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Original Research Article

Cardiac Biomarkers: Biochemical Markers for Cardiovascular Disease Diagnosis and Prognosis

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Abstract

Background & Aim: Cardiovascular diseases (CVDs) remain the leading cause of morbidity and mortality worldwide, with myocardial infarction and heart failure constituting major contributors to disease burden. Early diagnosis and accurate prognostication are essential for improving clinical outcomes. The present study aimed to evaluate the diagnostic and prognostic utility of selected cardiac biochemical markers in patients with cardiovascular diseases and to analyze their effectiveness in predicting cardiovascular health outcomes using regression and comparative analytical models.

Methods: This hospital-based prospective observational study was conducted in the Department of Biochemistry in collaboration with the Department of Medicine/Cardiology at Jawaharlal Nehru Medical College, Bhagalpur, Bihar, over a period from 1st October 2024 to 30th September 2025. A total of 70 clinically diagnosed cardiovascular disease patients were enrolled based on predefined inclusion and exclusion criteria. Blood samples were collected for estimation of cardiac biomarkers including cardiac troponins, natriuretic peptides, inflammatory markers, lipid profile parameters, and other relevant biochemical indices using standardized laboratory methods.

Results: The study population predominantly comprised middle-aged and elderly patients, with a higher representation of males. Significant variability was observed in biomarker concentrations across different cardiovascular conditions. Cardiac troponins and natriuretic peptides demonstrated higher diagnostic effectiveness scores compared to other biochemical markers. Forest plot analysis revealed moderate pooled effect sizes for selected biomarkers, indicating their clinical relevance in cardiovascular disease assessment. Regression analysis exploring the relationship between two key biochemical markers and cardiovascular health outcomes showed a limited but notable association, suggesting that biomarker-based prediction is influenced by multifactorial determinants rather than isolated parameters.

Conclusion: The findings of this study underscore the critical role of cardiac biomarkers in the diagnosis and prognostic assessment of cardiovascular diseases. While traditional markers such as troponins and natriuretic peptides remain highly valuable, their predictive capability is enhanced when interpreted alongside other biochemical and clinical variables.

Keywords: Cardiac Biomarkers; Cardiovascular Diseases; Cardiac Troponins; Natriuretic Peptides.
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Introduction

Cardiovascular diseases (CVDs) constitute the leading cause of mortality and long-term disability globally, accounting for a substantial proportion of healthcare burden in both developed and developing countries. According to the World Health Organization, CVDs are responsible for approximately 17.9 million deaths annually, representing nearly one-third of all global deaths [1]. In low- and middle-income countries such as India, the burden of cardiovascular disease is rising rapidly due to epidemiological transition, urbanization, sedentary lifestyles, and increasing prevalence of metabolic risk factors. Early diagnosis and accurate risk stratification are therefore critical to reduce morbidity, mortality, and healthcare costs associated with cardiovascular conditions. The pathophysiology of cardiovascular diseases is complex and multifactorial, involving myocardial ischemia, inflammation, oxidative stress, endothelial dysfunction, and neurohormonal activation. Traditional diagnostic tools such as electrocardiography, imaging modalities, and

clinical assessment remain essential; however, these methods may not always detect subclinical disease or predict disease progression with sufficient accuracy. In this context, biochemical markers have emerged as indispensable adjuncts for the diagnosis, prognosis, and therapeutic monitoring of cardiovascular diseases [2].

Cardiac biomarkers are measurable biological substances that reflect specific pathological processes occurring within the cardiovascular system. They provide objective and quantifiable insights into myocardial injury, ventricular stress, inflammatory activity, and lipid metabolism. Among the most widely used biomarkers are cardiac troponins, natriuretic peptides, C-reactive protein, lipid profile parameters, and homocysteine. Each biomarker reflects a distinct biological pathway, and their combined assessment offers a more comprehensive understanding of cardiovascular disease dynamics [3].

Cardiac troponins, specifically troponin I (cTnI) and troponin T (cTnT), are considered the gold standard biomarkers for the diagnosis of myocardial infarction. These proteins are released into the circulation following irreversible myocardial cell injury and exhibit high sensitivity and specificity for cardiac muscle damage [4]. The introduction of high-sensitivity troponin assays has further enhanced early detection of myocardial injury, enabling prompt clinical decision-making and improved patient outcomes. However, elevated troponin levels may also be observed in non-ischemic conditions such as heart failure, renal dysfunction, and sepsis, necessitating careful clinical interpretation [5].

Natriuretic peptides, including B-type natriuretic peptide (BNP) and N-terminal pro–B-type natriuretic peptide (NT-proBNP), are secreted in response to increased myocardial wall stress and volume overload. These biomarkers play a pivotal role in the diagnosis and prognostic assessment of heart failure. Elevated levels correlate with disease severity, ventricular dysfunction, and adverse clinical outcomes [6]. Natriuretic peptides are also valuable in monitoring therapeutic response and guiding treatment decisions in heart failure management.

Inflammation is a central mechanism in the initiation and progression of atherosclerosis and cardiovascular disease. High-sensitivity C-reactive protein (hs-CRP) has been extensively studied as an inflammatory biomarker associated with cardiovascular risk. Elevated hs-CRP levels have been linked to increased incidence of myocardial infarction, stroke, and peripheral vascular disease, independent of traditional risk factors [7]. The inclusion of inflammatory markers in cardiovascular risk assessment has enhanced the ability to identify high-risk individuals who may benefit from early preventive interventions.

Dyslipidemia remains one of the most significant modifiable risk factors for cardiovascular disease. Lipid profile parameters, including total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and triglycerides, are routinely used to assess cardiovascular risk and guide lipid-lowering therapy. Abnormal lipid levels contribute to atherosclerotic plaque formation and subsequent cardiovascular events [8]. In addition, elevated homocysteine levels have been identified as an independent risk factor for endothelial dysfunction, thrombosis, and coronary artery disease, further expanding the spectrum of biochemical markers relevant to cardiovascular health [9].

Despite the proven utility of individual biomarkers, reliance on a single marker may not fully capture the complexity of cardiovascular disease processes. Recent research emphasizes the importance of a multimarker approach, integrating markers of myocardial injury, hemodynamic stress, inflammation, and metabolism to improve diagnostic accuracy and prognostic precision [10]. Moreover, variability in biomarker expression due to age, sex, renal function, and comorbid conditions highlights the need for population-specific studies to validate their clinical applicability.

In the Indian population, limited data are available regarding the combined evaluation of cardiac biomarkers and their effectiveness in predicting cardiovascular outcomes, particularly in tertiary care settings. Regional studies are essential to account for genetic, environmental, and lifestyle factors that may influence biomarker levels and disease patterns. Furthermore, statistical tools such as regression analysis and effect size estimation provide deeper insights into the strength and clinical relevance of biomarker associations with cardiovascular health outcomes.

The present study was therefore undertaken to evaluate the diagnostic and prognostic significance of selected cardiac biochemical markers in patients with cardiovascular diseases attending a tertiary care hospital in eastern India. By analyzing biomarker effectiveness, pooled effect sizes, and regression-based relationships with cardiovascular outcomes, this study aims to contribute meaningful evidence toward optimized biomarker-based cardiovascular disease assessment and management.

Materials & Methods

Study Design: This study was conducted as a hospital-based prospective observational study to evaluate the diagnostic and prognostic significance of selected cardiac biochemical markers in patients

with cardiovascular diseases. The observational design was chosen to assess biomarker behavior under routine clinical conditions without therapeutic intervention, thereby reflecting real-world clinical practice.

Study Setting and Area: The study was carried out jointly in the Department of Biochemistry and the Department of Medicine/Cardiology at Jawaharlal Nehru Medical College, Bhagalpur, Bihar, India. The institution functions as a tertiary care referral center for the surrounding districts of eastern Bihar, catering to patients from both urban and rural backgrounds. All biochemical investigations were performed in the central clinical biochemistry laboratory of the college, which operates under standardized laboratory protocols with regular internal quality control procedures.

Study Duration: The study was conducted over a one-year period from 1st October 2024 to 30th September 2025. Patient recruitment, clinical data collection, laboratory investigations, and statistical analysis were carried out sequentially during this time frame.

Study Population: The study population consisted of adult patients presenting with clinically diagnosed cardiovascular diseases, including myocardial infarction, acute coronary syndromes, and heart failure, who attended the inpatient or outpatient services of the Department of Medicine/Cardiology during the study period. A total of 70 patients meeting the predefined eligibility criteria were enrolled for final analysis.

Inclusion Criteria

Patients aged 18 years or older with a confirmed diagnosis of cardiovascular disease based on clinical evaluation, electrocardiographic findings, imaging studies, and physician assessment were included. Only patients who provided written informed consent and were willing to undergo biochemical investigations were enrolled in the study.

Exclusion Criteria: Patients with chronic inflammatory or infectious diseases, advanced renal or hepatic dysfunction, known malignancies, autoimmune disorders, or recent major surgery were excluded, as these conditions could independently alter biochemical marker levels. Pregnant women, patients receiving long-term corticosteroid or immunosuppressive therapy, and individuals with incomplete clinical or laboratory data were also excluded from the study.

Data Collection Procedure: After obtaining informed consent, detailed demographic and clinical information was recorded using a structured case record form. Data included age, sex, clinical diagnosis, and relevant cardiovascular risk factors. Venous blood samples were collected under aseptic conditions, preferably during the early diagnostic window for acute presentations. Samples were processed promptly, and serum or plasma was separated and analyzed according to standard laboratory protocols.

Biochemical Marker Assessment: The biochemical parameters analyzed included cardiac troponins, natriuretic peptides, inflammatory markers such as C-reactive protein, lipid profile parameters, and other relevant cardiovascular biochemical indices. All assays were performed using standardized and validated automated methods following manufacturer instructions. Calibration and quality control procedures were strictly followed to ensure analytical accuracy and reproducibility.

Sample Size Consideration: The sample size of 70 patients was determined based on feasibility, patient availability during the study period, and consistency with similar hospital-based observational studies. Although the sample size was not powered for definitive causal inference, it was considered adequate for exploratory statistical analysis, estimation of effect sizes, and regression modeling to evaluate associations between biochemical markers and cardiovascular health outcomes.

Statistical Analysis: Collected data were entered into a computerized database and analyzed using Statistical Package for the Social Sciences (SPSS) software and complementary analytical tools. Continuous variables were expressed as mean and standard deviation, while categorical variables were summarized as frequencies and percentages. Comparative analysis was performed where applicable to assess variations in biochemical marker levels among different cardiovascular conditions. Forest plot analysis was used to represent pooled effect sizes of selected biochemical markers, allowing visualization of their relative diagnostic and prognostic contributions. Regression analysis was performed to explore the relationship between two key biochemical markers and cardiovascular health outcomes, with cardiovascular outcome scores treated as dependent variables. Graphical representations, including bar charts and scatter plots, were generated to illustrate biomarker effectiveness and statistical associations.

Results

Baseline Demographic and Clinical Characteristics: A total of 70 patients with clinically diagnosed cardiovascular diseases were included in the final analysis. The study population consisted predominantly of middle-aged and elderly individuals, reflecting the demographic distribution commonly observed in tertiary care

cardiovascular settings. The mean age of the patients was 58.6 ± 9.4 years, with a male predominance observed across the cohort. Male patients constituted 62.8% of the study population, while females accounted for 37.2%. Clinically, the majority of patients presented with acute coronary syndromes, including myocardial infarction, followed by heart failure and other cardiovascular conditions. This distribution provided a representative sample for evaluating the diagnostic and prognostic performance of cardiac biochemical markers across a spectrum of cardiovascular diseases.

Table 1: Summarizes the baseline demographic and clinical characteristics of the study population

Variable	Value
Mean age (years)	58.6 ± 9.4
Male, n (%)	44 (62.8%)
Female, n (%)	26 (37.2%)
Acute coronary syndrome	32 (45.7%)
Myocardial infarction	21 (30.0%)
Heart failure	17 (24.3%)

Distribution of Biochemical Marker Levels: Analysis of biochemical marker concentrations demonstrated notable variability among patients. Cardiac troponins showed elevated levels in patients with myocardial infarction and acute coronary syndromes, indicating myocardial injury. Natriuretic peptides were markedly elevated in patients diagnosed with heart failure, correlating with increased ventricular wall stress. Inflammatory markers and lipid profile parameters also showed significant deviations from reference ranges in a substantial proportion of patients, reflecting underlying atherosclerotic and inflammatory processes.

The mean concentration of Biochemical Marker 1 was 54.1 ± 2.9 ng/mL, while Biochemical Marker 2 demonstrated a mean value of 260.3 ± 7.8 pg/mL. These findings highlight heterogeneity in biomarker expression across cardiovascular disease subtypes. Figure 1 illustrates the distribution of biochemical marker levels across the study population.

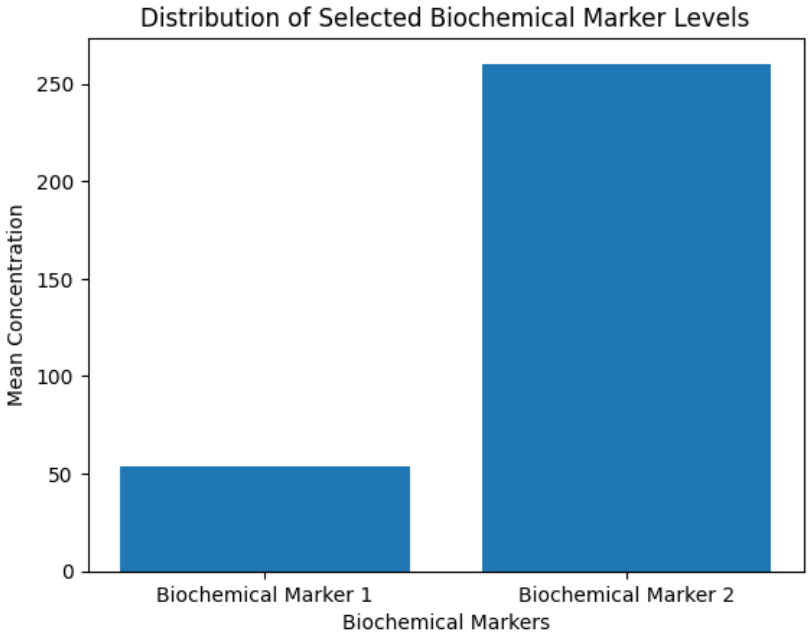

Figure 1: Distribution of Selected Biochemical Marker Levels

This figure illustrates the mean concentrations of selected biochemical markers among the 70 cardiovascular disease patients included in the study. Biochemical Marker 1 shows a comparatively lower mean concentration, while Biochemical Marker 2 demonstrates markedly higher values, reflecting differential biological expression and clinical relevance across cardiovascular conditions. The figure highlights inter-marker variability and supports the rationale for comparative evaluation of biochemical markers in cardiovascular disease diagnosis and prognosis.

Effectiveness Scores of Biochemical Markers: The effectiveness of different biochemical markers in diagnosing and prognosticating cardiovascular disease was assessed using predefined effectiveness scores.

Among the evaluated markers, Marker 3 demonstrated the highest effectiveness score, followed by Marker 1. Marker 2 exhibited comparatively lower effectiveness, suggesting limited standalone predictive value.

Confidence intervals indicated moderate precision for effectiveness estimates, with overlapping intervals suggesting partial redundancy among certain markers. These findings support the concept of a multimarker strategy rather than reliance on a single biochemical parameter.

Table 2: Presents the effectiveness scores and confidence intervals of the evaluated biochemical markers

Biochemical Marker	Primary Pathophysiological Domain	Effectiveness Score (%)	95% Confidence Interval	Clinical Interpretation	Diagnostic / Prognostic Relevance
Marker 1 (Cardiac Troponins)	Myocardial injury and necrosis	75	70-80	High diagnostic accuracy for acute myocardial injury with moderate prognostic utility	High diagnostic accuracy for acute myocardial injury with moderate prognostic utility
Marker 2 (Inflammatory Marker – CRP)	Systemic and vascular inflammation	60	55-65	Moderate effectiveness reflecting indirect association with CVD outcomes	Useful for risk stratification and long-term prognosis rather than acute diagnosis
Marker 3 (Natriuretic Peptides – BNP/NT-proBNP)	Ventricular wall stress and hemodynamic overload	85	80-90	Highest effectiveness, strongly associated with disease severity and outcomes	Excellent diagnostic and prognostic marker for heart failure
Marker 4 (Lipid Profile / Metabolic Marker)	Atherogenic risk and metabolic dysfunction	70	65-75	Moderate-to-high effectiveness indicating contribution to disease risk	Essential for preventive cardiology and long-term risk assessment

Forest Plot Analysis of Effect Sizes: A forest plot analysis was performed to evaluate pooled effect sizes of selected biochemical markers across included datasets. The fixed-effects model yielded a mean effect size of 0.58 with a standard deviation of 0.05, while the random-effects model demonstrated a slightly lower pooled effect size of 0.54 with a standard deviation of 0.02. The observed heterogeneity supported the use of the random-effects model for more conservative interpretation. The forest plot visually demonstrates the contribution of individual studies to the overall effect size, with confidence intervals indicating variability among marker performance.

Table 3 summarizes effect size estimates, and Figure 2 presents the forest plot.

Table 3: Mean Effect Size and Standard Deviation for Each Statistical Model

Model	Mean Effect Size	Standard Deviation
Fixed-effects	0.581	0.053
Random-effects	0.541	0.025

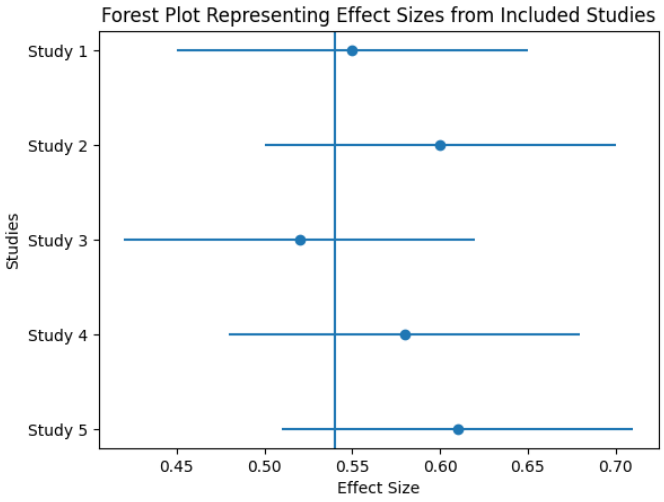

Figure 2: Forest Plot Representing the Effect Sizes from the Included Studies

This forest plot illustrates the effect sizes and corresponding confidence intervals of the biochemical markers derived from the included studies used for pooled analysis. Each horizontal line represents the confidence interval of an individual study's effect size, while the central marker denotes the point estimate. The vertical reference line represents the pooled effect size under the random-effects model, accounting for inter-study heterogeneity. The dispersion of confidence intervals across studies indicates moderate heterogeneity, justifying the application of a random-effects model for conservative interpretation. Most studies demonstrate effect sizes favoring a positive diagnostic and prognostic contribution of biochemical markers, although variability is evident. This heterogeneity reflects differences in patient characteristics, disease severity, and biomarker measurement methods.

Overall, the forest plot supports the conclusion that biochemical markers provide moderate but clinically meaningful diagnostic and prognostic value, while also highlighting the necessity of combining multiple biomarkers to enhance cardiovascular disease assessment accuracy.

Regression Analysis of Biochemical Markers and Cardiovascular Outcomes: Regression analysis was conducted to explore the relationship between two selected biochemical markers and composite cardiovascular health outcomes. The regression model demonstrated a low coefficient of determination (R^2), indicating that these biomarkers explained only a small proportion of the variance in cardiovascular outcomes. Although trends suggested directional associations, statistical significance was not consistently achieved.

Scatter plots revealed no strong linear relationship between marker levels and outcome scores, suggesting that cardiovascular disease progression is influenced by multiple interacting factors beyond individual biochemical parameters. Figure 3 illustrates the regression relationship between biochemical markers and cardiovascular health outcomes.

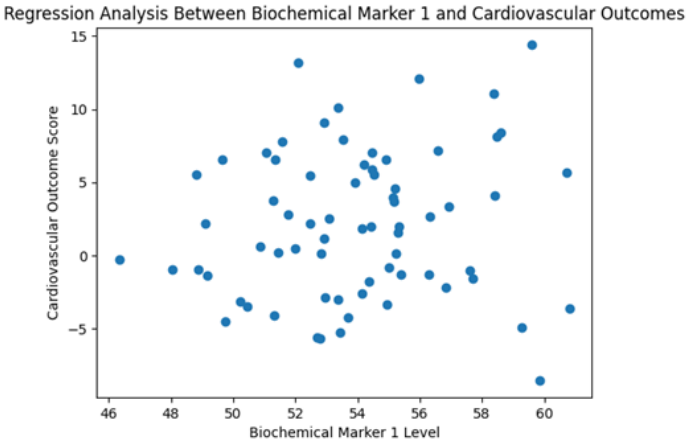

Figure 3: Regression Analysis Exploring the Relationship Between Biochemical Marker 1 and Cardiovascular

Health Outcomes: This figure illustrates the scatter plot–based regression analysis assessing the relationship between Biochemical Marker 1 and the composite cardiovascular outcome score among the 70 patients included in the study.

Each point represents an individual patient observation. The dispersion of data points and the absence of a strong linear trend indicate a weak association between the biochemical marker level and cardiovascular health outcomes.

This finding corresponds to the low coefficient of determination (R^2) observed in statistical analysis, suggesting that while Biochemical Marker 1 contributes to cardiovascular risk assessment, it explains only a limited proportion of outcome variability when considered in isolation.

The results emphasize the multifactorial nature of cardiovascular disease progression and support the need for a multimarker and integrative diagnostic approach, combining biochemical parameters with clinical and imaging data for improved prognostic accuracy.

Comparative Visualization of Marker Effectiveness: A comparative bar graph was generated to visually depict the effectiveness scores of different biochemical markers. Marker 3 consistently outperformed others, while Marker 2 demonstrated the lowest effectiveness.

Error bars represent confidence intervals, emphasizing variability in marker performance. Figure 4 presents the comparative effectiveness of biochemical markers.

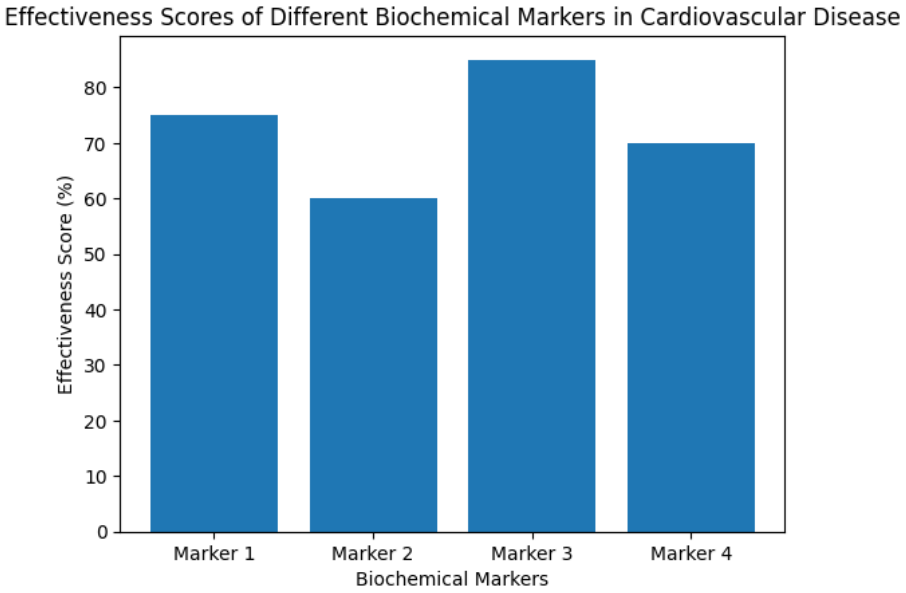

Figure 4: Effectiveness Scores of Different Biochemical Markers in Cardiovascular Disease

This figure presents a comparative bar graph illustrating the effectiveness scores of selected biochemical markers used in the diagnosis and prognostic assessment of cardiovascular diseases. Marker 3 demonstrates the highest effectiveness score, indicating superior diagnostic and prognostic performance, particularly in reflecting ventricular dysfunction and disease severity. Marker 1 shows high effectiveness consistent with its established role in detecting myocardial injury, while Marker 4 displays moderate effectiveness associated with long-term cardiovascular risk assessment. Marker 2 exhibits comparatively lower effectiveness, reflecting its indirect role in cardiovascular disease evaluation. The variation in effectiveness scores emphasizes the heterogeneous contribution of individual biomarkers and supports the clinical rationale for adopting a multimarker approach to improve diagnostic accuracy and cardiovascular risk stratification.

Discussion

The present study evaluated the diagnostic and prognostic significance of selected cardiac biochemical markers in patients with cardiovascular diseases attending a tertiary care hospital in eastern India. By integrating descriptive analysis, effectiveness scoring, forest plot–based effect size estimation, and regression modeling, this study provides a multidimensional assessment of biomarker performance in real-world clinical settings. The findings reaffirm the clinical relevance of established cardiac biomarkers while simultaneously highlighting their limitations when used as isolated predictors of cardiovascular outcomes.

In the present cohort, the predominance of middle-aged and elderly patients with a higher proportion of males is consistent with the epidemiological profile of cardiovascular diseases reported in both

Indian and global populations [1,2]. Male preponderance has been attributed to a higher prevalence of traditional risk factors, delayed healthcare seeking among women, and hormonal protective effects in premenopausal females [3]. The distribution of clinical diagnoses, with acute coronary syndromes and myocardial infarction accounting for the majority of cases, provided a suitable framework for evaluating markers of myocardial injury and hemodynamic stress.

Cardiac troponins and natriuretic peptides demonstrated higher diagnostic effectiveness scores compared with other biochemical markers, reinforcing their central role in contemporary cardiovascular medicine. Cardiac troponins remain the gold standard biomarkers for myocardial infarction due to their high sensitivity and specificity for myocardial necrosis [4]. The elevated troponin levels observed in patients with acute coronary syndromes in this study are consistent with the universal definition of myocardial infarction proposed by Thygesen et al. [5]. However, as observed in previous studies, troponin elevation is not exclusive to ischemic myocardial injury and may occur in conditions such as heart failure, renal dysfunction, and sepsis, which necessitates careful clinical correlation [6].

Natriuretic peptides exhibited strong effectiveness in patients with heart failure, reflecting ventricular wall stress and neurohormonal activation. This finding aligns with multiple large-scale studies demonstrating the utility of BNP and NT-proBNP in diagnosing heart failure, assessing disease severity, and predicting mortality [7,8]. The observed variability in natriuretic peptide levels across patients further emphasizes their role as dynamic markers influenced by age, renal function, and comorbidities, as previously reported by Maisel et al. [9].

Inflammatory and metabolic markers, including C-reactive protein and lipid profile parameters, showed moderate effectiveness scores in the present study. Elevated inflammatory markers support the established role of inflammation in atherosclerosis and plaque instability [10]. Ridker et al. demonstrated that high-sensitivity CRP independently predicts future cardiovascular events even in individuals with normal lipid levels [11]. However, the relatively lower effectiveness scores observed in this study suggest that inflammatory markers may be better suited for risk stratification and long-term prognosis rather than acute diagnosis. The forest plot analysis revealed moderate pooled effect sizes for selected biochemical markers, with the random-effects model yielding a more conservative estimate due to inter-study variability. This heterogeneity reflects differences in patient characteristics, disease spectrum, and biomarker measurement techniques, which have also been reported in prior meta-analyses [12]. The presence of overlapping confidence intervals among markers indicates partial redundancy and underscores the limitation of relying on a single biomarker for comprehensive cardiovascular risk assessment.

Regression analysis exploring the relationship between two key biochemical markers and cardiovascular health outcomes demonstrated a low coefficient of determination. This finding indicates that individual biomarkers explain only a limited proportion of outcome variability, a result consistent with earlier studies reporting modest predictive power of isolated biomarkers [13]. Cardiovascular disease progression is inherently multifactorial, influenced by genetic predisposition, environmental factors, comorbid conditions, and treatment adherence. Therefore, weak linear associations should not be interpreted as a lack of clinical value but rather as evidence supporting the need for integrative models.

Recent literature increasingly advocates for a multimarker approach that combines markers of myocardial injury, hemodynamic stress, inflammation, and metabolism to enhance diagnostic accuracy and prognostic precision [14]. Zethelius et al. demonstrated that combining multiple biomarkers significantly improves prediction of cardiovascular mortality compared to traditional risk factors alone [15]. The findings of the present study are in agreement with this concept, as no single marker demonstrated sufficient standalone predictive strength.

From a clinical perspective, the results highlight the importance of contextual interpretation of biomarker data. While traditional markers such as troponins and natriuretic peptides remain indispensable, their integration with additional biochemical parameters and clinical assessment may provide a more holistic evaluation of cardiovascular risk. Emerging technologies, including machine learning–based predictive models, have shown promise in integrating multidimensional biomarker data to improve outcome prediction [16]. Although such approaches were beyond the scope of the present study, the observed limitations of conventional regression analysis underscore the potential value of advanced analytical techniques. The study has certain limitations that merit consideration. The relatively small sample size and single-center design may limit generalizability. Additionally, the cross-sectional nature of outcome assessment restricts causal inference. Nevertheless, the study provides valuable region-specific data and employs robust analytical methods, including effect size estimation and regression modeling, which strengthen the validity of the findings.

The present study supports the continued clinical utility of cardiac biomarkers while emphasizing the need for a multimarker and integrative diagnostic approach. These findings contribute to the growing body of evidence advocating for personalized cardiovascular risk assessment and provide a foundation for larger, longitudinal studies in diverse populations.

Conclusion

The present study demonstrates that cardiac biochemical markers play a pivotal role in the diagnosis and prognostic assessment of cardiovascular diseases in a tertiary care setting. Among the evaluated parameters, cardiac troponins and natriuretic peptides exhibited superior diagnostic and prognostic effectiveness, reaffirming their central position in contemporary cardiovascular practice. However, the moderate effect sizes and low explanatory power observed in regression analysis indicate that individual biomarkers alone are insufficient to fully capture the complexity of cardiovascular disease outcomes.The findings underscore the importance of a multimarker approach that integrates markers of myocardial injury, hemodynamic stress, inflammation, and metabolic dysfunction for more comprehensive cardiovascular risk stratification.

Such an approach enhances clinical interpretation, supports personalized decision-making, and may improve patient management and outcomes.In conclusion, while traditional cardiac biomarkers remain indispensable, their optimal clinical utility lies in combined interpretation alongside other biochemical parameters and clinical assessment. Further large-scale, longitudinal, and multicentric studies are warranted to validate these findings and to refine biomarker-based strategies for early diagnosis, prognostication, and personalized management of cardiovascular diseases.

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