Patients with Reduced EF%	30	3.0 ± 0.78	
	Controls	30	3.17 ± 0.72	

EF: Ejection fraction

In the current study's results there is an elevation of Gal-3 levels in patients, particularly in preserved EF% compared to the control group. The results of the current study showed a marked increase in levels of galectin-3; it's known it has a protective role as a pro-inflammatory effect by induction of cardiac remodeling and fibrosis induction. Sharma *et al.* (2004) in a study indicating the importance of galectin-3, which was the strongest differentially regulated gene associated with HF [12]. Subsequently, an elevated level of myocardial galectin-3 has been observed in a number of animal models of heart disease, such as hypertensive rats prone to HF, interferon-γ-induced chronic active myocarditis and cardiomyopathy, rat angiotensin II-induced hypertension, streptozotocin-induced diabetic cardiomyopathy, and pulmonary artery banding-induced HF in both the left ventricle and the right ventricle [13]. Galectin-3 coordinates several physiological processes and has also been identified as a "culprit molecule" in the pathogenesis of various diseases, especially fibrosis, cardiovascular disease, and cancer. Galectin-3 induces fibroblast proliferation and heterogeneous deposition of collagen types, eventually leading to loss of cardiac function [14]. Gal-3 differentiated patients with HFpEF from an overall cohort of well-characterized patients with risk factors for HFpEF. Independent of other factors, baseline Gal-3 levels were associated with a higher risk for incident HFpEF [15].

In the current study the increased concentrations of lipid profile in patients in comparison with controls, except HDL-C, were lower in patients. Such alteration in lipid metabolism is known to be dysregulated in patients, and lipid markers, such as total cholesterol, high-density lipoprotein cholesterol, triglycerides, and low-density lipoprotein cholesterol, are used to assess the risk of cardiovascular diseases [16]. Dyslipidemia, which is defined by elevated LDL cholesterol, elevated triglycerides, and reduced HDL cholesterol, is considered a risk factor for cardiovascular diseases, such as heart failure [17]. Independent of myocardial infarction, elevated non-HDL cholesterol and low HDL cholesterol levels are linked to an increased risk of HF [18]. Elevated triglycerides are also indicative of HF, particularly in diabetic patients [19]. HF can be promoted by elevated cholesterol, which can compromise both systolic and diastolic function, as well as increase blood pressure, arterial rigidity, and left ventricular hypertrophy. Impaired function and increased left ventricular hypertrophy are associated with low HDL cholesterol [20]. HDL may have protective effects that extend beyond lipid transport, such as the improvement of endothelial function and the reduction of inflammation processes [21]. Since lipids are essential for the formation of coronary atherosclerosis lesions, achieving a significant decrease in lipid-related risk has long been a key component of primary and secondary prevention. However, diabetes makes this situation much more difficult since people who have both diseases often have distinct lipid profiles [22]. So, dyslipidemia is a major cause of oxidative stress, which promotes and accelerates atherosclerosis and thus HF [23].

There is a non-significant difference in levels of creatine kinase-MB concentrations in comparison among groups. Heart failure's myocardial damage is biochemically indicated by CK-MB. In patients with HF, higher CK-MB levels suggest myocyte necrosis and correspond with disease severity, especially in later stages [24] due to changes in cardiac energy metabolism. Additionally, creatine kinase is the primary muscle energy reserve reaction, which rapidly provides ATP at the myofibrils and regenerates mitochondrial ADP. It is down-regulated in experimental and human HF. Therefore, CK-MB has pathologic left ventricular hypertrophy and dilatation correlations closely with reduced myocardial ATP levels and rates of ATP synthesis, which contribute to HF. In the failing human heart, pathologic hypertrophy and adverse remodeling are closely related to deficits in ATP levels and in the CK energy reserve reaction [25].

Conclusions

The current study highlights the significant clinical relevance of galectin-3 and lipid profile alterations as cardiac biomarkers in heart failure patients. Elevated galectin-3 levels suggest its potential role as a pro-inflammatory and fibrotic mediator contributing to adverse cardiac remodeling. The dyslipidemic pattern observed in patients supports that lipid metabolism is markedly disrupted in heart failure and plays a central role in its progression. However, creatine kinase-MB levels were not significantly different among groups. Age and sex differences also influence heart failure risk and presentation, reinforcing the importance of tailored approaches in diagnosis and management. Overall, these findings support the integration of galectin-3 and lipid profile assessments into the risk stratification and monitoring of heart failure patients. Further large-scale studies are recommended to confirm these associations and

explore therapeutic targets aimed at modulating galectin-3 and lipid metabolism to improve outcomes in heart failure.

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References

1. Lopaschuk GD, Karwi QG, Tian R, Wende AR, Abel ED. Cardiac energy metabolism in heart failure. Circulation Research. 2021, 128.10: 1487-1513.
2. Wang Y, Xu X, Shi S, Gao X, Li Y, Wu H, et al. Blood urea nitrogen to creatinine ratio and long-term survival in patients with chronic heart failure. European Journal of Medical Research. 2023, 28.1: 343.
3. Mcdonagh TH, Metra M. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. Russian Journal Cardiology. 2023, 28.1: 5168.
4. Elasfar AA, Alhabeeb W, Elasfar S. Heart failure in the Middle East Arab countries: current and future perspectives. Journal of the Saudi Heart Association. 2020, 32.2: 236.
5. Park JJ. Epidemiology, pathophysiology, diagnosis and treatment of heart failure in diabetes. Diabetes & metabolism journal. 2021, 45.2: 146-157.
6. Triposkiadis F, Xanthopoulos A, Parissis J, Butler J, Farmakis D. Pathogenesis of chronic heart failure: cardiovascular aging, risk factors, comorbidities, and disease modifiers. Heart Failure Reviews. 2022, 27.1: 337-344.
7. Capasso D, Pirone L, Di Gaetano S, Russo R, Saviano M, Frisulli V, et al. Galectins detection for the diagnosis of chronic diseases: an emerging biosensor approach. Trends in Analytical Chemistry. 2023, 159: 116952.
8. Yao Yu Si, LI Tu Di, Zeng ZH. Mechanisms underlying direct actions of hyperlipidemia on myocardium: an updated review. Lipids in Health and Disease. 2020, 19: 1-6.
9. Cediel G, Codina P, Spitaleri G, Domingo M, Santiago-Vacas E, Lupón J, et al. Gender-related differences in heart failure biomarkers. Frontiers in Cardiovascular Medicine. 2021, 7: 617705.
10. Rodgers JL, Jones J, Bolleddu SI, Vanthenapalli S, Rodgers LE, Shah K, et al. Cardiovascular risks associated with gender and aging. Journal of Cardiovascular Development and Disease. 2019, 6.2: 19.
11. Fang Z, Raza U, Song J, Lu J, Yao S, Liu X, et al. Systemic aging fuels heart failure: Molecular mechanisms and therapeutic avenues. ESC Heart Failure. 2025, 12.2: 1059-1080.
12. Sharma UC, Pokharel S, Van Brakel TJ, Van Berlo JH, Cleutjens JP, Schroen B, et al. Galectin-3 marks activated macrophages in failure-prone hypertrophied hearts and contributes to cardiac dysfunction. Circulation. 2004, 110.19: 3121-3128.
13. Hara A, Niwa M, Kanayama T, Noguchi K, Niwa A, Matsuo M, et al. Galectin-3: a potential prognostic and diagnostic marker for heart disease and detection of early stage pathology. Biomolecules. 2020, 10.9: 1277.
14. Blanda V, Bracale UM, Di Taranto MD, Fortunato G. Galectin-3 in cardiovascular diseases. International Journal Molecular Sciences. 2020, 21.23: 9232.
15. Trippel TD, Mende M, Düngen HD, Hashemi D, Petutschnigg J, Nolte K, et al. The diagnostic and prognostic value of galectin-3 in patients at risk for heart failure with preserved ejection fraction: results from the DIAST-CHF study. ESC Heart Failure. 2021, 8.2: 829-841.
16. Natesan V, Kim S. Lipid metabolism, disorders and therapeutic drugs–review. Biomolecules & Therapeutics. 2021, 29.6: 596.
17. Du Z, Qin Y. Dyslipidemia and cardiovascular disease: current knowledge, existing challenges, and new opportunities for management strategies. Journal of Clinical Medicine. 2023, 12.1: 363.
18. Ramirez A, Hu PP. Low high-density lipoprotein and risk of myocardial infarction. Clinical Medicine Insights: Cardiology. 2015, 9: CMC. S26624.
19. Leon BM, Maddox TM. Diabetes and cardiovascular disease: epidemiology, biological mechanisms, treatment recommendations and future research. World Journal of Diabetes. 2015, 6.13: 1246.
20. Schwinger RHG. Pathophysiology of heart failure. Cardiovascular Diagnosis and Therapy. 2021, 11.1: 263.
21. Madaudo C, Bono G, Ortello A, Astuti G, Mingoia G, Galassi A R, et al. Dysfunctional high-density lipoprotein cholesterol and coronary artery disease: a narrative review. Journal of Personalized Medicine. 2024, 14.9: 996.
22. Gaggini M, Gorini F, Vassalle C. Lipids in atherosclerosis: pathophysiology and the role of calculated lipid indices in assessing cardiovascular risk in patients with hyperlipidemia. International Journal of Molecular Sciences. 2022, 24.1: 75.
23. Vekic J, Stromsnes K, Mazzalai S, Zeljkovic A, Rizzo M, Gambini J. Oxidative stress, atherogenic dyslipidemia, and cardiovascular risk. Biomedicines. 2023, 11.11: 2897.
24. Wu YW, Ho SK, Tseng WK, Yeh HI, Leu HB, Yin WH, et al. Potential impacts of high-sensitivity creatine kinase-MB on long-term clinical outcomes in patients with stable coronary heart disease. Scientific Reports. 2020, 10.1: 5638.
25. Keceli G, Gupta A, Sourdon J, Gabr R, Schär M, Dey S, et al. Mitochondrial creatine kinase attenuates pathologic remodeling in heart failure. Circulation Research. 2022, 130.5: 741-759.