

Role of ivabradine in postoperative tachyarrhythmias after congenital cardiac surgery

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Abstract

BACKGROUND

Postoperative tachyarrhythmias are a common complication following congenital cardiac surgery. Junctional ectopic tachycardia (JET) is the most frequent arrhythmia, often linked to heightened automaticity. Ivabradine, a selective inhibitor of the funny current (HCN4), has recently gained attention for its potential role in managing automatic tachyarrhythmias. Standard antiarrhythmic therapies, such as amiodarone, are limited by significant side effects.

METHODS

This retrospective study was conducted at a high-volume cardiac center between January 2024 and June 2025. 55 patients developed postoperative tachyarrhythmias who were treated with ivabradine at 0.2 mg/kg/dose, either as monotherapy or in combination with other antiarrhythmic agents. Patients with postoperative ventricular tachycardia were excluded.

RESULTS

Among 55 patients, the most common arrhythmia was JET (n = 42), followed by ectopic atrial tachycardia (n = 5), premature atrial contractions (n = 5), and inappropriate sinus tachycardia (n = 3). Overall, 69% of patients were successfully managed with ivabradine monotherapy, while 31% required adjunctive therapy, most commonly amiodarone. Patients requiring adjunctive therapy were more difficult to achieve rhythm control and had longer ICU and hospital durations (72 hours vs 24 hours, $p < 0.001$). No significant hemodynamic compromise or adverse effects associated with ivabradine were observed.

CONCLUSION

Ivabradine monotherapy is effective for the majority of postoperative automaticity-driven tachyarrhythmias in patients undergoing congenital cardiac surgery who are hemodynamically stable. However, adjuvant therapy to ivabradine might be needed, especially in patients at risk for deteriorated condition.

Background

Postoperative tachyarrhythmias are common after congenital cardiac surgery, with a reported incidence ranging from 8% to 47% (1). These arrhythmias, if not managed appropriately, are a significant cause of morbidity and mortality. The underlying mechanisms of common postoperative tachyarrhythmias, such

as junctional ectopic tachycardia (JET) and ectopic atrial tachycardia (EAT), are often linked to heightened automaticity (2).

A variety of pharmacological agents are employed to manage postoperative arrhythmias in patients with congenital heart disease (CHD), including amiodarone, procainamide, and sotalol (3). However, these therapies may be limited by significant side effects, especially in low-resource settings where advanced interventions such as extracorporeal membrane oxygenation (ECMO) are not available (4). Recently, growing evidence supports the use of ivabradine in patients with postoperative junctional ectopic tachycardia and in those with ectopic atrial tachycardia, with no significant side-effect profile or hemodynamic derangement (5, 6).

This study aims to highlight the role of ivabradine in the management of postoperative tachyarrhythmias and their immediate outcome.

Methodology

Study Design

Single-center retrospective observational study.

Ethics

The study adheres to the ethical guidelines outlined by the Declaration of Helsinki, and the study was approved by the institutional review board (IRB-89/2025). The IRB waived written informed consent as anonymous data were accessed.

Setting

The study was conducted at the National Institute of Cardiovascular Diseases, Karachi, Pakistan.

Participants

We extracted de-identified data of pediatric/congenital cardiac patients who developed postoperative tachyarrhythmias and were treated with ivabradine between January 2024 and June 2025. Patients with a previous history of preoperative tachyarrhythmia were excluded from the study.

Variables

As per routine institutional practice, all postoperative patients had atrial and ventricular epicardial temporary pacing wires placed after surgery. Patients underwent a 12-lead ECG immediately after transferring to the cardiac ICU. For patients with tachyarrhythmia, a 12-lead ECG was repeated, with additional atrial electrograms recorded from temporary epicardial atrial pacing wires, in cases where the diagnosis was not certain based on the 12-lead ECG. When atrial electrograms were obtained, the relationship between atrial and ventricular activity was assessed to assist in differentiating junctional

from atrial tachyarrhythmias, including assessment for atrioventricular dissociation. When appropriate, adenosine administration was used to aid in diagnostic confirmation.

Data Sources/Measurement

All patients with junctional ectopic tachycardia (JET) were managed as per the routine institutional practice. The management strategy included core body cooling to the recommended target temperature of 34–35°C, followed by optimization of serum electrolytes, correction of fever, anemia, and acidosis, reduction of inotropic support, sedation, and preload augmentation (7), followed by oral ivabradine administration at a dose of 0.2 mg/kg/dose, when unresponsive to the initial measures. In cases of hemodynamic instability or sustained heart rates exceeding 170 bpm, despite at least one hour of ivabradine treatment, as well as in those experiencing tachyarrhythmias other than JET, management was adjusted according to the recommendations of a Pediatric Electrophysiologist. The duration from initiation of ivabradine therapy to treatment success (rate/rhythm control) was assessed for all cases. Hemodynamic status at the onset of tachyarrhythmia was assessed using the institutional inotropic score, and patients were subsequently categorized according to whether ivabradine was used alone or required adjunctive antiarrhythmic therapy.

Study Size

Analysis was conducted for a consecutive sample of patients fulfilling the inclusion criteria between January 2024 and June 2025. A total of 1100 pediatric congenital cardiac surgeries were performed during the study period, and 56 patients were prescribed ivabradine for postoperative tachyarrhythmias, but one patient had a previous history of atrial arrhythmia, which was excluded from the study; hence, 55 patients were enrolled in this study.

Statistical Methods: Data were analyzed and compiled using IBM SPSS (Version 21). Data were summarized as either mean $\pm$ standard deviation (SD) or median [interquartile range (IQR)] and frequency (%). Patients were further categorized into two groups based on management strategy: ivabradine alone and combination. Chi-square test and Fisher's exact test were used to compare the differences in proportions between the two groups. Independent-samples t-tests and Mann-Whitney U tests will be used for the comparison of continuous variables. A p-value < 0.05 will be accepted as statistically significant.

Results

In this retrospective study, 55 patients developed postoperative tachyarrhythmias and were treated with ivabradine, either as monotherapy or in combination with other antiarrhythmic agents. The cohort comprised 54.5% males and 45.5% females, with a median age of 5 years (IQR: 3–8 years) and a median weight of 14.5 kg (IQR: 11–18 kg). Detailed demographic and patient characteristics are shown in Fig. 1 (A–C). The most common arrhythmia was junctional ectopic tachycardia (JET), diagnosed in 42 patients. Other diagnoses included ectopic atrial tachycardia (EAT) in 5 patients, premature atrial

contractions (PACs) in 5 patients, and inappropriate sinus tachycardia in 3 patients. Of these, 38 patients received ivabradine monotherapy, while 17 required combination therapy with additional antiarrhythmic drugs, as illustrated in Table 1.

Regarding treatment, 28 of 42 patients with JET were managed successfully with ivabradine alone, whereas 14 required adjunctive amiodarone. Among the 5 patients with EAT, 3 responded to ivabradine monotherapy, while 2 required combination therapy, one with a beta-blocker and the other with flecainide along with ivabradine. All 3 patients with inappropriate sinus tachycardia were treated with ivabradine alone. Out of the 5 patients with PACs, 4 responded to ivabradine monotherapy, while 1 required the addition of a beta-blocker. There were no differences in preoperative diagnosis between patients treated with monotherapy and those treated with combination therapy.

The maximum heart rate at arrhythmia onset was higher in the combination therapy group (175.1 ± 18.4 bpm) compared with the monotherapy group (166.1 ± 16.1 bpm). Time to sinus rhythm reversion was significantly longer in the combination group (72 hours) compared with the Ivabradine-only (24 hours) ($p < 0.001$). Similarly, the median length of ICU and postoperative hospital stay was significantly longer in the combination group. However, there were no differences in inotropic scores at arrhythmia onset (8.8 ± 3.3 vs 8.7 ± 3.2).

Table 1
Diagnosis, clinical presentation, treatment, and follow-up

	Medical Therapy (Group)			P-value
	Total	Ivabradine alone	Combination	
Total (N)	55	38	17	
Diagnosis				
ATRIAL TACHYCARDIA	5 (9.1%)	3 (7.9%)	2 (11.8%)	
JET	42 (76.4%)	28 (73.7%)	14 (82.4%)	
PACS	5 (9.1%)	4 (10.5%)	1 (5.9%)	
INAPPROPRIATE SINUS TACHYCARDIA	3 (5.5%)	3 (7.9%)	0 (0%)	
Bi-Pass Time (Mins)	92.9 ± 31.5	87.6 ± 30.6	104.6 ± 31.2	0.063
Cord Clamp Time (Mins)	56.9 ± 22.9	55.1 ± 22.5	60.8 ± 24	
Onset of Post-Operative Arrhythmia (Hrs.)	24 [24–48]	24 [24–48]	48 [24–48]	
HR at Rhythm Abnormality Onset (Min)	124.2 ± 10.2	122.6 ± 10.3	127.8 ± 9.2	0.075
Maximum HR at Onset of Arrhythmia. (Min)	168.9 ± 17.2	166.1 ± 16.1	175.1 ± 18.4	0.075
Inotropic Score At Rhythm Abnormality	8.8 ± 3.3	8.8 ± 3.3	8.7 ± 3.2	0.900
Medical Therapy				
IVABRADINE + BB	2 (3.6%)	0 (0%)	2 (11.8%)	-
IVABRADINE MONOTHERAPY	38 (69.1%)	38 (100%)	0 (0%)	
IVABRADINE+AMIODARONE	14 (25.5%)	0 (0%)	14 (82.3%)	
IVABRADINE + FLECAINIDE	1 (1.8%)	0 (0%)	1 (5.9%)	
Reversion of Sinus Rhythm (Hours)	48 [24–50]	24 [24–48]	72 [48–96]	< 0.001
Total Number of Days Of Stay In PICU	4 [2–6]	3 [2–4]	5 [4–7]	0.001
Duration of Post-Operative Hospital Stay (Days)	6 [5–9]	5.5 [4–7]	9 [8–11]	0.001

Discussion

This study aims to contribute to the growing body of evidence on the use of ivabradine for postoperative tachyarrhythmias following congenital cardiac surgery by presenting our clinical experience. Ivabradine has gained increasing attention among cardiologists and electrophysiologists for its potential role in managing automatic tachycardias, such as ectopic atrial tachycardia and postoperative junctional ectopic tachycardia (JET) (8).

Junctional ectopic tachycardia, EAT, AT, and sinus tachycardia may involve enhanced automaticity but have distinct electrophysiological mechanisms. While sinus tachycardia and EAT are largely related to I_f -mediated pacemaker activity, postoperative JET involves injury- and catecholamine-associated abnormal automaticity and altered calcium handling. Therefore, ivabradine role in JET should not be directly extrapolated from its established I_f -mediated effects and remains mechanistically incompletely understood. Our findings extend this knowledge by demonstrating its utility not only in postoperative JET but also in other multifactorial enhanced-automaticity arrhythmias, including premature atrial contractions (PACs), ectopic atrial tachycardia (EAT), and inappropriate sinus tachycardia.

Amiodarone has traditionally been the most used treatment; however, its utility is limited by a significant side-effect profile, especially in the pediatric population—particularly hypotension (9), which poses challenges in resource-limited settings without access to advanced life support such as ECMO (10). This has prompted the search for safer alternatives with a less adverse effect profile. Ivabradine, a selective inhibitor of hyperpolarization-activated cyclic nucleotide-gated (HCN4) channels, demonstrates significant potential in managing automaticity-driven arrhythmias due to its minimal impact on cardiac function and hemodynamics. Postoperative JET is primarily related to enhanced AV-junctional automaticity following surgical injury, involving multiple ionic currents, including calcium-dependent mechanisms. Although I_f is not the primary driver of JET, it may contribute to diastolic depolarization in junctional pacemaker tissue. By inhibiting I_f through HCN channels, ivabradine may reduce abnormal junctional firing. Thus, I_f inhibition may represent one component of the multifactorial mechanism underlying ivabradine effect in JET (11).

Arvind et al. demonstrated the non-inferiority of oral ivabradine compared with IV amiodarone in patients with postoperative JET (12). Although our results also demonstrate the efficacy of oral ivabradine in patients with JET, a substantial percentage of patients required combination therapy. One reason for the high efficacy of ivabradine reported by Arvind et al. could be the exclusion of patients with multiorgan dysfunction in their study because the bioavailability of oral ivabradine was affected in patients with hemodynamic instability and multiorgan dysfunction (13), which could explain the lower success rate of ivabradine in our cohort. Our experience shows that 66.66% of patients with JET can be successfully managed with ivabradine alone, while 33.33% required additional amiodarone therapy. The patients who received amiodarone were those with unstable hemodynamics or persistently elevated heart rates despite ivabradine, likely due to low cardiac output interfering with oral drug absorption (14). Because ivabradine was administered orally, impaired gastrointestinal absorption may potentially influence its clinical response in critically ill postoperative patients with reduced cardiac output. In our cohort, patients requiring combination therapy had a longer time to rhythm control and higher maximum heart

rates at arrhythmia onset, although baseline inotropic scores were not significantly different between treatment groups. As serum ivabradine concentrations and pharmacokinetic parameters were not measured, the contribution of impaired absorption to delayed or inadequate response cannot be established. These findings should therefore be interpreted as clinical associations rather than evidence of altered ivabradine pharmacokinetics.

There is also growing evidence of ivabradine use in patients with non-postoperative automatic tachycardias (15). Our results extend this knowledge by demonstrating its effectiveness in postoperative automatic tachyarrhythmias other than JET. Fifteen patients with such arrhythmias, 10 were treated successfully with ivabradine alone. These findings are in line with prior reports supporting the efficacy of ivabradine in ectopic atrial tachycardia and inappropriate sinus tachycardia (6, 16, 17). Furthermore, patients managed with ivabradine monotherapy had shorter median PICU and hospital stays compared with those receiving combination therapy, likely attributable to the greater severity of illness among patients requiring combination treatment.

Early studies have established ivabradine efficacy in congenital JET (18, 19), and further evidence supports its benefits in focal atrial tachycardias in post-congenital surgery patients (6). Our findings reinforce these observations and extend knowledge in postoperative PACs and inappropriate sinus tachycardia, emphasizing ivabradine effectiveness both as monotherapy and in combination with beta-blockers or amiodarone for postoperative tachyarrhythmias. Overall, our experience highlights that oral ivabradine is an effective therapeutic option for postoperative pediatric patients with automaticity-driven arrhythmias, particularly with hemodynamic stable patients, while combination therapy is needed for hemodynamically unstable patients or patients at high risk of deterioration.

Study limitations

Data on the use of ivabradine alone and in combination with other antiarrhythmic medications in the postoperative tachyarrhythmias in pediatric congenital cardiac surgeries are limited, and larger clinical trial studies are warranted before a change in protocol for treatment of postoperative tachyarrhythmias. Furthermore, our study is retrospective; the absence of a control group in the study is one of the other limitations.

Conclusion

Ivabradine monotherapy is effective for the majority of postoperative tachyarrhythmias after congenital cardiac surgery in hemodynamically stable patients. However, adjuvant therapy to ivabradine might be needed, especially in hemodynamically unstable patients.

Abbreviations

Hyperpolarization-activated cyclic nucleotide-gated Channel (HCN4)

Junctional ectopic tachycardia (JET)

Ectopic atrial tachycardia (EAT)

Premature atrial contractions PAC

Congenital heart disease (CHD)

Extracorporeal membrane oxygenation (ECMO)

Declarations

Conflict of interest: None

Clinical trial number: not applicable

Ethics statement

This retrospective study was approved by the institutional ethics review committee and IRB (IRB-89/2025) and conducted in accordance with the Declaration of Helsinki (1975, revised 2008).

Patient consent

Informed consent was exempted because of the retrospective nature of the study.

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Consent for publication

Consent form has been obtained from the patients/attendants for publication.

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Figures

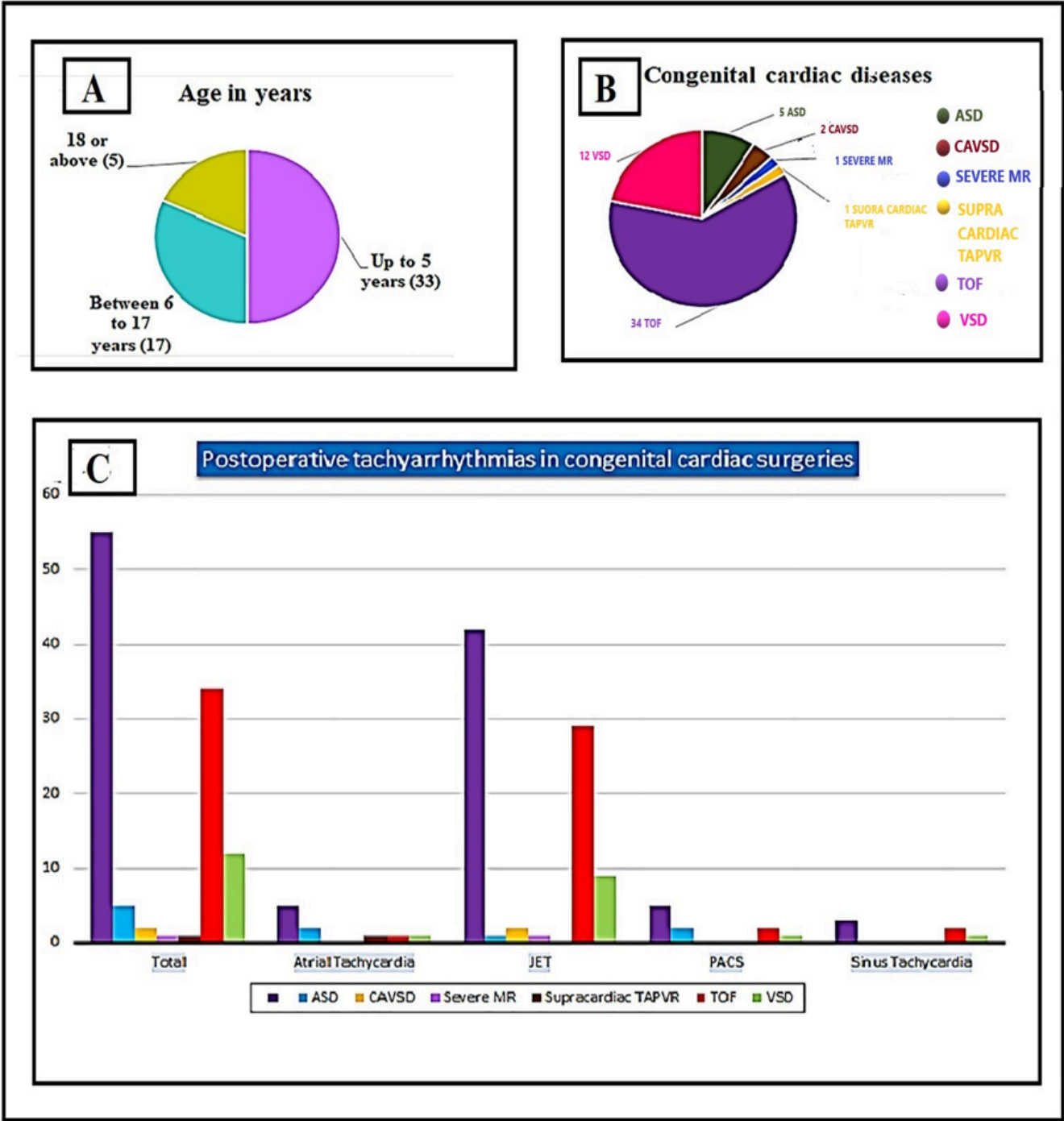


Figure 1

Results of our study [1A-1B] showing the demographics of patients, including age and primary cardiac diagnosis. [1C] indicating the postoperative tachyarrhythmias (JET, EAT, PACs, and inappropriate sinus

tachycardia) in relation to preliminary structural heart defects.

Supplementary Files

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