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Original Article

Correlation analysis of cardiac electrophysiological characteristics and cardiovascular disease progression in arrhythmia patients

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Abstract: Objective: To investigate a correlation between cardiac electrophysiological characteristics and cardiovascular disease (CVD) in patients with arrhythmia, and to identify indicators for predicting CVD onset. Methods: We enrolled 100 arrhythmia patients treated at West China Hospital of Sichuan University between May 2021 and May 2023. The incidence of CVD was assessed during hospitalization and within one year post-discharge. We compared baseline characteristics, biochemical markers, and electrocardiogram parameters between patients who developed CVD and those who did not. Spearman correlation analysis was conducted to explore linear relationships between indicators and CVD incidence. Multivariate logistic regression was applied to identify associations between variables and CVD. Receiver operating characteristic (ROC) curve analysis was used to evaluate the predictive power of individual and combined risk factors. Results: Of the 100 patients, 31 (31%) developed CVD. The CVD group exhibited significantly higher BMI, hypertension prevalence, triglycerides (TG), high-sensitivity C-reactive protein (hs-CRP), B-type natriuretic peptide (BNP), and QT/QTc intervals compared to the non-CVD group. HDL-C levels were significantly lower in the CVD group ($P < 0.05$). Spearman correlation analysis revealed positive correlations between BMI, hypertension, TG, hs-CRP, BNP, QT, and QTc with CVD ($r = 0.243, 0.563, 0.384, 0.514, 0.238, 0.355, 0.327$, all $P < 0.05$). Conversely, HDL-C showed a negative correlation with CVD ($r = -0.200$, $P < 0.05$). QTc correlated significantly with BMI, hypertension, TG, and hs-CRP ($r = 0.263, 0.221, 0.255, 0.200$, all $P < 0.05$). Multi-factor logistic regression identified BMI, TG, hs-CRP, and QT/QTc intervals as significant risk factors for CVD (all $P < 0.05$). ROC curve analysis showed that the combined assessment of BMI, TG, hs-CRP, QT, and QTc yielded an AUC of 0.951, with sensitivity of 92.7% and specificity of 86.4%, outperforming individual tests. Conclusion: Elevated BMI, TG, hs-CRP, and prolonged QT/QTc intervals are significantly associated with the development of CVD in arrhythmia patients. Combined evaluation of these factors improves the accuracy of CVD risk prediction.

Keywords: Arrhythmia, electrophysiological characteristics, cardiovascular disease, correlation analysis

Introduction

Arrhythmia refers to irregularities in the heart's rate or rhythm, including conditions such as atrial fibrillation, ventricular tachycardia, and premature ventricular contractions [1]. This disorder disrupts normal cardiac function and significantly affects the patient's quality of life. In severe cases, arrhythmias can lead to sudden death or stroke, posing a major risk to both physical and mental health. Studies indicate that arrhythmia is one of the leading causes of morbidity and mortality related to heart disease, contributing to approximately 15% to 20% of all heart disease-related deaths [2]. With the aging global population, the prevalence of arrhythmias has increased, making it an important area of medical research. The electrocardiogram (ECG) is an essential tool for diagnosing arrhythmias due to its accuracy and reliability, and it is commonly used to assess cardiac health and guide treatment decisions.

Arrhythmias not only serve as indicators of heart disease but also significantly contribute to the progression of cardiovascular conditions. Common cardiovascular issues associated with arrhythmias include coronary artery disease, left ventricular hypertrophy, heart failure, peripheral vascular atherosclerosis, and myocardi-

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al infarction [3]. Prolonged tachyarrhythmias can progressively weaken the heart muscle and damage its structure, ultimately leading to heart failure and reduced pumping efficiency [4]. The heart's electrophysiological properties, such as action potential duration and conduction velocity, can be significantly altered by cardiovascular disease (CVD). These abnormalities can disrupt heart pacing and conduction, triggering or exacerbating arrhythmias [5]. However, there is a lack of research examining the relationship between the electrophysiological characteristics of the heart and cardiovascular conditions in arrhythmic patients.

This study aims to investigate the relationship between the heart's electrophysiological features and the onset of new CVD in arrhythmia patients, providing valuable insight for clinical prevention and evaluation of cardiovascular issues.

Materials and methods

Study subjects and diagnostic criteria

This study was approved by the Ethics Committee of West China Hospital of Sichuan University. Using PASS 4.17 software (NCSS, Kaysville, Utah, USA), we estimated the main indicators of cardiac electrophysiological characteristics. Previous research has shown a correlation between QTc and the number of arrhythmias, with a Spearman correlation coefficient (r_s) of 0.36 [6]. Based on this, we set the Spearman correlation coefficient (r_s) at 0.36, with a power of 90% (1-β), an alpha level (α) of 0.05, and a potential attrition rate of 20%, to perform a two-sided Spearman rank correlation test. A sample size of 90 cases was deemed sufficient for this study.

This study retrospectively analyzed 145 arrhythmia patients treated at West China Hospital of Sichuan University from May 2021 to May 2023, ultimately including 100 patients in the final analysis. Patients were then categorized into two groups: those with CVD and those without, based on the development of new CVD during hospitalization and within one year of discharge follow-up.

CVD is classified in the 10th edition of the International Classification of Diseases [7], and primarily includes: (1) Coronary artery disease (CAD): Diagnosed by episodes of angina pectoris, an ECG showing a decline in the ST segment by over 0.1 mV lasting more than 1 minute, a positive treadmill exercise test, and coronary angiography showing ≥ 50% stenosis of coronary arteries. (2) Left ventricular hypertrophy (LVH): Confirmed by echocardiography with a left ventricular mass index exceeding 130 g/m^2 in males and 100 g/m^2 in females. (3) Congestive heart failure (CHF): Characterized by symptoms such as dyspnea, fatigue, reduced exercise capacity, pulmonary crackles, peripheral edema, jugular vein distension, irregular ECG findings, a positive treadmill exercise test, and structural or functional heart abnormalities. (4) Cerebrovascular accident (CVA): Diagnosed by brain CT or MRI, showing ischemic cerebral infarction or hemorrhagic cerebrovascular events. (5) Peripheral vascular atherosclerosis (LA): Diagnosed by arteriography revealing renal artery atherosclerotic lesions and ultrasonography showing increased carotid artery intima-media thickness.

Inclusion criteria for the study were: (1) Diagnosis of arrhythmia based on established criteria [8]; (2) 24-hour dynamic ECG showing more than 10,000 premature ventricular contractions within a single day. Exclusion criteria included: (1) Significant structural heart disease, such as cardiomyopathy or valvular disorders; (2) Left ventricular ejection fraction > 35%; (3) Serious comorbid conditions, including renal failure, hepatic failure, or other critical illnesses affecting vital systems; (4) Incomplete clinical records; (5) Patients who withdrew from the study at any time.

Observation indicators

We collected essential clinical data, biochemical markers, and ECG measurements from the patients. The clinical data included variables such as age, sex, duration of illness, body mass index (BMI), smoking history, alcohol consumption, family history of arrhythmia or CVD, and the presence of conditions like hypertension, diabetes, and hyperlipidemia. Biochemical markers included total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), high-sensitivity C-reactive protein (hs-CRP), B-type natriuretic peptide (BNP), serum creatinine (Scr), neutrophil and lymphocyte

counts, and the neutrophil-to-lymphocyte ratio (NLR). ECG measurements included heart rate (HR), QRS complex duration, PR interval, corrected QT interval (QTc), and QT interval.

Blood sample collection

Venous blood (2 mL) was collected from each patient and centrifuged at 4°C for 10 minutes at 3000 rpm to obtain serum for biochemical analysis. Biomarker analyses were performed within 4 hours of serum collection. For samples not immediately analyzed, they were stored in a cryogenic freezer at -20°C for later evaluation.

Measurement of biochemical indicators

The concentrations of TC, TG, LDL-C, and HDL-C in the blood samples were measured using an enzyme quantitative method with kits supplied by Shanghai Yazy Biomedical Technology Co., Ltd. hs-CRP was quantified using a latex immunoturbidimetric method. BNP and Scr levels were determined using a fully automated biochemical analyzer (Hitachi LAbOSPECT-008α). Neutrophil and lymphocyte counts were obtained using an automated hematology analyzer (Mindray BC-7500), and the NLR was subsequently calculated.

ECG inspection

Upon admission, each participant underwent a standard ECG test, performed at a paper speed of 25 mm/s and a voltage of 10 mm/mV. Subsequently, 24-hour continuous ECG monitoring was conducted using the Shenzhen Libang network ECG system (Libang SE-2012, Shenzhen Libang Precision Instrument Co., Ltd.). This monitoring captured heart rate (HR), QRS duration, PR interval, QTc interval, and QT interval.

Statistical analysis

Statistical analysis was performed using SPSS version 23.0 (SPSS Inc., Chicago, IL, USA). Continuous data with a normal distribution were presented as mean ± standard deviation. One-way analysis of variance (ANOVA) was used to compare differences among groups. Categorical data were expressed as percentages (%), and group comparisons were made using Chi-square test (χ^2). Spearman correlation analysis was employed to assess the linear association between various indicators and the incidence of CVD. Multivariate logistic regression was performed to identify risk factors associated with CVD in patients with arrhythmia. The receiver operating characteristic (ROC) curve was used to evaluate the predictive capabilities of individual risk factors and combined detection methods for CVD. A *p*-value of less than 0.05 was considered significant.

Results

Comparison of patient characteristics

A total of 100 patients diagnosed with arrhythmia participated in the study. Of these, 31 developed CVD, yielding an incidence rate of 31%. These patients were categorized into the CVD group, while the 69 patients who did not develop CVD formed the non-CVD group, representing 69% of the cohort. Additional details are shown in **Figure 1**. Statistical analysis revealed no significant differences between the two groups in terms of age, illness duration, sex, smoking habits, alcohol consumption, diabetes, hyperlipidemia, or family history of arrhythmia or cardiovascular disease (all $P > 0.05$). However, the CVD group had significantly higher BMI and a higher percentage of hypertension compared to the non-CVD group (both $P < 0.05$), as shown in **Table 1**.

Comparison of biochemical indicators

No significant differences were found in serum levels of TC, LDL-C, Scr, neutrophils, lymphocytes, or the NLR between the two groups (all $P > 0.05$). However, the CVD group showed significantly higher levels of TG, hs-CRP, and BNP compared to the non-CVD group, while HDL-C levels were significantly lower in the CVD group (all $P < 0.05$), as illustrated in **Figure 2**.

Comparison of ECG examination

No significant differences were observed in HR, PR interval, or QRS duration between the two groups (all $P > 0.05$). In contrast, the QT and QTc intervals were significantly prolonged in the CVD group compared to the non-CVD group (all $P < 0.05$), as shown in **Figure 3**.

Analysis of the correlation between clinical characteristics and CVD in patients with arrhythmia

Spearman correlation analysis revealed a positive association between hypertension, BMI,

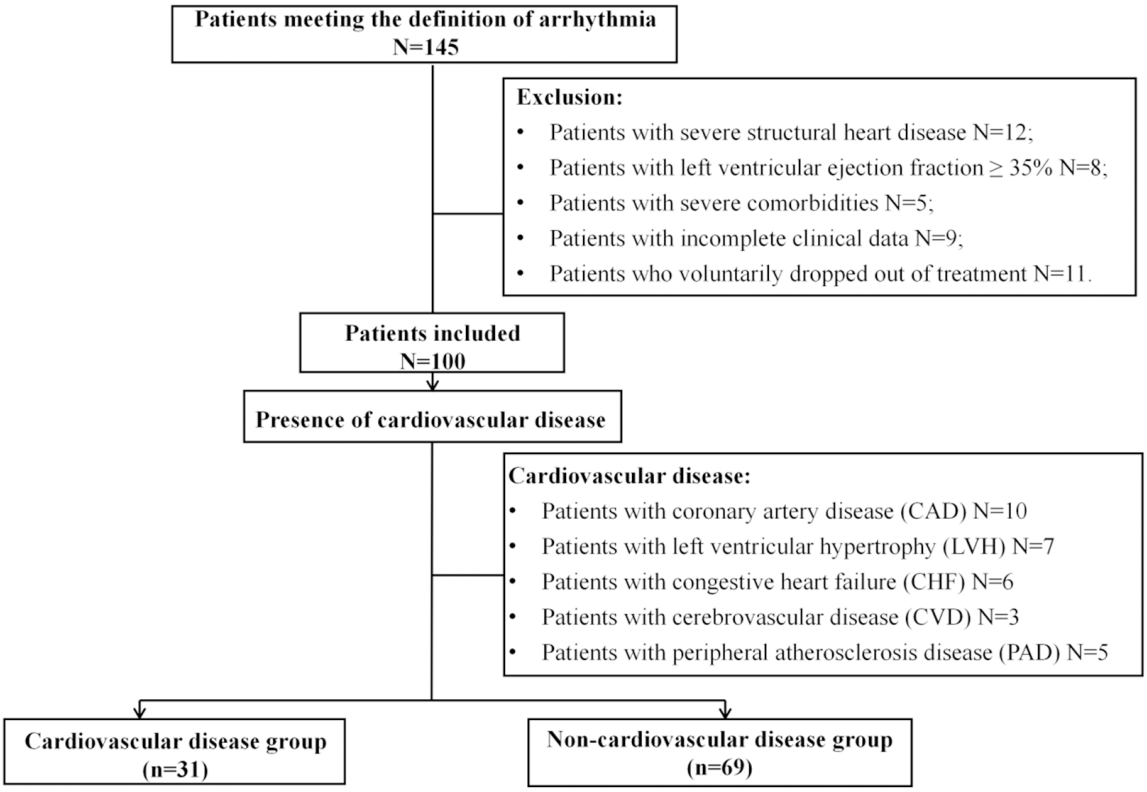

Figure 1. Roadmap of research technologies.

Table 1. Comparison of baseline characteristics between cardiovascular disease group and non-cardiovascular disease group

Datum		Cardiovascular disease group (n = 31)	Non-cardiovascular disease group (n = 69)	t/χ^2	*P*
Age		65.32±7.41	63.83±7.01	0.970	0.334
course of disease		3.58±0.99	3.81±1.08	-1.017	0.312
BMI (kg/m^2)		25.74±3.86	22.42±3.08	4.621	< 0.001
Sex	Male	19 (61.29)	36 (52.17)	0.718	0.397
	Female	12 (38.71)	33 (47.83)		
Hypertension	Yes	17 (54.84)	22 (31.88)	4.738	0.030
	No	14 (45.16)	47 (68.12)		
Diabetes	Yes	10 (32.26)	18 (26.09)	0.404	0.525
	No	21 (67.74)	51 (73.91)		
Hyperlipidemia	Yes	9 (29.03)	20 (28.99)	0.282	0.595
	No	17 (54.84)	49 (71.01)		
Smoking History	Yes	13 (41.94)	20 (28.99)	1.622	0.203
	No	18 (58.06)	49 (71.01)		
Drinking History	Yes	10 (32.26)	23 (33.33)	0.011	0.916
	No	21 (67.74)	46 (66.67)		
Family history of arrhythmias	Yes	12 (38.71)	25 (36.23)	0.056	0.812
	No	19 (61.29)	44 (63.77)		
Family history of cardiovascular disease	Yes	11 (35.48)	27 (39.13)	0.121	0.728
	No	20 (64.52)	42 (60.87)		

Note: Measured data that conform to a normal distribution were expressed as mean ± standard deviation, with comparisons between groups conducted using the t-test. Counted data were presented as n and %, and the χ^2 test was used for analysis. BMI, Body Mass Index.

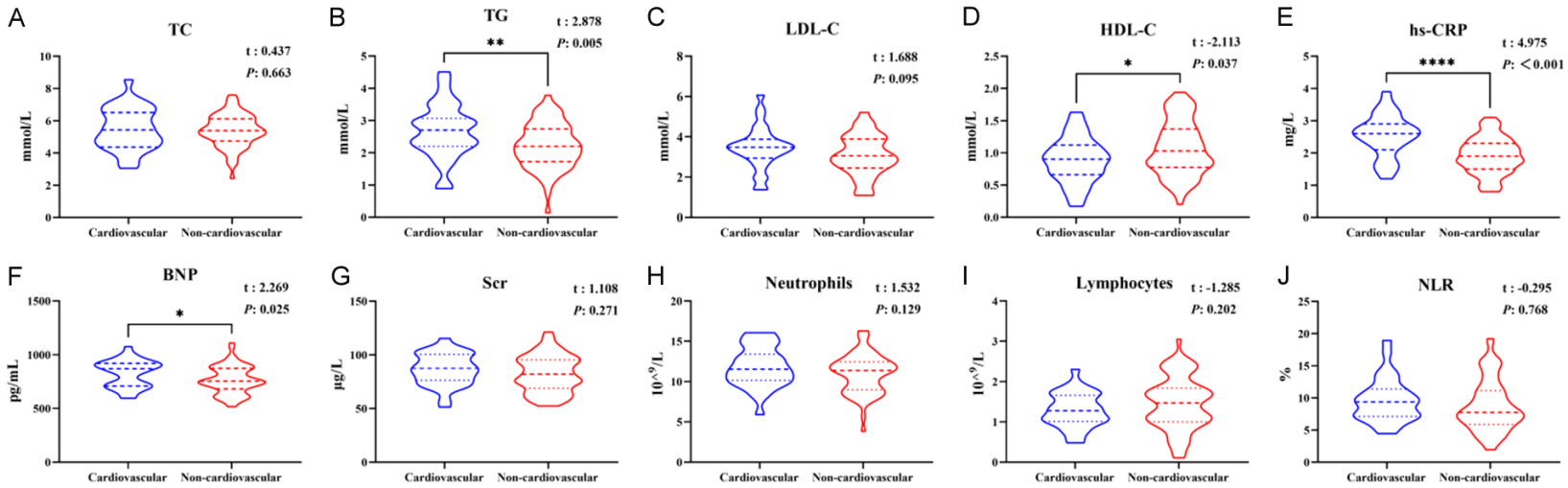

Figure 2. Comparison of biochemical indicators in cardiovascular group and non-cardiovascular disease groups. Note: Comparison between groups by t-test; TC, Total Cholesterol; TG, Triglycerides; LDL-C, Low-Density Lipoprotein Cholesterol; HDL-C, High-Density Lipoprotein Cholesterol; hs-CRP, High Sensitivity C-Reactive Protein; BNP, B-Type Natriuretic Peptide; Scr, Serum Creatinine; NLR, Neutrophil-to-Lymphocyte Ratio.

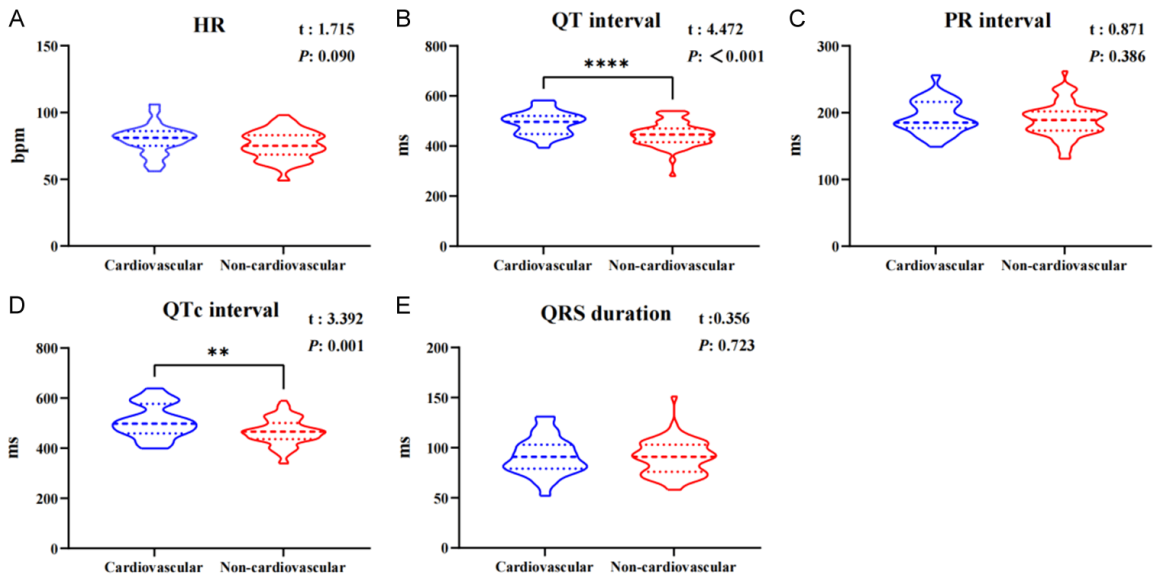

Figure 3. Comparison of ECG examinations in the cardiovascular group and the non-cardiovascular group. Note: t test was used for comparison between groups; HR, Heart Rate.

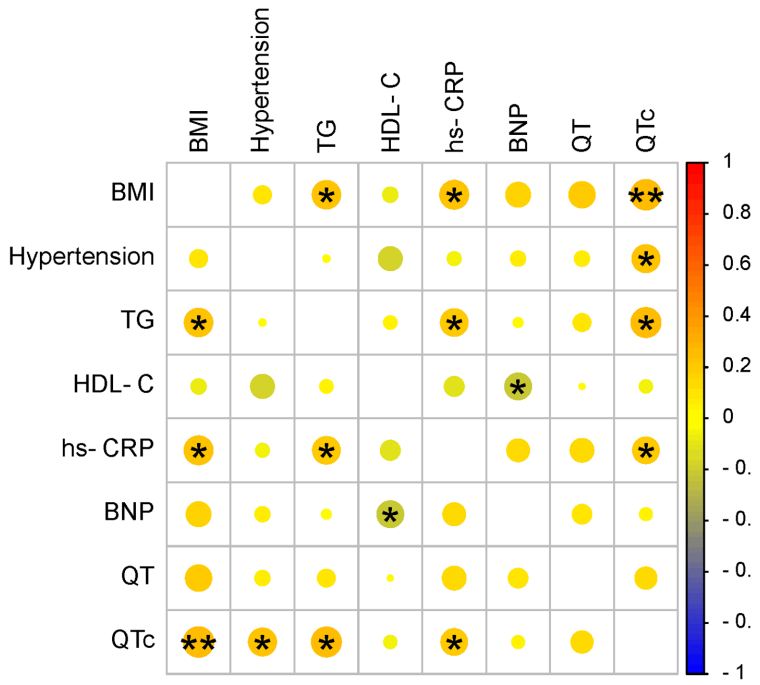

Figure 4. Spearman correlation coefficient analysis of clinical characteristics of patients with arrhythmia. Note: The shading of the color indicates the strength of the correlation, with red representing a positive correlation and blue representing a negative correlation. The intensity of the colors gradually shifts from light to dark as the absolute coefficient increases. A *P* value of less than 0.05 was considered significant, with $^{*}P < 0.05$ and $^{**}P < 0.01$.

TG, hs-CRP, BNP, QT interval, and QTc interval in patients with arrhythmia and the development of CVD (r = 0.243, 0.563, 0.384, 0.514, 0.238, 0.355, 0.327; all P < 0.05). In contrast, serum HDL-C levels showed a negative correlation with CVD incidence (r = -0.200, P < 0.05). Further analysis of the correlation between clinical characteristics in arrhythmic patients is shown in **Figure 4**. These results indicate that QTc is significantly positively correlated with BMI, hypertension, TG, and hs-CRP, with correlation coefficients of r = 0.263, 0.221, 0.255, and 0.200, respectively (all P < 0.05). Additionally, hs-CRP displayed a significant positive correlation with both BMI and TG (r = 0.236 and 0.215, respectively; both P < 0.05). A significant positive correlation was also observed between BMI and TG (r = 0.203; P < 0.05). Conversely, a significant negative correlation was found between BNP and HDL-C (r = -0.229; P < 0.05).

Analysis of risk factors for CVD in patients with arrhythmia

Multivariate logistic regression analysis identified BMI, TG, hs-CRP, QT interval, and QTc interval as risk factors for CVD in patients with arrhythmia (all P < 0.05), as shown in **Table 2**.

Table 2. Multivariate Logistic-analysis of arrhythmia patients with cardiovascular disease

Variable	*β*	*SE*	Wald χ^2	*P*	OR (95% CI)
BMI	0.750	0.198	14.409	< 0.001	2.118 (1.437-3.119)
Hypertension	0.761	0.865	0.773	0.379	2.140 (0.393-11.661)
TG	1.414	0.634	4.967	0.026	4.111 (1.186-14.255)
HDLC	-1.487	1.015	2.147	0.143	0.226 (0.031-1.652)
hsCRP	1.574	0.659	5.709	0.017	4.826 (1.327-17.555)
BNP	0.002	0.003	0.491	0.484	1.002 (0.996-1.008)
QT	0.020	0.009	5.041	0.025	1.021 (1.003-1.039)
QTc	0.023	0.010	5.249	0.022	1.023 (1.003-1.044)

Note: BMI, Body Mass Index; TG, Triglycerides; HDL-C, High-Density Lipoprotein Cholesterol; hs-CRP, High Sensitivity C-Reactive Protein; BNP, B-Type Natriuretic Peptide; Scr, Serum Creatinine; NLR, Neutrophil-to-Lymphocyte Ratio.

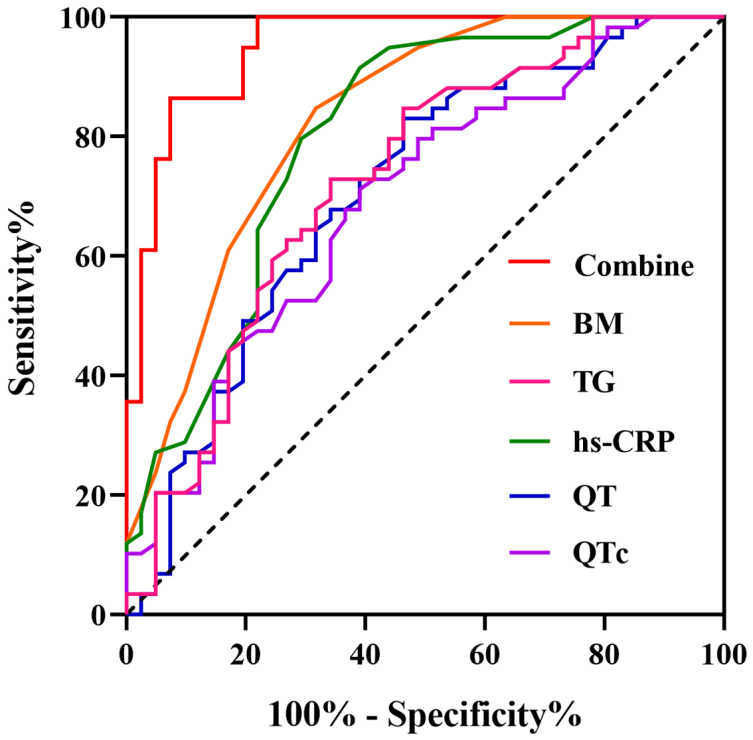

Figure 5. ROC curves for the predictive efficacy of cardiovascular disease in arrhythmia patients. Note: BMI, Body Mass Index; TG, Triglycerides; hs-CRP, High Sensitivity C-Reactive Protein.

Analysis of the predictive performance of CVD in patients with arrhythmia

The receiver operating characteristic (ROC) curve was used to assess the predictive effectiveness of the identified risk factors for CVD in arrhythmic patients. The areas under the ROC curve for BMI, TG, hs-CRP, QT, QTc, and combined indicators were 0.828, 0.725, 0.801, 0.709, 0.692, and 0.951, respectively (see **Figure 5**). The specificities for these factors were 56.1%, 74.2%, 74.2%, 61.3%, 67.7%, and 73.9%, while the sensitivities were 88.4%, 53.6%, 73.9%, 81.2%, 65.2%, and 90.3%, as detailed in **Table 3**.

Discussion

This study evaluates independent risk factors for CVD in patients with arrhythmia, including high BMI, elevated triglycerides, hs-CRP, and prolonged QT and QTc intervals. CVD is a common complication in patients with arrhythmia, with a prevalence of 31%, which is consistent with the findings of Papaporfyriou et al. [9]. Individuals with arrhythmias are at increased risk for CVD due to factors such as structural cardiac changes, myocardial ischemia, neuroregulation imbalances, and elevated blood pressure [1, 10]. CVD is the leading cause of mortality in arrhythmic patients. Thus, early identification of arrhythmic patients at high risk for CVD is essential to guide treatment strategies.

In clinical practice, ECGs are crucial for evaluating cardiac electrophysiological parameters, including heart rate, rhythm, and electrical conduction. Abnormalities in heart rate - whether elevated or reduced - along with the presence of arrhythmias, may indicate underlying CVD. Therefore, monitoring cardiac electrophysiological features in arrhythmic patients is critical, as these can serve as early indicators of CVD progression, enabling timely medical intervention.

This study identified BMI as an independent risk factor for CVD. Patients diagnosed with CVD had significantly higher BMI values com-

Table 3. ROC analysis of cardiovascular disease in patients with arrhythmia

Data	AUC	SE	*P*	95% *CI*	Sensitivity	Specificity
BMI	0.828	0.043	< 0.001	0.744-0.913	56.1%	88.4%
TG	0.725	0.053	< 0.001	0.621-0.83	74.2%	53.6%
hsCRP	0.801	0.047	< 0.001	0.709-0.894	74.2%	73.9%
QT	0.709	0.054	< 0.001	0.602-0.815	61.3%	81.2%
QTc	0.692	0.054	0.001	0.586-0.797	67.7%	65.2%
Combined	0.951	0.021	< 0.001	0.909-0.993	73.9%	90.3%

pared to those without the diagnosis, suggesting a correlation between obesity and CVD. Obesity can induce chronic low-grade inflammation, leading to the release of pro-inflammatory factors such as tumor necrosis factor α (TNF-α) and interleukin-6 (IL-6). These factors contribute to vascular endothelial dysfunction and promote the development of atherosclerosis [11]. Additionally, obesity increases overall blood volume and cardiac output, resulting in structural changes in the heart, such as cardiac hypertrophy and ventricular remodeling. These alterations heighten the risk of ventricular tachycardia [12]. Research indicates that for every 5-unit increase in BMI, the risk of atrial fibrillation and sudden cardiac death rises by 29% and 16%, respectively [13, 14]. Obesity is associated with long-term damage to the structure and function of the cardiovascular system [15].

Obese individuals typically exhibit elevated levels of TG. The accumulation of fat in these individuals interferes with lipid metabolism, leading to increased TG synthesis. Moreover, fatty acids released by adipocytes contribute to elevated TG levels [16]. Those with higher BMI values also tend to have higher rates of insulin resistance, which further increases TG levels [17]. In our study, we observed a positive relationship between TG levels and the risk of cardiovascular disease in patients with arrhythmia. Previous research has consistently demonstrated a strong link between elevated TG levels and an increased risk of CVD [18, 19]. This connection may be explained by the fact that elevated TG levels can cause endothelial dysfunction, promoting atherosclerosis, which results in vascular narrowing and reduced blood flow to the heart [20]. Consequently, elevated TG levels in arrhythmic patients may accelerate the progression of atherosclerosis by promoting lipid accumulation and inflammatory processes, further increasing the likelihood of cardiovascular events.

hs-CRP is an acute-phase protein synthesized by the liver in response to inflammation, infection, or tissue damage [21]. Inflammatory conditions alter myocardial cell depolarization and repolarization, affecting the heart's electrical conduction system. These changes increase the likelihood of atrial fibrillation and ventricular arrhythmias [22]. Furthermore, elevated hs-CRP levels can prolong or shorten action potentials in cardiomyocytes, affecting both heart rhythm and contractility. These disruptions may lead to cardiac mechanical dysfunction and increase the risk of cardiovascular events [23]. Studies also suggest that elevated hs-CRP levels stimulate the sympathetic nervous system, increasing sympathetic tone [24]. This stimulation affects heart rate, cardiac output, and causes vasoconstriction, elevating peripheral resistance, increasing the heart's workload, and contributing to arrhythmias and other cardiovascular conditions. Our findings indicate that higher hs-CRP levels significantly increase the risk of CVD in arrhythmic patients, supporting previous research. These results highlight the importance of monitoring hs-CRP levels in clinical settings for arrhythmia patients to more accurately assess their CVD risk.

This study detected ECG abnormalities in patients with arrhythmias and, in conjunction with the incidence of CVD, found that increased QT and QTc intervals are significantly associated with the onset of these diseases. These findings are consistent with the results reported by Lahey [25] and Saadatagah et al. [26]. This association may be related to changes in cardiac structure and function, as well as mechanisms that activate the sympathetic nervous system. Patients with arrhythmias often exhibit structural alterations in the heart, such as ventricular dilation and hypertrophy. These structural changes can modify the heart's electrophysiological properties, resulting in prolonged QT and QTc intervals. Extended QTc intervals over time can serve as indicators of myocardial ischemia in heart disease patients, highlighting the risk of coronary artery disease [27]. Additionally, activation of the sympathetic nervous

system increases cardiac excitability, prolonging repolarization, elevating heart rate, and further extending the QT interval, thereby increasing the risk of CVD [28].

This study demonstrates that elevated BMI, TG, hsCRP, QT, and QTc had significant predictive power for CVD in patients with arrhythmia, as confirmed by their sensitivity and specificity. Furthermore, the combined evaluation of these five parameters enhances predictive accuracy. This approach offers a promising method for the early detection and prevention of CVD in arrhythmic patients.

The ROC curve analysis indicated that elevated levels of BMI, TG, hsCRP, QT, and QTc provide significant sensitivity and specificity in predicting CVD in arrhythmic patients. Simultaneous evaluation of these biomarkers improves predictive accuracy, making it a valuable tool for clinical diagnosis and treatment. However, it is essential to recognize that other factors, such as dietary habits, lifestyle, and mental health, also play a crucial role. For instance, diets high in fat and sugar can increase BMI and TG levels, thereby heightening CVD risk [29]. Additionally, unhealthy lifestyle choices, including insufficient physical activity and irregular sleep patterns, reduce cardiac efficiency and worsen cardiovascular health [30, 31]. Regarding mental health, chronic stress and anxiety can elevate hsCRP levels, further increasing CVD risk [32].

Thus, in clinical practice, healthcare providers must not only consider biomarker test results but also evaluate the patient's dietary habits, lifestyle, and mental health status to formulate a comprehensive treatment plan. Regular monitoring of indicators such as BMI, TG, hsCRP, QT interval, and QTc, combined with ECG examinations, can help identify the risk of CVD early, facilitating the development of personalized treatment plans. Simultaneously, healthcare providers should encourage patients to adopt a healthy lifestyle that includes a balanced diet, moderate exercise, adequate sleep, and effective stress management to reduce the incidence of CVD. Moreover, individualized treatment plans should be developed, considering patient-specific differences, to achieve optimal treatment outcomes. Future research should explore additional biomarkers and risk factors to enhance the comprehensiveness of health management strategies for patients with arrhythmia.

Disclosure of conflict of interest

None.

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