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Original Article

Gulf of Tomini Cardiac Arrhythmia Research and Exploration (G-CARE): A Multicenter Hospital-Based Outpatient ECG Study

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Abstract

Background: Cardiac arrhythmias pose a significant burden on global health, especially in underserved regions with limited access to diagnostics. In Indonesia, particularly in the Gulf of Tomini, epidemiologic data on arrhythmia prevalence are scarce.

Methods: The G-CARE (Gulf of Tomini Cardiac Arrhythmia Research and Exploration) study was a hospital-based, multicenter, cross-sectional study conducted from 2023–2025 across four referral centers in Gorontalo Province. Adults aged ≥18 years who underwent 12-lead ECG examination were included through purposive sampling. ECGs were interpreted by board-certified cardiologists and classified by arrhythmia type.

Results: A total of 3,177 patients were included (mean age: 53.9±14.9 years; 54.6% female). Normal ECGs were found in 43.4%. The most common abnormalities were ischemic ST-T changes (18.9%, 95% CI: 17.5–20.3), QTc prolongation (15.5%, 95% CI: 14.2–16.8), and left ventricular hypertrophy (10.1%, 95% CI: 9.1–11.2). Atrial fibrillation/flutter occurred in 3.5% (95% CI: 2.8–4.3), AV block in 3.7% (95% CI: 3.0–4.5), and Brugada Pattern in 0.4% (95% CI: 0.2–0.8). Age-related increases were observed for AF, AV block, and QT prolongation. PVC morphology showed high-risk features (QRS >160 ms, coupling interval <300 ms) in young adults.

Conclusions: The G-CARE study identifies a high prevalence of electrocardiographic abnormalities among adults undergoing ECG in outpatient settings within the Gulf of Tomini region. Because the study used hospital-based purposive sampling of patients who had an ECG ordered as part of routine clinical care, these estimates may be biased by selection and do not directly represent the general population. Rather than serving as definitive evidence to support mass, population-level ECG screening, our findings should be considered hypothesis-generating and supportive of conducting a properly designed population-based study (with probability sampling) to determine the actual community burden and to inform screening policy.

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Keywords: Cardiac arrhythmia, epidemiology, atrial fibrillation, Brugada syndrome, premature ventricular complex

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Introduction

Cardiac arrhythmias represent a diverse group of electrical disturbances ranging from benign, asymptomatic findings to severe, life-threatening conditions such as ventricular fibrillation and complete heart block.[1] Globally, arrhythmias are estimated to affect approximately 1.5% to 5% of the general population, with Atrial Fibrillation (AF) being the most frequently encountered subtype.[2–4] This burden is expected to increase significantly in tandem with global population aging and the rising prevalence of cardiovascular risk factors, including hypertension, diabetes mellitus, and coronary artery disease. In Indonesia, epidemiological data on arrhythmias remain limited, especially in non-urban and resource-limited settings. Most prior studies have been concentrated in major urban centres, where access to health services and diagnostic tools is more readily available.[5-6] In contrast, there is a critical lack of population-based data from remote or underserved regions such as the Gulf of Tomini—an expansive coastal area in Eastern Indonesia with unique sociodemographic and environmental characteristics.[7-8]

The Gulf of Tomini region, located in the northern-central part of Sulawesi Island, is characterised by a predominant indigenous Gorontaloan community. In neighbouring regencies across the gulf, small but growing proportions of Bugis-Makassar (migrants) and Mongondow descent also reside, owing to historical migration and interregional mobility. Given that the Gorontaloan ethnic group represents the vast majority of the local population (in Gorontalo Province, >90% identify as Gorontaloan), the local electrophysiological and arrhythmic profile may reflect genetic and sociocultural factors distinct from those widely reported in Java or other major islands. We therefore posit that ethnic/genetic heterogeneity could be a relevant modifier of arrhythmia prevalence and Electrocardiography (ECG) characteristics in our cohort. This region is home to diverse ethnic communities and is characterized by varying dietary habits, physical activity patterns, and limited availability of cardiologic services. According to the 2023 Indonesian Health Survey, the provinces surrounding the Gulf of Tomini report disproportionately high rates of non-communicable diseases—including hypertension, diabetes, stroke, and chronic kidney disease—compared to the national average.[4,9] These conditions are known contributors to arrhythmogenesis and suggest a potentially high but undocumented burden of electrical cardiac disorders in this population.

Despite these risk factors, there has been no comprehensive investigation into the prevalence and patterns of arrhythmias in the Gulf of Tomini. This significant knowledge gap hampers both preventive strategies and early detection efforts. Moreover, the region's limited access to advanced diagnostics, such as echocardiography, Holter monitoring, and electrophysiological studies, further complicates the identification and management of high-risk arrhythmias.

To address this, the Gulf of Tomini Cardiac Arrhythmia Research and Exploration (G-CARE) study was initiated. This multicentre, hospital-based, epidemiologic investigation employs standardized 12-lead ECG interpretation to determine the prevalence of arrhythmia subtypes and to characterize demographic patterns among affected patients. The findings are expected to inform local and national health authorities in planning region-specific screening strategies, early referral systems, and investment in arrhythmia care infrastructure for underserved Eastern Indonesian populations.

Methods

Study Design

G-CARE is a cross-sectional, hospital-based, multicentre study conducted in Gorontalo Province, Indonesia. The study involved four referral hospitals representing the Gulf of Tomini region (Aloei Saboe General Hospital, Toto Kabila General Hospital, Ainun Habibie General Hospital, Tani dan Nelayan General Hospital). The study period spanned from February to July 2025, utilizing retrospective ECG records from January 2023 to January 2025. The study exclusively included ECG records from outpatient visits, reflecting arrhythmia patterns encountered in community-based clinical practice.

For this study, "outpatient visits" refers to non-admitted encounters occurring in the hospital's outpatient departments. These included: (1) general outpatient clinics (including internal medicine/general practice consultations), (2) specialized cardiology outpatient clinics (cardiology clinics where patients are referred for cardiac symptoms or follow-up), and (3) other ambulatory outpatient services where an ECG may be ordered (for example, pre-operative assessment clinics or chronic-disease follow-up visits). ECGs included in the study were obtained as part of routine clinical care and were recorded in the hospital's ECG archives. Because ECGs were included only when clinicians ordered them for clinical evaluation or risk assessment, the

dataset is c for individuals with symptoms or known cardiovascular risk factors rather than representing a randomly sampled community population.

Population and Sampling

The accessible population consisted of patients who had undergone ECG examinations at the outpatient clinic during the data collection period. Purposive sampling was used to select ECGs that met predefined quality and completeness criteria. These inclusion criteria were intended to ensure reliable ECG interpretation; however, this approach is a non-probability sample and introduces selection bias. Inclusion criteria were: (1) age ≥18 years, and (2) complete, interpretable 12-lead ECG recordings. Exclusion criteria included: (1) incomplete or technically unreadable ECG records, and (2) presence of acute or unrelated medical conditions not relevant to the study's objectives (e.g., trauma or post-surgical evaluations not related to cardiology).

Data Collection

All selected ECG records were accompanied by demographic data, including patient age and sex. Each ECG was independently interpreted by two board-certified cardiologists at each participating center. In cases of disagreement, a third senior cardiologist reviewed the tracing to achieve consensus. Detected arrhythmias were categorized into subtypes using standard diagnostic criteria, including AF/flutter, Atrioventricular (AV) blocks (first to third degree), Premature Ventricular Contractions (PVC), Brugada pattern, Wolff–Parkinson–White (WPW) pattern, QTc interval abnormalities, and conduction disturbances such as bundle branch blocks. PVCs were identified when at least one premature ventricular beat was present on a standard 12-lead ECG. Because a 10-second ECG does not provide sufficient duration to assess ectopic burden, the term 'frequent PVC' was not applied. PVC morphology was defined according to standard electrocardiographic criteria: (1) Right Bundle Branch Block (RBBB)-type PVCs, representing left ventricular origin (QRS ≥120 ms with rsR' or qR in V1); and (2) Left Bundle Branch Block (LBBB)-type PVCs, representing right ventricular origin (broad notched/slurred R wave in V5–V6 with absent Q waves in I and V6). These definitions were applied consistently across all ECGs, including AV block definitions and classification. AV block was defined and categorized using standard electrocardiographic criteria. First-degree AV block was defined as a PR interval > 200 ms with 1:1 AV conduction. Second-degree AV block (Mobitz I/Wenckebach) was defined by progressive PR prolongation culminating in a dropped QRS. Second-degree AV block (Mobitz II) was defined by intermittent non-conducted P waves with constant PR intervals in the conducted beats. High-grade AV block referred to ≥2 consecutive non-conducted P waves with some preserved AV conduction (e.g., 3:1, 4:1). Third-degree (complete) AV block was defined by AV dissociation with independent atrial and ventricular rhythms. PVC coupling intervals and QRS durations were measured manually by visual estimation ("by eye") using the standard ECG paper calibration (25 mm/s, 10 mm/mV). Early repolarization was defined as J-point elevation ≥0.1 mV in at least two contiguous inferior or lateral leads, following established consensus criteria. Cardiologists applied consistent measurement across tracings to ensure reproducibility. To illustrate this approach, a supplementary figure has been added, demonstrating how the coupling interval was identified between the preceding sinus beat and the premature ventricular complex. Standard diagnostic criteria were applied consistent with international recommendations including guidelines from the American Heart Association (AHA), American College of Cardiology (ACC), and the Heart Rhythm Society (HRS). Although the Minnesota Code is widely used in population-based epidemiologic studies, our hospital-based study relied on clinical diagnostic criteria appropriate for outpatient evaluation.

Variables and Outcomes

The primary outcome was the presence of any arrhythmia on ECG. Subtypes were defined per conventional ECG criteria. Secondary variables included age (<55, 55-64, and >64) and sex (male or female).

Statistical Analysis

Descriptive statistics were used to calculate prevalence estimates and characterize the study sample. The distribution of arrhythmia subtypes was stratified by age and sex. Chi-square or Fisher's exact tests were used to assess associations between arrhythmia prevalence and demographic variables, with 95% confidence intervals provided for key estimates. Statistical analyses were performed using STATA version 18.0. Results were displayed using summary tables and graphs.

Results

A total of 3177 eligible adult subjects were included in the final analysis of the G-CARE study. Data analysis was performed using STATA

18.0 to assess the distribution and characteristics of electrocardiographic abnormalities. The dataset comprised categorical and continuous variables, including age, sex, and multiple ECG parameters classified into arrhythmia types and conduction disorders. Descriptive statistics were used to estimate prevalence. At the same time, chi-square tests and Fisher's exact tests were used in bivariate analyses to evaluate associations between arrhythmia types and demographic factors.

The study involved 3,77 adult subjects, with a mean age of 53.92 years (SD ±14.95), ranging from 18 to 96 years. The majority were female (54.6%), while males comprised 45.4% of the cohort. Normal ECG findings were observed in 43.4% of participants. AV block (116 cases; 3.7%, 95% CI: 3.0–4.5) and atrial fibrillation/flutter (111 cases; 3.5%, 95% CI: 2.8–4.3) were also prevalent. Although less common, other clinically significant conduction and rhythm disorders of clinical significance were identified, including right bundle branch block (5.0%) and premature ventricular complexes (2.9%). Although rare (0.4%), the Brugada ECG pattern was present in both type 1 and type 2/3 variants, underscoring the need for greater awareness of this arrhythmogenic condition. Other structural and conduction abnormalities, such as left anterior hemiblock (0.7%), left posterior hemiblock (0.2%), and WPW syndrome (0.5%), were also documented (see Table 1).

Among male participants, age was significantly associated with increased prevalence of several arrhythmic conditions. AF was notably more common in older age groups, rising from 1.4% in those <55 years to 6.8% in those aged 65 and above ($p<0.001$). Similarly, AV block prevalence rose from 1.3% in the youngest group to 9.4% in the elderly ($p<0.001$), indicating progressive conduction system

Table 1. Study sample characteristic.

Baseline Characteristic (N=3177)	N or Distribution	Percentage
Age	53.9 ± 14.95 (18–96)	
Male Sex	1441	45.4
Initial ECG Diagnosis		
No ECG Abnormality	1378	43.4
Atrial Fibrillation/Flutter	111	3.5
Premature Ventricular Complex	93	2.9
AV Block (1st degree, 2nd degree, and 3rd degree)	116	3.7
Right Bundle Branch Block (RBBB)	158	5.0
Left Bundle Branch Block (LBBB)	23	0.7
Left Anterior Hemi Block (LAHB)	21	0.7
Left Posterior Hemi Block (LPHB)	6	0.2
ST and/or T wave changes suggestive for myocardial ischemia	599	18.9
Left Ventricular Hyperthrophy	322	10.1
Right Ventricular Hyperthrophy	19	0.6
Left Atrial enlargement	69	2.2
Right Atrial Enlargement	8	0.3
Brugada Pattern	12	0.4
Type 1	8	0.3
Type 2 or 3	4	0.1
Long QT Interval	492	15.5
Early Repolarization Pattern	25	0.8
Wolff Parkinson White Syndrome	15	0.5
Type A	5	0.2
Type B	10	0.3

ECG: Electrocardiography; AV: Atrioventricular; RBBB: Right Bundle Branch Block LBBB: Left Bundle Branch Block LAHB: Left Anterior Hemi Block LPHB: Left Posterior Hemi Block.

degeneration with aging. These findings highlight the impact of age-related electrical remodelling in males.

QTc prolongation was also significantly more frequent in older males, affecting 16.1% of those under 55 and nearly one-fourth (24.8%) of those aged ≥65 (p<0.001). The first detection of the Brugada ECG pattern was most frequent in the 55–64 age group (2.2%), then decreased again in the oldest age group. The overall prevalence of conduction abnormalities increased with age (from 6.4% in <55 to 12.6% in ≥65; p<0.001), supporting the notion that advanced age is associated with progressive conduction disturbances. PVC prevalence showed no significant age trend in men (p=0.40) (See Table 2).

In contrast to male patients, the distribution of atrial fibrillation across age groups in female participants did not show a statistically significant trend (p = 0.81). However, the absolute frequency still increased slightly with age. However, AV block prevalence was significantly higher in older women, increasing from 4.1% in those under 55 years to 8.8% in those 65 years and above. Conduction abnormalities were also more prevalent in older females, rising from 6.0% in <55 to 10.1% in ≥65 (p=0.02), consistent with trends observed in males. QTc prolongation was common but did not differ significantly by age group (p = 0.47), although the overall rate remained high in women (17.6%). Other arrhythmias, such as PVCs, WPW, and Brugada patterns, did not demonstrate meaningful variation with age (See Table 3).

Analysis of PVC morphology based on QRS duration revealed notable differences by age but not by sex. Among male patients, the majority of PVCs had a QRS duration ≥160 ms (34 cases), whereas females showed a more even distribution across QRS durations <140 ms, 140–159 ms, and ≥160 ms (p = 0.09). Age-related trends were highly significant (p<0.001). The youngest group (<55 years) accounted for the most considerable number of PVCs with QRS ≥160 ms (31 cases), suggesting early onset of potentially malignant ventricular

Table 2. Distribution of arrhythmia and conduction disorders by age group in male patients.

Variable	<55 (n/%)	55–64 (n/%)	65+ (n/%)	Total (n/%)	P-value
Atrial Fibrillation					
No	752 (98.6)	353 (95.9)	289 (93.2)	1394 (96.7)	0.00
Yes	11 (1.4)	15 (4.1)	21 (6.8)	47 (3.3)	
AV Block					
No	753 (98.7)	354 (96.2)	281 (90.6)	1388 (96.3)	0.00
Yes	10 (1.3)	14 (3.8)	29 (9.4)	53 (3.7)	
Premature Ventricular Contraction					
No	743 (97.4)	356 (96.7)	297 (95.8)	1396 (96.9)	0.40
Yes	20 (2.6)	12 (3.3)	13 (4.2)	45 (3.1)	
Brugada Pattern					
No	761 (99.7)	360 (97.8)	309 (99.7)	1430 (99.2)	0.00
Yes	2 (0.3)	8 (2.2)	1 (0.3)	11 (0.8)	
WPW Pattern					
No	757 (99.2)	368 (100.0)	308 (99.4)	1433 (99.4)	0.24
Yes	6 (0.8)	0 (0.0)	2 (0.6)	8 (0.6)	
QTc Interval					
Normal	640 (83.9)	287 (78.0)	233 (75.2)	1160 (80.5)	0.00
Prolonged	123 (16.1)	81 (22.0)	77 (24.8)	281 (19.5)	
Conduction Disorder					
No	714 (93.6)	336 (91.3)	271 (87.4)	1321 (91.7)	0.00
With Conduction Abnormality	49 (6.4)	32 (8.7)	39 (12.6)	120 (8.3)	

AV: Atrioventricular; WPW: Wolff–Parkinson–White.

Table 3. Distribution of arrhythmia and conduction disorders by age group in female patients.

Variable	<55 (n/%)	55–64 (n/%)	65+ (n/%)	Total (n/%)	P-value
Atrial Fibrillation					
No	658 (96.3)	522 (96.7)	492 (95.9)	1672 (96.3)	0.81
Yes	25 (3.7)	18 (3.3)	21 (4.1)	64 (3.7)	
AV Block					
No	655 (95.9)	516 (95.6)	468 (91.2)	1639 (94.4)	0.00
Yes	28 (4.1)	24 (4.4)	45 (8.8)	97 (5.6)	
Premature Ventricular Contraction					
No	651 (95.3)	514 (95.2)	482 (94.0)	1647 (94.9)	0.56
Yes	32 (4.7)	26 (4.8)	31 (6.0)	89 (5.1)	
Brugada Pattern					
No	680 (99.6)	538 (99.6)	511 (99.6)	1729 (99.6)	1.00
Yes	3 (0.4)	2 (0.4)	2 (0.4)	7 (0.4)	
WPW Pattern					
No	678 (99.3)	535 (99.1)	507 (98.8)	1720 (99.1)	0.58
Yes	5 (0.7)	5 (0.9)	6 (1.2)	16 (0.9)	
QTc Interval					
Normal	574 (84.0)	439 (81.3)	417 (81.3)	1430 (82.4)	0.47
Prolonged	109 (16.0)	101 (18.7)	96 (18.7)	306 (17.6)	
Conduction Disorder					
No	642 (94.0)	497 (92.0)	461 (89.9)	1600 (92.2)	0.02
With Conduction Abnormality	41 (6.0)	43 (8.0)	52 (10.1)	136 (7.8)	

AV: Atrioventricular; WPW: Wolff–Parkinson–White.

conduction abnormalities in this population.

PVC coupling interval analysis revealed that the majority of PVCs in both males and females had a coupling interval <300 ms, suggesting a pattern of early ectopic activity. There were no statistically significant differences between male and female patients in the distribution of coupling intervals (p=0.348). However, a slightly higher proportion of long-coupled PVCs (≥600 ms) was observed in females. When stratified by age, no significant associations were found (p = 0.190). However, a pattern emerged in which the youngest group (<55 years) had the highest number of short-coupled PVCs, while longer coupling intervals were more frequently seen in older patients (See Table 4).

Table 5 presents the distribution of PVC morphologies, classified as LBBB or RBBB, by gender. PVCs with RBBB morphology were significantly more frequent in males (6.2%) than in females (3.9%) (p = 0.00). In contrast, PVCs with LBBB morphology—which typically indicate a right ventricular origin, especially from the Right Ventricular Outflow Tract (RVOT)—were uncommon in both sexes and showed no statistically significant difference between males (0.8%) and females (0.7%) (p = 0.81). This finding appears inconsistent with previous epidemiologic studies that report LBBB-type PVCs as the most common morphology in the general population, particularly in cases of idiopathic or outflow-tract PVCs.

Age-wise analysis showed that LBBB-type PVCs became slightly more prevalent with age, increasing from 0.3% in those <55 years to 1.2% in those ≥65 (p = 0.02). Although the absolute numbers were small, this trend supports the hypothesis of progressive left-sided conduction slowing or structural ventricular remodelling with aging. RBBB-type PVCs, while more common overall, did not exhibit a significant association with age (p = 0.51) (See Table 5).

Among the 12 patients identified with Brugada Pattern in the G-CARE study, the majority (n = 8) were classified as having type 1 Brugada ECG pattern, which is considered diagnostically definitive. The remaining four cases were classified as type 2 or 3 patterns, which are less specific and often require pharmacologic provocation for confirmation. Type 1 cases were predominantly observed in males (87.5%), consistent with the established global epidemiology of Brugada syndrome, which shows

Table 4. PVC characteristic (QRS duration and coupling interval) by sex and age.

Variable	QRS <140 ms	QRS 140–159 ms	QRS ≥160 ms	P-value (QRS)	CI <300 ms	CI 300–599 ms	CI ≥600 ms	P-value (CI)
Sex								
Male	4	8	34	0.09	38	8	0	0.348
Female	12	9	27		42	5	0	
Age Group								
<55	3	3	31	0.000	28	8	0	0.190
55–64	7	3	23		30	3	0	
≥65	6	11	7		22	2	0	

Table 5. PVC morphology (LBBB and RBBB) by sex and age group.

Variable	LBBB - No	LBBB - Yes	P-value (LBBB)	RBBB - No	RBBB - Yes	P-value (RBBB)
Sex						
Male	1430	11	0.81	1351	90	0.00
Female	1724	12		1668	68	
Total	3154	23		3019	158	
Age Group						
<55	1442	4	0.02	1373	73	0.51
55–64	899	9		858	50	
≥65	813	10		788	35	
Total	3154	23		3019	158	

LBBB: Left Bundle Branch Block; RBBB: Right Bundle Branch Block.

Table 6. Characteristic Brugada ECG pattern.

Variable	Type 1 (n=8)	Type 2 or 3 (n=4)
Age	59.25	52
Male	7	4
Sinus Rhythm	5	4
Sinus Bradycardia	0	0
Sinus Tachycardia	3	0
Atrial Fibrillation	0	0
PR Interval	171.75	193.25
QT Interval Correction	415	410.5

a strong male predominance. The mean age of type 1 patients was 59.25 years, indicating that the phenotype may emerge or be more easily detected in later adulthood, even in populations without widespread access to advanced cardiac diagnostics (See Table 6).

Electrocardiographic characteristics of patients with Brugada syndrome revealed that most were in normal sinus rhythm at the time of recording. Five of the eight patients with type 1 exhibited baseline sinus rhythm, whereas the remaining three demonstrated sinus tachycardia. Several type 1 Brugada ECG recordings demonstrated sinus tachycardia, likely reflecting physiologic variation during outpatient recording rather than autonomic imbalance. Interestingly, none of the patients exhibited sinus bradycardia or atrial fibrillation, which are frequently reported in symptomatic Brugada cohorts. This may suggest that the individuals identified in this study were in early or asymptomatic stages, or that the ECGs were obtained in non-provocative conditions.

Discussion

The G-CARE study represents the first large-scale, multicentre epidemiologic investigation of electrocardiographic abnormalities in the coastal provinces of Eastern Indonesia. This study identified a considerable prevalence of arrhythmias

and conduction abnormalities among adults who underwent outpatient ECG examinations in the Gulf of Tomini region. Because the dataset consists of ECGs obtained during outpatient encounters at referral hospitals, it is important to recognize several mechanisms by which prevalence estimates may be inflated relative to the general population. First, clinicians are more likely to order ECGs for symptomatic patients (palpitations, syncope, chest pain) or for those with known cardiovascular risk factors (hypertension, diabetes, prior cardiac disease), thereby enriching the sampled population for arrhythmias and conduction abnormalities. Second, specialized cardiology outpatient clinics and referral centers often see patients with more complex or persistent problems, creating a referral bias. Third, certain high-risk conditions (e.g., symptomatic Brugada syndrome or malignant ventricular arrhythmias) may be overrepresented among hospital attenders. In contrast, other conditions—particularly asymptomatic or transient abnormalities in the community—may be undersampled. Collectively, these biases tend to push prevalence estimates upward relative to an age- and sex-matched, community-derived sample. For this reason, the prevalence figures reported here should be interpreted as the frequency of ECG-detected abnormalities in the outpatient hospital setting rather than as community prevalence. Future work employing probability-based sampling (community door-to-door surveys, primary-care registry sampling, or population cohorts) and statistical weighting will be required to infer population-level prevalence.

QTc Prolongation and Public Health Implications

A notable and alarming finding in this study is the high prevalence of prolonged QTc intervals, identified in 15.5% of participants. This figure, while falling within the broad prevalence range reported in previous studies (3% to 44.1%), aligns closely with studies reporting rates of approximately 34.1%.[10-11] The detection of QTc prolongation in both genders and across age categories—particularly concentrated among older males—highlights a potentially underrecognized public health risk. Several established determinants of QTc prolongation, such as increasing age, male sex, hypertension, and diabetes mellitus, were also prevalent in our study population[10,12–14], potentially compounding the observed burden. Clinically, prolonged QTc is a harbinger of malignant ventricular arrhythmias, including torsades de pointes and ventricular fibrillation, both of which are associated with increased risk of sudden cardiac death. This risk is further magnified in low-resource settings, where timely access to defibrillation or ICD therapy remains limited.[15] Long QTc values were identified based on standard cut-offs (QTc ≥ 460 ms in females, ≥ 440 ms in males, Bazett's correction). However, we were unable to systematically exclude acquired causes (e.g., medication use, electrolyte disturbances) due to the retrospective design and incomplete clinical data. Future studies should stratify congenital versus acquired prolonged QT and separate cardiac versus non-cardiac cohorts to obtain accurate prevalence estimates.

Age-Related Trends in Atrial Fibrillation and AV Block

Another critical observation concerns AF and AV block, which both showed marked age-related increases, particularly among males aged ≥65 years. These patterns reflect the well-documented phenomena of age-related atrial remodelling, sinus node dysfunction, and fibrotic degeneration of the His-Purkinje system.[16-17] However, what makes our findings unique is the identification of these conduction abnormalities in a population that is generally underrepresented in cardiovascular literature—semi-rural, outpatient adults from coastal Indonesia. Our findings on the prevalence of atrial fibrillation among outpatients (3.5%) are broadly comparable to national data from the InaHRS multicentre registry, which included 13 tertiary centres across Indonesia. However, the demographic profile of the G-CARE cohort—comprising semi-rural, mixed general-outpatient participants—differs substantially from that of the urban, referral-based population represented in InaHRS. This contextual difference may explain minor variations in prevalence and supports the need for regional ECG registries to capture arrhythmia characteristics beyond major urban centers.

High-Risk PVC Morphology in Young Adults and Unexpected Patterns in PVC Morphology

The predominance of PVCs with RBBB morphology in our cohort contrasts with several population-based studies reporting that LBBB-type PVCs (commonly originating in the RVOT) are more frequent in idiopathic PVC series. Several non-mutually exclusive explanations are plausible. One possibility is that left-ventricular structural disease or focal left ventricular scarring—possibly related to ischemic heart disease, prior myocarditis, or regional cardiomyopathy—could generate PVCs manifesting with RBBB morphology. Another is that

referral and selection patterns concentrate patients with concerning symptoms or prior structural heart disease into the hospital outpatient sample, inflating the relative proportion of left-ventricular ectopy. Finally, regional or genetic differences in arrhythmogenic substrate cannot be excluded. We note, however, that the absolute number of LBBB-type PVCs in our sample was small; therefore, formal subgroup comparisons are limited by sample size and power. To further explore this finding, we recommend: (1) a descriptive comparison of demographic and clinical characteristics between patients with RBBB- vs LBBB-type PVCs (age, sex, clinical history, ECG features), (2) echocardiographic or cardiac MRI assessment to identify underlying structural disease among RBBB-PVC patients, and (3) prospective registry or ambulatory monitoring to determine the burden and prognostic significance of these morphologies in the region. In the absence of a larger dataset, the present manuscript presents this observation as an essential hypothesis for follow-up rather than as definitive evidence of a region-specific arrhythmogenic phenotype.[20-22]

Detection of Brugada Syndrome and in a Non-Provoked Setting and Wolff–Parkinson–White (WPW) syndrome

Perhaps the most clinically provocative finding of the G-CARE study is the identification of Brugada patterns, including spontaneous type 1 ECG patterns in 8 subjects (0.3%). Brugada syndrome is an inherited arrhythmogenic disorder associated with a high risk of sudden cardiac death, particularly in younger males. Its detection in a non-provoked setting—outside of pharmacologic challenge or febrile states—suggests that a subset of individuals in the Gulf of Tomini region may carry pathogenic SCN5A variants or other channelopathies that remain undiagnosed due to the absence of electrophysiology labs and genetic services. QTc interval was analysed separately in the general dataset as part of conduction abnormalities and was not used as a diagnostic parameter for Brugada syndrome.

Interestingly, we observed a mean age of ~59 years for type 1 Brugada-pattern ECGs, which at first glance appears older than typical descriptions emphasizing risk in younger males. Several considerations may explain this discrepancy. In hospital-based cross-sectional datasets, older age at detection can reflect delayed diagnosis (limited prior ECG screening), survivorship or ascertainment bias (younger individuals with malignant phenotypes may have experienced events before presenting to outpatient clinics), or age-dependent phenotypic expression influenced by comorbidities or extrinsic triggers (fever, drugs, electrolyte disturbances). It is also possible that the individuals identified in this study represent asymptomatic carriers whose ECG phenotype becomes manifest later in life or in the presence of coexisting conditions.[23-25]

In addition to Brugada syndrome, we identified 15 cases (0.5%) of WPW syndrome, a pre-excitation disorder that may predispose patients to paroxysmal supraventricular tachycardias or even sudden cardiac arrest. While the absolute prevalence may appear modest, the identification of WPW on outpatient ECGs underscores the value of routine screening in identifying asymptomatic yet potentially high-risk individuals—particularly when more advanced modalities, such as Holter monitors or event recorders, are unavailable.[26]

Sex-Based Differences in Arrhythmogenesis

The observed sex-based differences in arrhythmia expression are also noteworthy. Men exhibited higher rates of AF and Brugada patterns, whereas AV block was more prevalent among older women. The absence of a significant age-related increase in atrial fibrillation among females may relate to oestrogen's cardioprotective effect on atrial structural remodelling, lower prevalence of hypertension and coronary artery disease, and differences in autonomic tone. These trends are consistent with known sex-specific electrophysiological responses—such as oestrogen's protective effect on atrial remodelling—but the biological underpinnings remain complex. They are likely influenced by a combination of hormonal, structural, and autonomic factors.[27-28]

Early-Onset Electrical Abnormalities and Subclinical Risk

Our data also suggest that early arrhythmogenic risk is under-recognized. A substantial number of patients under 55 years displayed QT prolongation, PVCs, or even early repolarization patterns. These findings may serve as early electrophysiologic markers of subclinical cardiovascular disease or inherited channelopathies, particularly in a region where comorbid conditions such as diabetes, hypertension, and CKD are highly prevalent. These patterns support the hypothesis that arrhythmogenic substrates may develop earlier in populations with high burdens of noncommunicable diseases.

From a public health standpoint, the study provides a strong justification for ECG-based screening in outpatient settings, particularly in remote or coastal regions. The detection of clinically

actionable arrhythmias in nearly 60% of ECGs reviewed—despite no pre-screening for cardiac symptoms—suggests that the cost-effectiveness of ECG screening may be far higher than previously assumed in low- and middle-income countries (LMICs), especially when interpreted by trained cardiologists.[29-30]

The implications for health system planning are significant. Given that ECG is a low-cost, non-invasive modality, its use could be expanded as part of primary cardiovascular screening programs, particularly for populations at risk of sudden cardiac death, including those with strong family histories, prior syncope, or unexplained seizures. Training primary care physicians to recognize high-risk ECG features could facilitate earlier referrals and potentially life-saving interventions.

Importantly, our study highlights the utility of hospital-based retrospective ECG analysis as a surrogate for population-based surveillance in resource-limited environments. While accurate community-based screening would offer broader generalizability, our data nevertheless capture real-world outpatient practice patterns and serve as a foundational step toward scalable arrhythmia registries in Indonesia and comparable settings.

In terms of novelty, this is the first published study to stratify arrhythmia burden in the Gulf of Tomini—an underserved region with distinctive sociodemographic and environmental characteristics. The study not only contributes original epidemiologic data but also provides a framework for future research on arrhythmia genetics, electrophysiologic mapping, and implementation of preventive cardiology strategies in rural Southeast Asia.

Conclusion

In this multicenter hospital-based outpatient ECG study from the Gulf of Tomini region, a high prevalence of ECG abnormalities was identified among adults who underwent clinically indicated ECG testing. These findings generate essential hypotheses about potential regional patterns of arrhythmia and conduction disease, but cannot be extrapolated to the community without confirmatory population-based research. We therefore recommend that policymakers and researchers consider (1) designing probability-based community studies to quantify true population prevalence, (2) performing prospective clinical and imaging follow-up for patients with high-risk ECG features, and (3) prioritizing targeted screening or referral pathways for high-risk subgroups rather than immediate mass ECG screening across the general population.

Study Limitations

This study should be interpreted in light of several limitations. First, it was conducted in a hospital-based outpatient setting rather than through population-based sampling. As a result, individuals who underwent ECG examination were more likely to present with symptoms, cardiovascular risk factors, or established cardiac disease, which introduces selection bias and may lead to overestimation of arrhythmia prevalence compared with the general community.

Second, although the dataset included both cardiac and non-cardiac patients, the absence of stratification between these groups limits the ability to determine the actual community burden of arrhythmias. Similarly, while QTc prolongation was prevalent, our retrospective design did not allow us to systematically exclude acquired causes (e.g., medications, electrolyte disturbances), which could have influenced the reported prevalence.

Third, ECG interpretation was based on clinical diagnostic guidelines (AHA/ACC/HRS) rather than the Minnesota Code, which is traditionally employed in epidemiologic surveys. While this approach reflects real-world outpatient practice, it may limit comparability with prior population-based studies.

Fourth, PVC coupling intervals and QRS durations were measured manually by visual inspection ("by eye") on standardized ECG paper. Although this method is widely accepted in clinical practice and is consistently applied by cardiologists, it exhibits greater interobserver variability than digital calliper techniques.

Taken together, these limitations highlight that the findings should be regarded as hypothesis-generating rather than definitive prevalence estimates. Future research employing probability-based community sampling, prospective clinical follow-up, and integration of advanced diagnostic tools will be necessary to confirm and extend these observations in the general population.

List of Abbreviations

ACC	American College of Cardiology
AF	Atrial Fibrillation
AHA	American Heart Association
AV	Atrioventricular

ECG	Electrocardiogram
G-CARE	Gulf of Tomini Cardiac Arrhythmia Research and Exploration
HRS	Heart Rhythm Society
LAHB	Left Anterior Hemi Block
LBBB	Left Bundle Branch Block
LMICs	Low- and Middle-Income Countries
LPHB	Left Posterior Hemi Block
PVC	Premature Ventricular Contraction
RBBB	Right Bundle Branch Block
RVOT	Right Ventricular Outflow Tract
WPW	Wolff–Parkinson–White

Ethical Clearance

This study was conducted in accordance with the Declaration of Helsinki. It was approved by the Health Research Ethics Committee of the State University of Gorontalo, with ethics committee reference number 116/UN47.B7/KE/2025. Written informed consent was obtained from all participants before the study commenced.

Publication Approval

All authors consent to the publication of this manuscript.

Authors Contributions

MNIS: Writing – review & editing, Writing – original draft, Validation, Methodology, Data accuracy, Investigation, Conceptualization. ZKY: Writing – review & editing, Writing – original draft, Validation, Project administration. DPI: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition. MYID: Writing – review & editing, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization.

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None.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Availability of Data and Materials

De-identified data and analytic code are available from the corresponding author upon reasonable request and subject to institutional policies.

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No AI tools were used to generate, analyse, or interpret data, figures, or scientific content. All text was reviewed, verified, and edited by the authors, who take full responsibility for the content.

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