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Clinical Predictors of Cardiac Rhythm Disorders Associated with Sudden Cardiac Death in Pediatric Athletes: A Prospective Longitudinal Study

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Abstract: Sudden cardiac death (SCD) in pediatric athletes is rare but is frequently related to previously undiagnosed cardiac rhythm disorders (CRD). In this population, early identification of clinically relevant arrhythmias through pragmatic screening strategies remains essential for prevention. This prospective, observational, longitudinal study (2020–2024) included 80 pediatric athletes evaluated at the "Sf. Ioan" Children's Emergency Clinical Hospital, Galați. All participants underwent structured anamnesis, clinical examination, 24-hour Holter ECG monitoring, and exercise stress testing. Demographic characteristics, perinatal history, lifestyle factors, stimulant consumption, and family history of SCD were recorded. Statistical analysis was performed using SPSS Statistics version 24. Although male athletes predominated (56.25%), cardiac rhythm disorders were more frequently detected in females (62.71%). Most participants originated from urban areas (98.75%). Perinatal pathology was not associated with arrhythmia prevalence. Precordial pain (13.75%) and palpitations (12.5%) were the most frequently reported symptoms. Notably, all athletes reporting recurrent precordial pain were diagnosed with Holter-documented CRD, including clinically significant arrhythmias, with a strong correlation confirmed by Spearman analysis ($p < 0.01$). A family history of SCD was present in 22.5% of cases. Coffee consumption (28.8%) clustered with sinus tachycardia and premature atrial and ventricular beats. Five athletes (6.25%) required temporary or permanent withdrawal from competitive sports due to high-risk arrhythmias. Follow-up compliance was 22.5%. In pediatric athletes, structured symptom-based anamnesis combined with targeted Holter ECG monitoring facilitates the identification of occult and clinically significant arrhythmias. Recurrent precordial pain and palpitations should be regarded as warning symptoms warranting mandatory cardiological evaluation to reduce the risk of SCD.

Keywords: heart rhythm disorders; sudden cardiac death; children; young, athletes

1. Introduction

In the past two decades, extensive population-based studies conducted across all continents have focused on identifying risk factors for sudden death and on preventing these events through the early detection of potentially lethal cardiac arrhythmias (CA) [1]. Despite advances in diagnostic techniques, sudden cardiac death (SCD) remains a major public health concern, particularly among children, young adults, and athletes.

A meta-analysis including nine population-based studies evaluated 469 cases of sudden death in children and young individuals. The reported incidence of sudden cardiac death ranged from 1.3 to 8.5 per 100,000 persons, with a consistent male predominance across all studies [1]. Autopsy findings identified a structural cardiac cause in approximately two-thirds of cases, while the remaining deaths were attributed to malignant cardiac arrhythmias occurring in structurally normal hearts [1].

As early as 1985, Valdes et al. highlighted that nearly 10% of the approximately 7000 sudden deaths occurring annually in infants were attributable to CA [2]. In the same year, Topaz et al. reported that among individuals aged 1–30 years who experienced SCD, nearly 50% had presented prior prodromal symptoms—including syncope, vertigo, precordial pain, or palpitations—despite being considered clinically healthy. Notably, these symptoms had not been investigated from a cardiological perspective before the fatal event [3].

Further evidence was provided by a retrospective analysis of data from the National Registry for the Registration and Prevention of Sudden Infant Deaths, covering five years between 2005 and 2009. This study documented 1098 deaths, confirming a predominance of males (58%) and individuals of the white race (71%) among the affected population [4].

Regarding the etiology of SCD, data from the literature indicate that approximately 20–40% of cases are attributable to CA. Among these, the most frequently implicated arrhythmic substrates with a high risk of sudden death include Wolff–Parkinson–White (WPW) syndrome, Brugada syndrome, and long QT syndrome [4–6].

Although the overall incidence of SCD in athletes is relatively low, these events carry a disproportionately high psychosocial impact, as athletes are widely perceived as paradigms of health. Large-scale studies have identified previously undiagnosed hypertrophic or dilated cardiomyopathy, as well as malignant CA, as the most common underlying causes of SCD in this population.

A landmark study conducted in the United Kingdom between 1994 and 2014, published in 2016, analyzed 357 cases of SCD among athletes. The findings revealed that 42% of deaths occurred in the context of previously undiagnosed CA, while 61% took place during sports activity. These results underscore the critical importance of identifying athletes with occult rhythm disorders and emphasize sustained physical exertion as a significant triggering factor for SCD [7].

In response to these findings, several countries have implemented pre-participation screening protocols aimed at identifying athletes at increased risk of SCD before medical clearance for competitive sports. In 2015, the North American professional societies revised their screening recommendations, placing primary emphasis on a structured medical history questionnaire. Routine electrocardiography, exercise stress testing, and Holter monitoring are not recommended for universal screening but are reserved for athletes with identified risk factors based on clinical history [8].

In contrast, Corrado at al. conducted two large-scale studies in the Veneto region of Italy. The first study identified a substantial number of sudden deaths among athletes and concluded that many could have been prevented through the restriction of intense physical activity [9]. In the second study, the authors implemented a comprehensive cardiac screening program, which resulted in a marked reduction in sudden

deaths among athletes, albeit at the expense of disqualifying several hundred individuals from competitive sports [10].

In Romania, precise epidemiological data regarding SCD in athletes are lacking. However, since the sudden death of football player Constantin Tăbarcea in 1963 at the age of 26, and up to the on-field collapse and death of Patrick Ekeng in 2016, several dozen cases of SCD among athletes have been reported, most occurring during sports activities.

Against this background, the present study aims to determine the incidence of cardiac rhythm disorders (CRD) associated with an increased risk of SCD among athletes from Galați County. Additionally, the study seeks to propose a structured investigation protocol to enable appropriate risk stratification and to ensure safe participation in high-intensity physical activity.

2. Materials and Methods

2.1. Study Design

This prospective, observational, longitudinal study was conducted over five years, between 2020 and 2024. The research aimed to evaluate the presence of CRD associated with an increased risk of SCD in pediatric athletes and to identify potential predictive and risk factors.

The study protocol was approved by the Ethics Committee of "Sf. Ioan" Children's Emergency Clinical Hospital, Galați (approval no. 25222/9 October 2024). All procedures were conducted in accordance with the principles of the Declaration of Helsinki. Participation was voluntary, and informed consent was obtained from the legal guardians of all participants.

2.2. Participants

A total of 80 pediatric patients were included in the study. All participants were minors whose medical records were available in the archives of the "Sf. Ioan" Children's Emergency Clinical Hospital, Galați, and those who were actively engaged in organized sports activities within various sports clubs in Galați County.

Participants were referred for inclusion either by their family physician or by a sports medicine specialist. For the purpose of this study, a pediatric athlete was defined as a child or adolescent engaged in organized sports activity within a registered sports club, requiring periodic medical clearance for competitive participation.

The inclusion criteria were: age between 1 and 18 years; active participation in organized sports activities; availability for complete cardiological and clinical evaluation.

The exclusion criteria were: refusal to participate in the study; history of cardiac surgery or previously diagnosed congenital heart malformations; presence of neurological diseases or other significant disabilities that could interfere with evaluation or participation.

The included age range (1–18 years) reflects real-world referral patterns in pediatric sports cardiology; however, given the limited sample size, formal age-stratified analyses (e.g., children versus adolescents) were not performed.

2.3. Evaluation and Data Collection

All participants underwent a standardized and comprehensive clinical evaluation protocol. This included 24-hour 12-lead Holter ECG monitoring, followed by exercise stress testing performed on a cycle ergometer. Additional assessments comprised ambulatory blood pressure monitoring, capillary blood glucose testing, and ASTRUP analysis to support metabolic and physiological profiling. All 24-hour Holter ECG recordings and exercise stress tests were independently reviewed and interpreted by board-certified cardiologists with experience in pediatric and sports

cardiology. Interpretation was performed using dedicated analysis software and followed standardized clinical criteria. In cases of uncertainty, findings were reviewed by a second senior cardiologist, and consensus was reached.

Anthropometric measurements were obtained for all participants, including body weight and waist circumference, and body mass index (BMI) was calculated accordingly.

Exercise stress testing was conducted using a standardized incremental protocol on a cycle ergometer, under continuous electrocardiographic monitoring and medical supervision. The workload was progressively increased according to age and physical capacity until achievement of the target heart rate, development of limiting symptoms, significant ECG changes, or voluntary exhaustion. The test was terminated in the presence of clinically relevant arrhythmias, abnormal blood pressure responses, ischemic ECG changes, or patient intolerance.

2.3.1. Study Objectives

The primary objectives of the study were:

- to identify cardiac arrhythmias associated with an increased risk of sudden cardiac death in pediatric athletes and to determine the main predictive and risk factors;
- to recommend temporary or permanent withdrawal from sports competitions for athletes diagnosed with arrhythmias posing a significant risk of SCD, when clinically indicated.

The secondary objectives included:

- evaluation of the clinical status at the time of inclusion and completion of a comprehensive medical history;
- assessment of demographic and socio-economic characteristics, as well as individual lifestyle factors (including screen time, use of stimulants, and daily habits), to determine their potential role in identifying CRD and in SCD risk stratification;
- evaluation of the prognostic relevance of cardiac symptoms and the role of early diagnosis in preventing SCD.

2.3.2. Data Collection Tools

To standardize and streamline data collection, the following tools were employed:

- Individual standardized questionnaire;
- 12-lead Holter ECG devices, dedicated interpretation software, blood pressure monitors, glucose testing devices, and ASTRUP analysis;
- Sampling lists;
- Centralized data tables.

The individual questionnaire collected detailed information regarding date of birth, perinatal history, physiological and pathological personal history, family medical history, lifestyle and dietary habits, use of stimulants or supplements, and the presence or absence of cardiac symptoms such as palpitations, precordial pain, dyspnea, fatigue, or lipothymia. Additional data included the number of hours spent daily in front of electronic devices (television, tablet, smartphone, video games) and information on the consumption of vitamins, immunostimulants, or anabolic substances. The average completion time for the questionnaire was approximately 15 minutes.

Sampling lists documented general participant information, including name, age, sex, environment of origin, and relevant medical antecedents. Centralized tables were used to summarize group structure and to synthesize findings encountered throughout the study period.

2.3.3 Definition of High-Risk Arrhythmias

For this study, arrhythmias considered to carry an increased risk of sudden cardiac death were defined a priori based on Holter ECG findings and current pediatric sports cardiology practice. These included WPW pre-excitation syndrome, sustained or non-sustained ventricular tachycardia, frequent or complex ventricular ectopy (e.g., couplets or runs), high-grade or complete atrioventricular block, and tachy–brady syndrome or clinically relevant sinus node dysfunction. Identification of these arrhythmias prompted further cardiological evaluation and, when clinically indicated, temporary or permanent restriction from competitive sports participation.

2.4. Statistical Analysis

Statistical analysis was performed using SPSS Statistics version 24. The database (.sav format) was validated and coded prior to analysis. Continuous variables are presented as mean ± standard deviation (SD) or median (interquartile range), as appropriate, while categorical variables are reported as frequencies and percentages.

Comparisons between categorical variables were performed using contingency tables and the chi-square (χ^2) test. Group comparisons for normally distributed continuous variables were conducted using Student's *t*-test or one-way analysis of variance (ANOVA), as appropriate.

Correlation analyses were performed using Pearson's correlation coefficient (r) for normally distributed continuous variables and Kendall's tau for ordinal or categorical variables. All tests were two-tailed, and statistical significance was set at $p < 0.05$.

3. Results

The study cohort comprised 80 pediatric athletes, with a predominance of male participants. Specifically, 45 patients (56.25%) were male, and 35 patients (43.75%) were female. Despite the higher proportion of male participants, the incidence of CRD was greater among females, accounting for 62.71% of all detected CA, compared to 37.29% in males. This sex-specific distribution contrasts with the trends generally reported in the existing literature, where a higher prevalence of rhythm disorders is typically observed in males.

Regarding the environment of origin, the vast majority of participants were from urban areas, with 79 children (98.75%) residing in urban settings. Only one patient (1.25%) originated from a rural area, indicating a highly urbanized study population.

Analysis of perinatal history revealed that most participants had no significant perinatal pathology, accounting for 51 patients (63.75%). The remaining participants presented with documented neonatal conditions, including:

- Neonatal jaundice in 20 patients (25%);
- Neonatal respiratory distress in 8 patients (10%);
- One patient (1.25%) had a history of both neonatal jaundice and respiratory distress.

The distribution of perinatal conditions within the study group is illustrated in Figure 1.

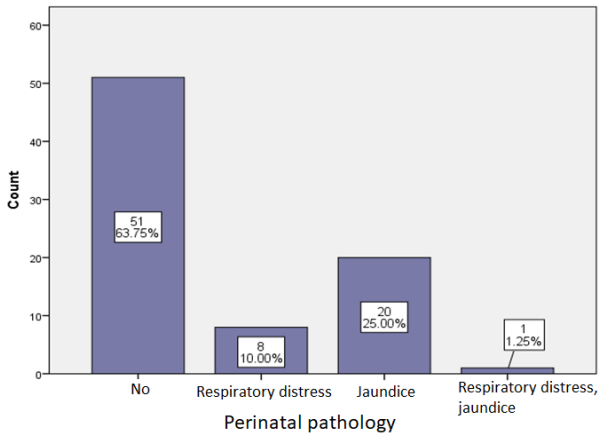

Figure 1. Distribution of cases according to perinatal pathology

Among the 80 pediatric athletes, none had experienced more than 4 hospitalizations in their lifetimes. Multiple hospital admissions were recorded in only two patients, both of whom had a documented history of perinatal respiratory distress. Overall, 56 patients had been hospitalized at least once, whereas 18 children had no hospitalization history. Statistical analysis showed that the presence of perinatal pathology did not influence the number of subsequent hospitalizations, indicating no clear association between neonatal complications and later healthcare utilization.

The majority of participants (78 athletes) were evaluated exclusively in the outpatient clinic of the *"Sf. Ioan" Children's Emergency Hospital* in Galați. These evaluations were performed as part of routine medical assessments required to obtain clearance for continued participation in organized physical activity. Standard clinical and paraclinical investigations were conducted in accordance with current recommendations in sports medicine.

Table 1. Anamnestic incidence of symptoms in the group of athletes

Vertigo		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	78	100.0	100.0	100.0
Chest pain		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	67	85.9	85.9	85.9
	Yes	3	3.8	3.8	89.7
	Occasionally	8	10.3	10.3	100.0
	Total	78	100.0	100.0	
Palpitations		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	68	87.2	87.2	87.2
	Yes	1	1.3	1.3	88.5
	Occasionally	9	11.5	11.5	100.0
	Total	78	100.0	100.0	
Dyspnea		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	78	100.0	100.0	100.0
Faintness		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	76	97.4	97.4	97.4
	Yes	2	2.6	2.6	100.0
	Total	78	100.0	100.0	

Through the use of structured questionnaires, symptoms suggestive of previously undiagnosed CRD and potentially unfavorable prognosis were identified, even though the majority of athletes were otherwise considered clinically healthy. Given the recognized importance of anamnestic symptom assessment in detecting occult arrhythmias in athletic populations, the prevalence of these symptoms was evaluated within the study cohort.

Each reported symptom was subsequently analyzed in relation to the presence or absence of cardiac arrhythmias detected by 24-hour Holter ECG monitoring, in order to assess its potential predictive value. The anamnestic incidence of symptoms identified in the athlete group is presented in Table 1.

For improved clinical clarity, rhythm disorders identified by 24-hour Holter ECG were interpreted and reported according to clinically meaningful categories, including pre-excitation syndromes (Wolff–Parkinson–White), ventricular arrhythmias (frequent premature ventricular complexes and ventricular tachycardia), sinus node dysfunction, and clinically significant conduction disorders (high-grade and complete atrioventricular block), in addition to benign rhythm findings.

Incidence of Rhythm Disorders According to Precordial Pain (Subgroup A)

Within the study group, eight patients reported experiencing occasional chest discomfort, while three patients (3.75%) declared frequent episodes of precordial pain. As shown in Table 2, the presence of precordial pain—particularly when recurrent—was associated with a higher incidence of CRD identified on Holter ECG monitoring. This finding suggests a clinically relevant relationship between chest pain symptoms and underlying rhythm abnormalities in pediatric athletes.

Table 2. Incidence of cardiac arrhythmias among athletes who reported precordial pain

			Atrial extrasystoles (AE)	Ventricular extrasystoles (VE)	Systematized ventricular extrasystoles	Sinus tachycardia (ST)	Ventricular tachycardia (VT)
Athletes		1	<1%	<1%	Yes	Yes	No
		2	>1%	<1%	Yes	Yes	Yes
		3	<1%	<1%	Yes	Yes	No
		N	3	3	3	3	3
	Total	N	3	3	3	3	3

			WPW	Right bundle block (RBB)	Left bundle block (LBB)
Athletes		1	No	Yes	No
		2	No	No	No
		3	Yes	No	Yes
		N	3	3	3
	Total	N	3	3	3

			AE	TS	TACHY_BRADI	WPW	Atrio-ventricular block AVB 1
Athletes		1	<1%	Yes	Yes	No	No
		2	<1%	Yes	No	No	Yes
		3	No	Yes	No	No	No
		4	No	Yes	No	Yes	No
		5	>1%	Yes	Yes	No	No
		6	No	No	No	No	Yes
		7	No	Yes	No	No	Yes
		8	No	No	No	No	No
		N	8	8	8	8	8
	Total	N	8	8	8	8	8

The Spearman correlation analysis, presented in Table 3, revealed a strong and statistically significant association between the presence of precordial pain and the incidence of CRD among the evaluated athletes. This relationship reached a high level of statistical significance ($p < 0.01$), indicating that precordial pain constitutes a clinically relevant marker associated with underlying cardiac rhythm abnormalities in this population.

Table 3. Statistical correlations regarding precordial pain in athletes

			Precordial pain	Athlete
Spearman's rho	Precordial pain	Correlation Coefficient	1.000	-.611**
		Sig. (2-tailed)		0.000
		N	80	80
	Athlete	Correlation Coefficient	-.611**	1.000
		Sig. (2-tailed)	0.000	
		N	80	80

Incidence of Heart Rhythm Disorders According to the Presence of Palpitations.

Only 10 athletes (12.5%) reported experiencing episodes of palpitations. Among these, one patient (1.25%) described frequent palpitations, while the remaining nine patients (11.25%) reported occasional episodes. The distribution of palpitations in relation to the presence of CRD identified by Holter ECG monitoring is presented in Table 4.

Table 4. Incidence of rhythm disorders in relation to a history of palpitations

			AE	Systematized	VE	Systematized VE	ST
Athlete		1	<1%	Trigeminy	>1%	Yes	Yes
		2	>1%	No	No	No	Yes
		3	<1%	No	<1%	No	Yes
		4	<1%	Bigeminy	<1%	Yes	Yes
		5	No	No	No	No	Yes
		6	No	No	No	No	Yes
		7	<1%	No	<1%	Yes	Yes
		8	>1%	No	<1%	Yes	Yes
		9	No	No	No	Yes	Yes
		N	9	9	9	9	9
	Total	N	9	9	9	9	9
			TACHY_BRADI	VT	WPW	RBB	LBB
Athlete	Yes	1	No	Yes	No	No	No
		2	Yes	No	No	No	No
		3	No	No	No	Yes	No
		4	Yes	No	No	No	No
		5	No	No	No	No	No
		6	No	No	Yes	No	Yes
		7	No	No	No	No	No
		8	No	Yes	No	No	No
		9	No	No	Yes	No	No
		N	9	9	9	9	9
	Total	N	9	9	9	9	9

According to Table 5, the Spearman correlation analysis demonstrated a strong and statistically significant association between the presence of palpitations and the incidence of CRD among the evaluated athletes ($p < 0.01$), supporting the role of palpitations as a relevant clinical risk indicator. In contrast, the Spearman analysis showed no statistically significant correlation between family history of sudden cardiac death and the occurrence of palpitations in this athletic population.

Table 5. Statistical correlations regarding Palpitations in athletes

			Palpitations	Presence of SCD
Spearman's rho	Palpitations	Correlation Coefficient	1,000	-0,024
		Sig. (2-tailed)		0,739
		N	80	80
	Athlete	Correlation Coefficient	-.452**	-0,012
		Sig. (2-tailed)	0,000	0,867
		N	80	80

Incidence of Cardiac Rhythm Disorders According to the Presence of Lipothymic Episodes

Only two patients out of the total cohort of 80 athletes reported lipothymic episodes as part of their symptomatology. Further cardiological evaluation was performed to determine whether these symptoms were associated with underlying cardiac rhythm abnormalities. Among the two symptomatic patients, only one was found to present both atrial and ventricular extrasystoles on Holter ECG monitoring, while no rhythm disorder was identified in the other case.

Relationship Between Sudden Cardiac Death and Cardiac Rhythm Disorders

A family history of SCD was identified in 18 patients (22.5%). Of these cases, 55.56% involved first-degree relatives, while 44.44% were reported in second-degree relatives.

Analysis of the reported causes revealed that 76.25% of familial SCD cases could not be clearly identified through questionnaire-based assessment alone. In contrast, 18.75% of cases were attributed to a cardiac etiology, and 5% to neurological causes, highlighting the limitations of anamnesis in accurately determining the underlying cause of SCD in family members.

Eating Habits and Cardiac Rhythm Disorders

To improve interpretability, lifestyle-related factors were analyzed with emphasis on clinically relevant patterns. In this cohort, dietary habits and body mass index were not associated with high-risk cardiac rhythm disorders, whereas stimulant consumption—particularly caffeine—clustered with sinus tachycardia and atrial/ventricular ectopy; these findings should be interpreted as exploratory given subgroup size.

Most participants (60 patients, 75%) reported a healthy lifestyle and considered their diet to be balanced. However, a substantial proportion of the cohort (20 patients, 25%) acknowledged the frequent consumption of fast food, processed foods, and acidic beverages, despite being engaged in competitive sports activities.

Overall, no increased incidence of CRD was observed among athletes reporting an unhealthy diet, except for one subject in this subgroup who was diagnosed with a complete atrioventricular (AV) block. Additionally, only one participant who reported frequent junk food consumption exhibited elevated blood glucose levels (>106 mg/dL).

Anthropometric analysis showed a mean BMI of 19.85, with a standard deviation of ±2.293, as illustrated in the BMI distribution (Figure 2)

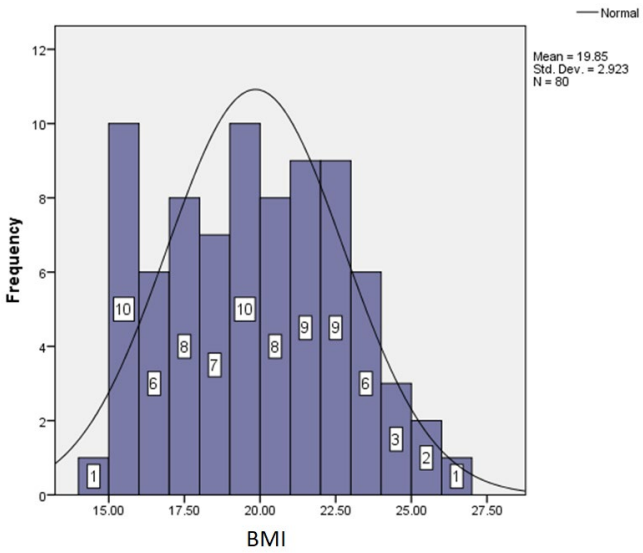

Figure 2. Histogram of BMI

The BMI distribution followed an approximately normal (Gaussian) curve, with a slight leftward deviation. Extreme BMI values were identified in three subjects, with values below 15 or above 25. Among the three athletes with a BMI greater than 25, two were diagnosed with sinus tachycardia associated with right bundle branch block. Importantly, none of these subjects presented CRD associated with an increased risk of sudden cardiac death.

Stimulants, Anabolic Substances, Vitamin Supplementation, and Cardiac Rhythm Disorders

A total of 23 participants (28.8%) reported the use of caffeine as a stimulant. This was followed by 3 participants (3.8%) who reported regular chocolate consumption, and 2 athletes (2.5%) who admitted to the combined use of coffee and an additional stimulant, such as chocolate or energy drinks.

The relationship between coffee consumption and the presence of CRD is illustrated in Figure 3, highlighting the distribution of rhythm abnormalities among athletes according to stimulant intake.

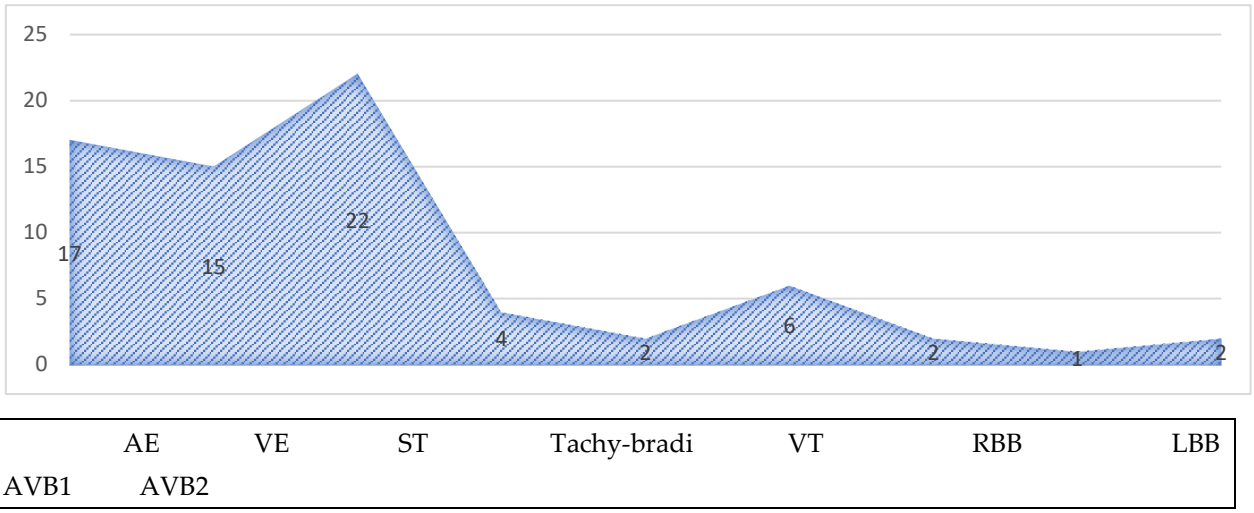

Figure 3. Incidence of rhythm disorders according to coffee consumption

Analysis of Figure 3 reveals a strong association between coffee consumption and the presence of sinus tachycardia, as well as atrial and ventricular premature beats among the evaluated athletes, suggesting a potential stimulatory effect of caffeine on cardiac rhythm in this population.

Most participants (51.35%) reported no use of chronic medication or supplementation. In contrast, 22 athletes (27.5%) declared daily vitamin supplementation, while 7.5% acknowledged the use of immunostimulants or anabolic substances. Additionally, one participant reported the chronic use of calcium supplementation to support the physiological demands associated with sustained physical effort. The distribution of chronic treatments and supplements within the study group is summarized in Table 6.

Table 6. Incidence of arrhythmias among those receiving immunostimulant medication

Chronic treatment = Vitamins, immunostimulants

Cases		AE	Systematized VE	ST	RBB	LBB	AVB1
Athlete	1	<1%	No	No	No	No	No
	2	No	Yes	Yes	Yes	No	No
	3	No	Yes	Yes	No	Yes	No
	4	<1%	Yes	Yes	No	No	Yes

Exercise Tolerance

A total of 76 athletes (95%) demonstrated a very high level of exercise tolerance, despite documented variations in heart rate recorded during 24-hour Holter ECG monitoring. Only two patients exhibited low exercise tolerance. Both of these athletes were diagnosed with WPW preexcitation syndrome and had a positive family history of sudden cardiac death. During physical exertion, these patients developed palpitations and precordial pain, indicating clinically relevant exercise-induced symptomatology.

Compliance with Follow-Up Monitoring

Adherence to follow-up recommendations was limited, with only 22.50% of participants returning for re-evaluation at the Children's Emergency Clinical Hospital in Galați within the recommended timeframe. This low compliance rate highlights a potential barrier to effective longitudinal monitoring and early risk stratification in pediatric athletes.

4. Discussion

4.1. Interpretation of the Main Findings

The present study provides a comprehensive analysis of CRD and associated risk factors for SCD in a cohort of pediatric athletes over five years. Although the study population showed a male predominance, consistent with previous epidemiological reports [11–13], the incidence of detected arrhythmias was higher among female athletes, a finding that contrasts with most published data and suggests potential sex-related differences in arrhythmia susceptibility or symptom reporting in this age group.

Unlike studies that retrospectively analyze sudden deaths [14], our investigation focused on the early identification of arrhythmias at risk for SCD and on the detection of clinical and anamnestic predictors to prevent fatal events. In this context, we explored the potential influence of perinatal pathology, hospitalization history, and personal medical background on the later development of CRD. While perinatal respiratory distress was associated with increased respiratory morbidity throughout childhood and adolescence, it did not demonstrate a direct correlation with arrhythmia occurrence in our cohort. Nevertheless, previous studies have shown that severe

viral respiratory infections, particularly those caused by respiratory syncytial virus, may induce both acute and long-term cardiac electrical and structural alterations capable of predisposing to malignant arrhythmias [15–17].

A key finding of our study concerns the importance of symptom-based anamnesis in pediatric athletes. Consistent with prior reports [18–21], the majority of athletes considered themselves clinically healthy; however, structured questionnaires revealed symptoms with potential arrhythmic significance. Precordial pain (13.75%) was the most frequently reported symptom, followed by palpitations (12.5%), while lipothymic episodes were rare (2.5%).

Chest pain in children and adolescents is generally benign, but its cardiac etiology must be excluded, particularly in athletes [23]. In our cohort, a substantial proportion of athletes reporting precordial pain were diagnosed with high-risk arrhythmias, including WPW syndrome and ventricular tachycardia. The Spearman correlation analysis ($p < 0.01$) confirmed a strong and statistically significant association between precordial pain and the presence of CRD, supporting previous observations that this symptom may represent an early clinical marker of potentially malignant electrical abnormalities [24–26].

Similarly, among athletes reporting palpitations, supraventricular and ventricular arrhythmias predominated, in line with existing literature [27]. Although the overall number of symptomatic patients was limited, the identification of WPW syndrome and ventricular tachycardia in this subgroup reinforces the need for systematic cardiological evaluation when palpitations are reported.

Syncope and lipothymia are widely recognized as red flags in athletic populations [28,29]. Although the incidence of such episodes in our cohort was lower than reported in other athletic populations, one of the two affected athletes was diagnosed with WPW preexcitation syndrome, underlining the potentially severe implications of even isolated syncopal symptoms.

With respect to family history of SCD, nearly one quarter of participants reported affected relatives. However, questionnaire-based assessment alone proved insufficient to accurately identify the underlying cause in most cases, emphasizing the complexity of SCD pathophysiology and the interaction between structural substrates and transient functional triggers [30].

Lifestyle-related factors were also explored. No clear association was found between dietary habits, BMI, or mild hyperglycemia and the presence of arrhythmias at risk of SCD, consistent with the limited and heterogeneous evidence available in pediatric populations [31]. Although a small number of athletes had BMI values above 25, none exhibited malignant arrhythmias.

In contrast, stimulant consumption, particularly caffeine, was strongly associated with sinus tachycardia and atrial and ventricular premature beats. These findings align with experimental and clinical studies demonstrating the arrhythmogenic potential of caffeine, especially during physical exertion [32,33]. Notably, all athletes who reported combined use of vitamins and immunostimulants presented with some form of arrhythmia, suggesting a possible cumulative pro-arrhythmic effect that warrants further investigation.

Finally, exercise tolerance was preserved in the vast majority of athletes. However, the two patients with WPW syndrome, positive family history of SCD, and exercise-induced symptoms represent a clinically critical subgroup. In accordance with Corrado's observations [9,10], the identification and temporary exclusion of such athletes from high-intensity sports may be a decisive preventive measure, as many sudden deaths could potentially be avoided through early restriction of competitive activity.

Recent evidence suggests that metabolic and inflammatory mechanisms may contribute to arrhythmogenesis independently of structural heart disease. Dyslipidemia, as a component of metabolic dysregulation, has been shown to influence myocardial cellular homeostasis through inflammatory activation, oxidative stress, and autonomic imbalance, mechanisms that are implicated in atrial electrical and structural remodeling. In this context, Mauriello et al. highlighted that lipoprotein(a), adiposity,

and systemic inflammation—rather than conventional lipid fractions such as LDL-cholesterol, HDL-cholesterol, or triglycerides—appear to be the main drivers of atrial fibrillation onset. Although atrial fibrillation was not identified in our pediatric athletic cohort, these data are relevant when interpreting lifestyle- and metabolism-related findings, particularly stimulant consumption and early metabolic profiling, as potential contributors to arrhythmic vulnerability [35, 36]. Other authors state that Grosu et al. (2025) reported that these findings are consistent with previous research demonstrating that mental and cognitive stimuli can induce measurable autonomic responses, including variations in heart rate and cardiovascular activation, even in the absence of physical effort, reflecting sympathetic and parasympathetic modulation in young athletes [37]. Importantly, the proposed inflammatory and autonomic pathways may represent shared substrates linking metabolic disturbances to rhythm disorders across age groups, supporting the need for early preventive strategies even in young athletic populations [34].

4.2. Study Limitations

Several limitations should be acknowledged. The relatively small sample size (n = 80) and the single-center design limit both the statistical power and the generalizability of the findings. This study was intentionally designed as a prospective, exploratory investigation aimed at identifying clinically relevant patterns and hypothesis-generating associations rather than establishing definitive predictors of sudden cardiac death; therefore, no a priori sample size calculation was performed, and post-hoc power analysis was not undertaken due to its limited interpretative value in observational exploratory studies. Additionally, the wide pediatric age range encompasses heterogeneous stages of cardiac maturation, and the absence of age-stratified analyses may have masked age-specific differences in arrhythmia patterns.

In addition, the study relied partially on self-reported data, which may be subject to recall bias, particularly regarding symptoms, stimulant consumption, and family history of sudden cardiac death. Long-term follow-up compliance was low, restricting the ability to assess the progression and clinical significance of identified arrhythmias over time. Finally, the absence of systematic genetic testing and advanced cardiac imaging in all participants may have led to an underestimation of underlying arrhythmogenic substrates, underscoring the need for future larger, multicenter studies with extended follow-up and comprehensive diagnostic protocols.

Additionally, the absence of a non-athlete control group limits the ability to determine whether the observed rhythm disorders are specific to athletic participation or reflect background arrhythmia prevalence in the general pediatric population.

5. Conclusions

This study identified a predominantly male, urban-based cohort of pediatric athletes, yet revealed a higher incidence of CRD among female participants, diverging from most published data. Perinatal pathology did not directly influence the number of subsequent hospitalizations or the incidence of arrhythmias, although neonatal respiratory distress was associated with increased respiratory morbidity in early childhood.

Among potentially arrhythmogenic symptoms, precordial pain emerged as the most prevalent, followed by palpitations and lipothymic episodes. Importantly, all athletes reporting precordial pain were diagnosed with CRD on Holter ECG, with a strong and statistically significant correlation confirmed by Spearman analysis. This finding underscores the critical role of systematic anamnestic screening for chest pain in athletes, even in those perceived as clinically healthy. Lipothymic episodes were rare; however, one case was associated with WPW syndrome, highlighting their potential prognostic relevance.

A family history of SCD was identified as a relevant risk factor, with a prevalence comparable to that reported in the literature. In contrast, dietary habits, BMI, and

mild hyperglycemia were not associated with an increased incidence of CRD in this cohort.

Lifestyle factors showed notable effects: coffee consumption was strongly associated with arrhythmias, including sinus tachycardia and ventricular rhythm disturbances, while the combined use of vitamins and immunostimulants was uniformly associated with cardiac rhythm abnormalities.

Despite generally preserved exercise tolerance, five athletes were withdrawn from competitive sports due to the identification of arrhythmias with a high risk of sudden cardiac death—two with WPW syndrome, two with ventricular tachycardia, and one with complete atrioventricular block—emphasizing the preventive value of structured cardiovascular screening in young athletes. However, compliance with follow-up monitoring was low, with fewer than one quarter of participants attending reassessment visits.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CRD	cardiac rhythm disorders
CV	Cardiac arrhythmias
SCD	Sudden cardiac death
WPW	Wolff–Parkinson–White

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