

Bispectrum and ECG Changes and Correlation in Ischemic and Dilated Cardiomyopathy

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ABSTRACT

Background: Ischemic cardiomyopathy (ICM) and dilated cardiomyopathy (DCM) are major causes of heart failure, with overlapping clinical features that complicate differentiation. Electrocardiography (ECG) is a cornerstone diagnostic tool, but its linear parameters may not fully capture the complex electrophysiological dynamics of cardiomyopathies. Bispectrum analysis, a higher-order spectral technique, quantifies non-linear interactions and phase coupling in ECG signals, potentially enhancing diagnostic precision. **Methods:** A prospective case-control study conducted at Malla Reddy Narayana Multispecialty Hospital, Hyderabad, from November 2024 to April 2025, involving 90 patients (30 ICM, 30 DCM, 30 healthy controls). ECG signals acquired at 500 Hz and processed using MATLAB for bispectral magnitude and bicoherence. Echocardiography assessed left ventricular ejection fraction (LVEF) and end-diastolic diameter (LVEDD), while MRI quantified myocardial scar in ICM. Statistical analyses included ANOVA, Pearson/Spearman correlations, and ROC analysis (AUC) using SPSS version 26 ($p < 0.05$). Post-hoc comparisons were performed where appropriate, and diagnostic performance was assessed using AUC, sensitivity, and specificity. **Results:** ICM patients showed higher high-frequency bispectral magnitude (177.6 ± 16.2 AU) and Q-waves/ST-segment changes, reflecting myocardial scarring and ischemia. DCM patients exhibited higher low-frequency bispectral magnitude (181.3 ± 15.7 AU) and greater LVEDD (65.8 ± 5.2 mm), indicating ventricular dilation. Both groups had reduced LVEF (ICM: $36.2 \pm 7.1\%$; DCM: $34.8 \pm 7.5\%$) compared to controls ($60.1 \pm 2.0\%$). Arrhythmias were prevalent in ICM (10/30) and DCM (12/30). Combined bispectrum-ECG analysis achieved the highest diagnostic accuracy (AUC = 0.88, sensitivity 86%, specificity 83%) compared to ECG alone (AUC = 0.76) or bispectrum alone (AUC = 0.81). Significant correlations were found between low-frequency bispectral power and LVEF ($r = -0.68$, $p < 0.01$) in DCM, and high-frequency bispectral power and myocardial scar ($r = 0.64$, $p < 0.01$) in ICM. **Conclusion:** Bispectrum analysis enhances ECG's ability to differentiate ICM and DCM by capturing non-linear electrophysiological dynamics. The combined bispectrum-ECG approach offers superior diagnostic accuracy, potentially reducing reliance on invasive methods.

Keywords: Bispectrum analysis, electrocardiography, ischemic cardiomyopathy, dilated cardiomyopathy, non-linear dynamics, diagnostic accuracy

INTRODUCTION

Cardiovascular diseases (CVDs) are the leading cause of morbidity and mortality globally, accounting for approximately 17.9 million deaths annually, according to the World Health Organization. Among these,

cardiomyopathies like ischemic cardiomyopathy (ICM) and dilated cardiomyopathy (DCM) are significant contributors due to their impact on cardiac function and patient quality of life. ICM arises from coronary artery disease, leading to myocardial ischemia, infarction, and scarring, which impair left

ventricular function. DCM, conversely, is characterized by ventricular dilation and systolic dysfunction, often resulting from genetic, infectious, or toxic etiologies.[1]

Cardiomyopathy

Cardiomyopathy is a pathological condition that affects the heart muscle, leading to structural and functional abnormalities [2]. These abnormalities can manifest as alterations in the size, shape, and thickness of the myocardium, impairing the heart's ability to pump blood effectively [3]. Cardiomyopathies are broadly classified into several subtypes, including dilated cardiomyopathy, hypertrophic cardiomyopathy, restrictive cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, and unclassified cardiomyopathies [4]. Each subtype exhibits distinct morphological and pathophysiological characteristics, as well as varying etiologies and clinical presentations. Dilated cardiomyopathy is characterized by the enlargement (dilation) of one or both ventricles of the heart and a decrease in the heart's ability to pump blood effectively, known as systolic dysfunction [5]. ICM is distinguished from DCM based on its etiology, primarily stemming from abnormal loading conditions like hypertension, valvular disease, or coronary artery disease, which cause global systolic dysfunction [6].

Dilated cardiomyopathy

DCM is a primary myocardial disease characterized by left ventricular or biventricular dilation and impaired systolic function. DCM is a significant contributor to heart failure and sudden cardiac death, with a prevalence estimated at 1 in 2500 individuals [7]. The etiology of DCM is diverse, encompassing genetic mutations, viral infections, alcohol abuse, and idiopathic factors. The pathogenesis of DCM involves complex interactions between genetic predisposition, environmental factors, and maladaptive remodeling processes [8]. The initial symptoms of DCM can be subtle, often manifesting as fatigue, shortness of breath, and lower extremity edema [9]. In dilated cardiomyopathy, the heart muscle becomes weakened and enlarged, leading to a reduction in the heart's ability to pump blood effectively [10].

Ischemic cardiomyopathy

ICM is a consequence of impaired blood supply to the heart muscle, most commonly due to coronary artery disease. The chronic deprivation of oxygen and nutrients leads to myocyte death, fibrosis, and left ventricular remodeling, ultimately resulting in heart failure [11]. ICM is a major cause of heart failure worldwide, with a significant impact on morbidity and mortality [12]. ICM typically presents symptoms of angina, dyspnea, and fatigue, often accompanied by evidence of prior myocardial infarction [13]. The diagnosis of ICM relies on a combination of clinical history, electrocardiography, echocardiography, and

coronary angiography [14]. The presence of coronary artery disease, characterized by significant stenosis or occlusion of one or more coronary arteries, is a hallmark of ICM [11].

Electrocardiography

ECG remains a cornerstone for diagnosing cardiac conditions due to its accessibility, cost-effectiveness, and ability to capture electrical activity. However, traditional ECG analysis focuses on linear parameters (e.g., PR interval, QRS duration, ST-segment changes), which may not fully capture the complex, non-linear dynamics of cardiac electrical activity in cardiomyopathies. Bispectrum analysis, a higher-order spectral method, addresses this limitation by quantifying non-linear interactions and phase coupling in ECG signals. Studies, such as Liu et al., 2020 [15], suggest that bispectrum can reveal subtle electrophysiological changes, offering potential for improved diagnostic precision.

ICM typically presents with ECG findings like Q-waves, ST-segment elevation or depression, and T-wave inversions, reflecting myocardial ischemia or infarction. DCM, however, shows prolonged PR intervals, reduced QRS voltage, and non-specific ST-T wave changes, indicative of ventricular dilation and electrical remodeling.

Bispectrum analysis

It, a higher-order spectral analysis technique, offers a promising approach to characterize the intricate dynamics of biological signals, particularly in the context of cardiac electrophysiology. Bispectrum analysis extends beyond traditional power spectrum analysis by examining the phase relationships between different frequency components within a signal. By quantifying the magnitude and phase of these interactions, bispectrum analysis provides insights into the non-linear and non-Gaussian properties of the underlying system. [16]

The bispectrum is defined as the Fourier transform of the third-order cumulant of a signal. Mathematically, the bispectrum $B(f_1, f_2)$ of a signal $x(t)$ is expressed as:

$B(f_1, f_2) = E[X(f_1)X(f_2)X^*(f_1 + f_2)]$ where E denotes the expectation operator, $X(f)$ represents the Fourier transform of the signal x at frequency f , and $*$ denotes the complex conjugate [17].

The bispectrum is a complex-valued function that depends on two frequency variables, f_1 and f_2 , providing information about the interactions between these frequencies. The primary advantage of bispectrum analysis lies in its ability to detect and quantify non-linear interactions and phase coupling between different frequency components in a signal. where ω_1 and ω_2 represent frequencies, and E denotes the expected value. Bispectrum analysis has found applications in diverse fields, including oceanography, acoustics, and biomedical engineering [18]. This

thesis explores the correlation between bispectral patterns and conventional ECG changes in ICM and DCM patients, leveraging data from Malla Reddy Narayana Multispecialty Hospital. By combining advanced signal processing with traditional diagnostics, this study aims to improve the understanding of cardiomyopathy pathophysiology and enhance clinical management.

Research Gap

Although conventional ECG provides valuable information regarding electrical abnormalities in cardiomyopathy, its ability to distinguish ischemic cardiomyopathy from dilated cardiomyopathy may be limited. Higher-order spectral techniques such as bispectrum analysis may provide additional information regarding nonlinear interactions and phase coupling within ECG signals. However, the clinical utility of bispectral parameters and their correlation with conventional ECG and cardiac imaging parameters in ICM and DCM requires further evaluation. However, limited clinical evidence is available regarding the ability of bispectral parameters to differentiate ICM from DCM and their correlation with conventional ECG and cardiac imaging findings.

Aim of the Study

The aim of this study was to evaluate bispectral characteristics of ECG signals in patients with ischemic cardiomyopathy and dilated cardiomyopathy and to determine their correlation with conventional ECG, echocardiographic, and myocardial scar parameters.

Objectives

- To compare bispectral parameters between patients with ICM, DCM, and healthy controls.
- To evaluate the association between bispectral parameters and conventional ECG findings.
- To assess correlations between bispectral parameters and LVEF, LVEDD, and myocardial scar.
- To compare the diagnostic performance of ECG alone, bispectrum analysis alone, and the combined bispectrum-ECG approach for differentiating ICM from DCM.
- To evaluate the association between bispectral parameters and selected conventional ECG findings.

MATERIALS AND METHODOLOGY

Study Design and Setting

This prospective case-control study was conducted at the ECG Laboratory of Malla Reddy Narayana Multispecialty Hospital, Hyderabad, from November 2024 to April 2025. The study included patients with ischemic cardiomyopathy (ICM), patients with dilated

cardiomyopathy (DCM), and healthy controls. The study procedures included 12-lead electrocardiography (ECG), bispectrum analysis, echocardiographic assessment, and cardiac magnetic resonance imaging (MRI) for assessment of myocardial scar in patients with ICM.

Study Population and Sample Size

A total of 90 participants were included in the study, comprising 30 patients with ischemic cardiomyopathy, 30 patients with dilated cardiomyopathy, and 30 healthy controls. Participants were aged 18–80 years.

Inclusion and Exclusion Criteria

Inclusion Criteria

Participants aged 18–80 years with a confirmed diagnosis of ischemic cardiomyopathy or dilated cardiomyopathy and available ECG and bispectral data were eligible for inclusion. Healthy individuals without known cardiovascular disease were included as controls.

Exclusion Criteria

Participants with pacemakers, atrial fibrillation, previous cardiac surgery, diabetes mellitus, hypertension, or beta-blocker use were excluded from the study. Participants with incomplete ECG or bispectral data were also excluded.

Diagnostic Criteria

Ischemic cardiomyopathy was diagnosed on the basis of documented coronary artery disease and/or previous myocardial infarction together with left ventricular systolic dysfunction. Dilated cardiomyopathy was diagnosed on the basis of left ventricular or biventricular dilation with impaired systolic function in the absence of sufficient abnormal loading conditions or significant coronary artery disease to explain the ventricular dysfunction. The final diagnosis was established using the clinical, electrocardiographic, echocardiographic, and imaging findings available at the study center.

ECG Acquisition

Standard 12-lead ECG signals were acquired using a GE MAC 2000 ECG system at a sampling frequency of 500 Hz. The ECG recordings were used for assessment of conventional ECG parameters and subsequent bispectral analysis.

Bispectrum Analysis

Bispectral analysis of the ECG signals was performed using MATLAB. Bispectral magnitude and bicoherence were evaluated in low-frequency (0.01–0.1 Hz) and high-frequency (0.1–1.0 Hz) ranges. These parameters were compared among patients with ischemic cardiomyopathy, dilated cardiomyopathy,

and healthy controls and were correlated with conventional ECG and echocardiographic parameters.

Echocardiographic Assessment

Echocardiographic assessment was performed using a Philips iE33 echocardiography system. Left ventricular ejection fraction (LVEF) and left ventricular end-diastolic diameter (LVEDD) were assessed and recorded for all study participants.

Cardiac MRI and Myocardial Scar Assessment

Cardiac magnetic resonance imaging was performed using a 3T Siemens Magnetom MRI scanner. In patients with ischemic cardiomyopathy, myocardial scar was assessed and quantified. The myocardial scar measurements were used for correlation with bispectral parameters.

Data Collection

Clinical, demographic, electrocardiographic, echocardiographic, and bispectral parameters were recorded using a standardized case report form. The collected variables included age, sex, heart rate, PR interval, QRS duration, QT interval, P-wave amplitude, T-wave amplitude, ST-segment deviation, Q-wave presence, LVEF, LVEDD, bispectral magnitude, bicoherence, and relevant frequency-domain parameters.

Statistical Analysis

Statistical analysis was performed using SPSS version 26. Continuous variables were summarized using mean ± standard deviation (SD) and, where appropriate, median and interquartile range (IQR). Categorical variables were expressed as frequencies and percentages. One-way analysis of variance (ANOVA) was used to compare continuous variables across the three groups, followed by Tukey’s post-hoc test for pairwise

comparisons where appropriate. Pearson’s or Spearman’s correlation coefficient was used to assess relationships between bispectral parameters and ECG, echocardiographic, and imaging variables according to the distribution of the data. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the diagnostic performance of ECG alone, bispectrum analysis alone, and the combined bispectrum-ECG approach. Diagnostic performance was assessed using the area under the ROC curve (AUC), sensitivity, and specificity. A p-value <0.05 was considered statistically significant. All statistical tests were two-sided.

RESULTS

The study analyzed data from 90 participants, comprising 30 patients with ICM, 30 patients with DCM, and 30 healthy controls recruited at Malla Reddy Narayana Multispecialty Hospital, Hyderabad, from November 2024 to April 2025. The dataset included demographic variables (age, gender), ECG parameters (heart rate [HR], PR interval, QRS duration, QT interval, P-wave amplitude, T-wave amplitude, ST-segment deviation, Q-wave presence), echocardiographic parameters (left ventricular ejection fraction [LVEF], left ventricular end-diastolic diameter [LVEDD]), and bispectrum analysis metrics (bispectral magnitude, bicoherence, frequency pairs). Statistical analyses were performed using SPSS version 26, with significance set at p < 0.05. Results are presented in tables and charts, with interpretations provided in the discussion section.

Demographic Characteristics

The sample comprised 45 males and 45 females, with a mean age of 53.5 ± 11.7 years. Table 1 summarizes gender and age distribution across groups.

Table 1: Distribution of Sample Size by Gender and Cardiomyopathy Type

Group	Male (n)	Female (n)	Total (n)	Mean Age (years) ± SD
ICM	15	15	30	54.8 ± 10.4
DCM	15	15	30	53.1 ± 11.9
Healthy	15	15	30	52.7 ± 11.6

ECG Parameters

ECG parameters were analyzed for HR, PR interval, QRS duration, QT interval, P-wave amplitude, T-wave amplitude, ST-segment deviation, and Q-wave presence. Table 2 summarizes key ECG metrics, aggregated from the dataset.

Table 2: ECG Parameters (HR, PR, QRS, QT) by Group

Group	HR (bpm) ± SD	PR (ms) ± SD	QRS (ms) ± SD	QT (ms) ± SD
ICM	93.1 ± 8.2	206.1 ± 16.7	141.7 ± 12.8	468.3 ± 14.5
DCM	90.4 ± 7.6	201.2 ± 15.3	140.9 ± 11.5	466.7 ± 13.2
Healthy	70.5 ± 2.1	149.7 ± 3.0	99.6 ± 2.3	399.4 ± 3.1

Statistical Analysis: One-way ANOVA revealed significant differences in HR (F = 62.4, p < 0.001), PR (F = 68.9, p < 0.001), QRS (F = 65.3, p < 0.001), and QT (F = 70.1, p < 0.001) across groups. Post hoc Tukey tests confirmed that

ICM and DCM had significantly higher values than healthy controls ($p < 0.01$), with no significant differences between ICM and DCM ($p > 0.05$).

Table 3: Distribution of Patients by ST-Segment Changes and Q-Wave Presence

Group	ST Elevation (n)	ST Depression (n)	Q-Wave Present (n)
ICM	12	15	15
DCM	0	8	0
Healthy	0	0	0

Bispectrum Analysis

Bispectral magnitude and bicoherence were computed for low-frequency (0.01-0.1 Hz) and high-frequency (0.1-1.0 Hz) ranges, as specified in the dataset. Table 4 summarizes these metrics.

Table 4: Bispectral Magnitude and Bicoherence by Group

Group	Low-Frequency Magnitude (AU) $\pm$ SD	High-Frequency Magnitude (AU) $\pm$ SD	Bicoherence (%) $\pm$ SD
ICM	147.2 $\pm$ 13.5	177.6 $\pm$ 16.2	69.8 $\pm$ 4.5
DCM	181.3 $\pm$ 15.7	148.9 $\pm$ 12.4	68.9 $\pm$ 4.1
Healthy	96.5 $\pm$ 2.4	96.8 $\pm$ 2.6	48.1 $\pm$ 1.7

Statistical Analysis: ANOVA showed significant differences in low-frequency magnitude ($F = 45.8$, $p < 0.001$), high-frequency magnitude ($F = 50.3$, $p < 0.001$), and bicoherence ($F = 42.6$, $p < 0.001$). Post-hoc tests indicated higher low-frequency magnitude in DCM vs. ICM ($p < 0.01$) and higher high-frequency magnitude in ICM vs. DCM ($p < 0.01$).

Echocardiographic Parameters

LVEF and LVEDD were assessed to evaluate left ventricular function and structure, as provided in the dataset. Table 5 summarizes these metrics.

Table 5: Mean and Standard Deviation of LVEF and LVEDD by Group

Group	LVEF (%) $\pm$ SD	LVEDD (mm) $\pm$ SD
ICM	36.2 $\pm$ 7.1	57.1 $\pm$ 3.8
DCM	34.8 $\pm$ 7.5	65.8 $\pm$ 5.2
Healthy	60.1 $\pm$ 2.0	48.1 $\pm$ 1.8

Statistical Analysis: ANOVA indicated significant differences in LVEF ($F = 55.7$, $p < 0.001$) and LVEDD ($F = 60.4$, $p < 0.001$). Post-hoc tests confirmed that DCM had significantly higher LVEDD than ICM ($p < 0.01$), while both had lower LVEF than healthy controls ($p < 0.001$).

Correlations

Correlations between bispectral parameters and clinical metrics (LVEF, LVEDD, myocardial scar) were analyzed using Pearson's correlation coefficient.

Table 6: Correlation of Bispectral Parameters with Echocardiographic and Myocardial Scar Parameters

Bispectral Parameter	Group	Clinical/Imaging Parameter	Correlation Coefficient (r)	p-value
Low-Frequency Power	DCM	LVEF	-0.68	<0.01
Low-Frequency Power	DCM	LVEDD	0.61	<0.01
High-Frequency Power	ICM	LVEF	-0.59	<0.01
High-Frequency Power	ICM	Myocardial Scar	0.64	<0.01

Arrhythmia Prevalence

The presence of arrhythmias was assessed based on ECG data. Table 7 summarizes the findings.

Table 7: Distribution of Patients by Presence of Arrhythmias

Group	Arrhythmia Present (n)	Arrhythmia Absent (n)
ICM	10	20
DCM	12	18
Healthy	0	30

Diagnostic Accuracy

Receiver Operating Characteristic (ROC) analysis evaluated the diagnostic accuracy of ECG alone, bispectrum alone, and combined bispectrum-ECG analysis for differentiating DCM and ICM.

Table 8: Comparative Diagnostic Accuracy of Bispectrum and ECG

Method	AUC	Sensitivity (%)	Specificity (%)
ECG Alone	0.76	73	70
Bispectrum Alone	0.81	78	76
Combined Bispectrum + ECG	0.88	86	83

DISCUSSION

The results provide compelling evidence that bispectrum analysis of ECG signals enhances the diagnostic differentiation of ischemic cardiomyopathy (ICM) and dilated cardiomyopathy (DCM), addressing the study's primary aim. The following interpretations contextualize the findings within the framework of prior research and clinical implications.

The equal gender distribution (15 males, 15 females per group) and comparable mean ages (ICM: 54.8 ± 10.4 years; DCM: 53.1 ± 11.9 years; Healthy: 52.7 ± 11.6 years) ensured a balanced sample, minimizing bias in subsequent analyses. The age range (38–69 years) aligns with the typical onset of cardiomyopathies, as noted by Bella et al. (2018), who reported a mean age of 55 years in ICM and DCM cohorts. The lack of significant age differences ($p > 0.05$, ANOVA) supports the comparability of groups for ECG and bispectral analyses.[19]

The elevated HR, PR, QRS, and QT values in ICM and DCM compared to healthy controls (Table 2) reflect electrophysiological changes associated with cardiomyopathy. ICM patients exhibited a mean HR of 93.1 ± 8.2 bpm and prolonged PR (206.1 ± 16.7 ms), consistent with myocardial ischemia and scarring, which disrupt conduction pathways [20]. DCM patients showed similar elevations (HR: 90.4 ± 7.6 bpm; PR: 201.2 ± 15.3 ms), due to ventricular dilation and electrical remodeling, as described by Asher et al. (2021). The significant differences from healthy controls (HR: 70.5 ± 2.1 bpm; PR: 149.7 ± 3.0 ms) underscore the sensitivity of ECG parameters in detecting cardiomyopathy [21].

The prevalence of ST-segment changes and Q-waves in ICM (Table 3) aligns with the pathophysiology of myocardial infarction, where Q-waves indicate prior necrosis and ST changes reflect ischemia [20]. DCM patients showed ST depression in 8 cases, due to non-specific repolarization abnormalities, but no Q-waves, consistent with global rather than regional dysfunction. These findings corroborate prior studies, such as Haaf et al. (2016), which reported distinct ECG patterns in ICM vs. DCM.

Bispectrum analysis revealed distinct patterns in ICM and DCM, reflecting underlying pathophysiological mechanisms. The higher low-frequency magnitude in DCM suggests increased non-linear interactions from abnormal ventricular wall motion, consistent with dilation and impaired contractility. Conversely, the

higher high-frequency magnitude in ICM may reflect chaotic electrical activity due to ischemia and fibrosis. The significantly reduced LVEF in both ICM and DCM confirms impaired systolic function, consistent with the diagnostic criteria for cardiomyopathy, as outlined by Taylor et al. [22] The correlation between bispectral power and LVEF in DCM and ICM further supports the clinical relevance of bispectrum metrics in assessing cardiac function.

The bispectral analysis revealed distinct patterns: ICM patients had higher high-frequency magnitude (177.6 ± 16.2 AU), while DCM patients showed elevated low-frequency magnitude (181.3 ± 15.7 AU) (Table 4). These findings support the hypothesis that the bispectrum captures non-linear interactions not evident in traditional ECG. The high-frequency dominance in ICM likely reflects rapid, localized electrical disturbances due to myocardial scarring, as noted by Bella et al. (2018). Conversely, the low-frequency dominance in DCM corresponds to slower, global conduction changes associated with ventricular dilation (Liu et al., 2018). The significantly lower bispectral values in healthy controls (low-frequency: 96.5 ± 2.4 AU; high-frequency: 96.8 ± 2.6 AU) indicate normal electrophysiological stability.

Bicoherence values (ICM: $69.8 \pm 4.5\%$; DCM: $68.9 \pm 4.1\%$; Healthy: $48.1 \pm 1.7\%$) suggest stronger phase coupling in cardiomyopathy groups, reflecting complex electrical interactions. These results reflect altered bicoherence in cardiomyopathy due to non-linear signal dynamics [24]. Further analyses, such as time-frequency bispectrum, could delineate these changes dynamically.

The reduced LVEF in ICM ($36.2 \pm 7.1\%$) and DCM ($34.8 \pm 7.5\%$) compared to healthy controls ($60.1 \pm 2.0\%$) confirms systolic dysfunction as a hallmark of both conditions (Table 5). DCM's higher LVEDD (65.8 ± 5.2 mm) compared to ICM (57.1 ± 3.8 mm) reflects greater ventricular dilation, consistent with [25], which linked DCM to extracellular matrix expansion. These structural differences underpin the distinct electrophysiological patterns observed in bispectrum analysis.

Arrhythmia prevalence was notable: 10/30 ICM patients and 12/30 DCM patients exhibited arrhythmias, while none were observed in controls. ICM arrhythmias are linked to myocardial ischemia and scarring, while DCM arrhythmias arise from

ventricular remodeling. These were some of the important points in this study.

The AUC values indicate that bispectrum analysis improves diagnostic accuracy compared to ECG alone [26]. The strong negative correlation between low frequency bispectral power and LVEF in DCM ($r = -0.68$, $p < 0.01$) suggests that increased non-linear electrical activity is associated with worse systolic function (Table 6). This aligns with Asher et al. (2021), who noted that electrophysiological remodeling in DCM correlates with ventricular dysfunction. The positive correlation with LVEDD ($r = 0.61$, $p < 0.01$) indicates that bispectral power increases with ventricular dilation, reflecting altered conduction dynamics. In ICM, the correlation between high-frequency power and myocardial scar ($r = 0.64$, $p < 0.01$) (Table 6) suggests that scar tissue disrupts high-frequency electrical activity, as reported by Morellato et al. (2018) [27].

The significant differences in bispectral measures between ICM and DCM underscore their distinct Pathophysiology. Incorporating bispectrum analysis into clinical practice could improve early detection and risk stratification in cardiomyopathy [26].

Incorporating imaging modalities and genetic testing into the diagnostic pathway enhances the identification and management of DCM, especially in uncommon but clinically significant forms [5]. Advanced imaging techniques like cardiac magnetic resonance provide detailed assessments of cardiac structure and function, aiding in differentiating DCM subtypes and identifying potential etiologies [28].

The higher arrhythmia prevalence in DCM (12 patients) and ICM (10 patients) compared to healthy controls (0 patients) (Table 8) reflects increased electrical instability in cardiomyopathy. DCM's slightly higher rate may be due to global conduction abnormalities, while ICM's arrhythmias are likely linked to focal scar-related reentry circuits [29].

Diagnostic Accuracy

The combined bispectrum-ECG analysis achieved the highest diagnostic accuracy (AUC = 0.88, sensitivity 86%, specificity 83%) for differentiating DCM and ICM (Table 4.9). This improvement over ECG alone (AUC = 0.76) and bispectrum alone (AUC = 0.81) highlights the synergistic value of integrating non-linear and linear analyses. These findings support the assertion that combined analysis enhances diagnostic precision, potentially reducing reliance on invasive methods like coronary angiography [30].

Strengths of the Study

The strengths of this study include the prospective case-control design, inclusion of both ischemic and dilated cardiomyopathy groups along with healthy controls, and integration of conventional ECG findings with bispectral analysis. The study also evaluated the relationship of bispectral parameters with

echocardiographic measures and myocardial scar, providing a multimodal assessment of cardiac electrical and structural abnormalities. The use of ROC analysis further enabled comparison of the diagnostic performance of ECG, bispectrum analysis, and their combined approach.

Limitations

This study has some limitations. The sample size was relatively small and the study was conducted at a single center. The findings were not externally validated in an independent cohort. In addition, larger multicenter studies are required to confirm the diagnostic value and reproducibility of bispectral ECG parameters.

CONCLUSION

In conclusion, the study shows that bispectrum analysis of ECG signals improves the ability to distinguish between ischemic cardiomyopathy (ICM) and dilated cardiomyopathy (DCM). The research involved equal numbers of males and females and similar average ages across groups, reducing bias. Notable increases in heart rate (HR), PR interval, QRS duration, and QT interval were observed in ICM and DCM compared to healthy controls, indicating underlying heart issues. ICM patients showed specific ST-segment changes and Q-waves, reflecting prior heart damage, while DCM patients exhibited ST depression without Q-waves. Bispectrum analysis revealed contrasting patterns: ICM had higher high-frequency magnitude linked to chaotic electrical activity, while DCM showed greater low-frequency magnitude indicating abnormal ventricular motion. Lower left ventricular ejection fraction (LVEF) confirmed systolic dysfunction in both conditions. Arrhythmias were present in both ICM and DCM patients, absent in controls. The combined bispectrum-ECG analysis provided the highest diagnostic accuracy, surpassing results from ECG or bispectrum alone. This study underscores the potential of combining these methods for more precise diagnosis of cardiomyopathies while possibly reducing the need for invasive diagnostics. Bispectrum analysis of ECG signals shows potential for differentiating DCM and ICM. Bispectrum-ECG analysis offers a non-invasive approach to assess cardiac electrophysiology, complementing traditional diagnostic methods. Future studies with larger cohorts are needed to validate these findings and refine bispectrum-based diagnostic algorithms. Further research could explore bispectrum changes during disease progression and in response to therapy.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available

because they contain information that could potentially compromise the privacy of the study participants.

Ethics Approval

The study protocol was reviewed and approved by the Institutional Ethics Committee of the study center. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Consent for Publication

Written informed consent was obtained from all participants for participation in the study and for the use of their anonymized clinical data for research and publication purposes.

Conflict of Interest

The authors declare that they have no conflicts of interest related to this study.

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Authors' Contributions

All authors contributed to the conception and design of the study, data collection, analysis and interpretation of the findings, preparation and critical revision of the manuscript, and approval of the final version.

Abbreviations

AUC – Area Under the Curve
AU – Arbitrary Units
ANOVA – Analysis of Variance
CMR – Cardiac Magnetic Resonance
DCM – Dilated Cardiomyopathy
ECG – Electrocardiography
HR – Heart Rate
ICM – Ischemic Cardiomyopathy
IQR – Interquartile Range
LVEF – Left Ventricular Ejection Fraction
LVEDD – Left Ventricular End-Diastolic Diameter
MRI – Magnetic Resonance Imaging
PR – PR Interval
QRS – QRS Complex
QT – QT Interval
ROC – Receiver Operating Characteristic
SD – Standard Deviation

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