The Egyptian Journal of Hospital Medicine (July 2025) Vol. 100, Page 4323-4328

Holter and ECG Changes after Transcatheter Closure of VSD in Children

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ABSTRACT

Background: Ventricular septal defect (VSD) is a common congenital heart defect in children, and transcatheter VSD closure is a widely used treatment. However, its impact on cardiac rhythm and conduction remains uncertain, necessitating further evaluation.

Aim: To assess the changes in heart rate (HR) and electrocardiographic parameters following transcatheter VSD closure in children, with particular focus on the risk of arrhythmias and conduction abnormalities.

Patients and Methods: This prospective observational study was conducted on 76 children diagnosed with VSD who underwent transcatheter VSD closure. Demographic data, medical history, and electrocardiographic parameters were collected before and after the procedure. Pre- and post-procedural 12-lead ECG and Holter monitoring were performed, and follow-up evaluations were conducted at 1 month, 6 months, and 1 year post-procedure.

Results: The study found a significant reduction in heart rate (HR) post-procedure, with sustained lower HR at 1 month, 6 months, and 1 year compared to pre-procedural values ($P < 0.05$). Significant decreases were also observed in RV5, RV5+SV1, and SV1 at 1 month, 6 months, and 1 year ($P < 0.05$). RR intervals increased significantly post-procedure and at all follow-up intervals ($P < 0.05$). No significant differences were noted in PR interval, QRS duration, QTc interval, or cardiac axis deviation. Arrhythmic events were rare, with one patient developing complete heart block 1 year post-procedure.

Conclusion: Transcatheter VSD closure in children is associated with significant reductions in heart rate and improvements in heart rate variability. However, it does not significantly alter key ECG parameters, and long-term monitoring is important due to the risk of arrhythmias.

Keywords: Ventricular septal defect, Transcatheter VSD closure, Electrocardiogram, Holter monitoring, Heart rate variability.

INTRODUCTION

Ventricular septal defects (VSDs) are among the most common congenital heart defects in children, accounting for approximately 20-30% of all congenital heart diseases. These defects are characterized by an abnormal opening in the septum that divides the left and right ventricles of the heart, leading to abnormal blood flow between the two chambers. The size and location of the VSD play a crucial role in determining the severity of symptoms, ranging from mild to severe. While small VSDs may close spontaneously or remain asymptomatic, larger defects can lead to significant hemodynamic disturbances, pulmonary hypertension, and heart failure if left untreated [1].

Over the past two decades, transcatheter closure of VSDs has emerged as a less invasive alternative to traditional open-heart surgery, providing a promising option for children with certain types of VSDs. The procedure involves the insertion of a device through a catheter to seal the defect, offering several advantages over surgery, including shorter recovery times, reduced hospital stays, and fewer complications. The advent of this technology has led to improved outcomes and has revolutionized the management of congenital heart defects, particularly in pediatric patients [2].

Holter monitoring and electrocardiogram (ECG) analysis are crucial tools in assessing the electrical stability of the heart both before and after interventional procedures. Holter monitors provide continuous, real-time electrocardiographic recordings over a 24-48 hour period, allowing for the detection of arrhythmias that may not be evident during a standard ECG. Studies have shown that children with congenital heart defects, including VSDs, are at an increased risk for arrhythmias due to altered myocardial structure and function [3].

Recent studies have highlighted various ECG changes following VSD closure, including alterations in conduction patterns, ventricular repolarization, and even the development of new arrhythmias. While some studies report transient changes in the ECG post-procedure, the clinical significance of these findings remains unclear [4].

The role of Holter monitoring in identifying these changes over a prolonged period remains underexplored, particularly in children who have undergone transcatheter VSD closure. This study aims to investigate the ECG and Holter changes that occur after VSD closure in pediatric patients, with a particular focus on the long-term implications for heart rhythm stability and the potential need for post-procedural monitoring or interventions.

PATIENTS AND METHODS

This prospective observational study was conducted in the Cardiac Catheterization Unit of the Pediatric Department at Sohag University Hospital.

The study included all children under the age of 18 years who were diagnosed with VSD and scheduled to undergo transcatheter VSD closure in line with current clinical guidelines for the management of VSDs.

Received: 29/04/2025
Accepted: 29/06/2025

Data Collection and Methodology

A comprehensive data collection protocol was followed for all patients. Demographic details, including the patient's name, age, sex, and residence, were recorded. A detailed general medical history was obtained, with special attention to any prior cardiac conditions or comorbidities that might influence the study's results.

All participants underwent a series of diagnostic tests before and after the transcatheter procedure. Pre- and post-procedural 12-lead ECGs were conducted using a Fukuda Denshi CardiMax ECG device (model FCP-7101, UK), set to a paper speed of 25 mm/s and a gain of 10 mm/mV.

Holter monitoring was also performed on the day before and the day after the procedure using a Mortara H3+ Holter ECG device. These tests were chosen to monitor both immediate and delayed changes in electrical conduction and rhythm following the VSD closure.

Follow-up and Monitoring

Follow-up evaluations were carried out at specified intervals after the procedure to assess both clinical status and electrical changes. ECG and Holter monitoring were repeated at 24 hours, 1 month, 6 months, and 12 months post-procedure. These follow-ups aimed to track any short- and long-term arrhythmias, conduction disturbances, or other electrical abnormalities that might arise following the VSD closure. This structured follow-up design was intended to provide comprehensive data on the cardiac outcomes associated with transcatheter VSD closure in children.

Ethical approval

The study was conducted in accordance with ethical principles for medical research, as outlined in the Declaration of Helsinki. Approval for the study was sought from the Medical Research Ethics Committee at Sohag University Hospital prior to its commencement. Informed written consent was obtained from the legal guardians of all participants. Children whose legal guardians were unable or unwilling to provide informed consent were excluded from the study, as obtaining written consent was a prerequisite for participation.

Statistical analysis

The statistical analysis was performed using SPSS version 26.0. The Shapiro-Wilks test and histograms were employed to determine the normality of the data distribution. Quantitative data were given as mean and standard deviation (SD) and range and evaluated using a paired t-test. Qualitative data were provided as frequency and percentage (%) and evaluated using the Chi-square test or Fisher's exact test, as applicable. A two-tailed P value of < 0.05 was considered statistically significant.

RESULTS

This study was conducted on 76 children diagnosed with ventricular septal defect (VSD) who underwent transcatheter VSD closure. The mean ± standard deviation (SD) age of the participants was 6.69 ± 3.25 years. Among the study cohort, 61.84% were females. The mean ± SD body mass index (BMI) of the children was 15.95 ± 3.19 kg/m² (Table 1).

Table (1): Demographic data of the studied patients

		n=76
Age (years)	**Mean ± SD**	6.69 ± 3.25
	Range	2 - 15
Sex	**Male**	29 (38.16%)
	Female	47 (61.84%)
BMI (kg/m^2)	**Mean ± SD**	15.95 ± 3.19
	Range	8.7 - 26.22

Heart rate (HR) was significantly lower post-procedure, at 1 month, 6 months, and 1 year compared to pre-procedural levels. These findings suggest a sustained decrease in HR following the transcatheter closure of VSD. In contrast, the PR interval, QRS duration, and QTc interval did not show any significant differences between pre-procedural, post-procedural, 1 month, 6 months, and 1 year measurements. The amplitude of the SV1 was significantly reduced at 1 month, 6 months, and 1-year post-procedure compared to pre-procedural values. However, the difference between pre-procedural and post-procedural SV1 was not statistically significant. For RV5 and RV5+SV1, a significant reduction was observed post-procedure, and at 1 month, 6 months, and 1 year compared to pre-procedural values. The RR interval was significantly higher post-procedure, at 1 month, 6 months, and 1 year compared to pre-procedural levels (Table 2).

Table (2): ECG measurements of the studied patients

		Pre transcatheter	Post transcatheter	After 1 month	After 6 months	After 1 year
HR (beats/min)	**Mean ± SD**	102.09 ± 17.76	97.14 ± 16.02	94.45 ± 12.73	95.81 ± 11.85	94.87 ± 10.95
	Range	62 - 166	69 - 142	68 - 122	69 - 120	70 - 120
P value compared to pre			**0.002***	**<0.001***	**0.001***	**<0.001***
PR interval (ms)	**Mean ± SD**	133.33 ± 16.69	131.22 ± 18.94	132.8 ± 17.59	133.2 ± 15.48	131.54 ± 14.89
	Range	100 - 189	80 - 195	100 - 200	100 - 180	100 - 180
P value compared to pre			0.220	0.771	0.781	0.378
QRS (ms)	**Mean ± SD**	91.87 ± 12.88	90.25 ± 14.73	91.38 ± 13.43	90.92 ± 11.79	90.03 ± 10.44
	Range	70 - 133	17 - 124	40 - 120	60 - 120	69 - 115
P value compared to pre			0.306	0.751	0.775	0.122
QTc (ms)	**Mean ± SD**	427.51 ± 23.66	427.45 ± 25.05	428.41 ± 21.75	426.77 ± 22.18	426.35 ± 22.7
	Range	369 - 492	370 - 498	374 - 490	365 - 490	360 - 485
P value compared to pre			0.980	0.729	0.822	0.768
RV5 (mV)	**Mean ± SD**	1.23 ± 0.53	1.06 ± 0.37	1.01 ± 0.37	1.11 ± 0.46	1.03 ± 0.44
	Range	0.31 - 3.8	0.45 - 2.5	0.18 - 2.2	0.2 - 3	0.2 - 3
P value compared to pre			**0.032***	**0.002***	**0.034***	**<0.001***
SV1 (mV)	**Mean ± SD**	1.04 ± 0.37	0.95 ± 0.42	0.83 ± 0.32	0.91 ± 0.35	0.89 ± 0.36
	Range	0 - 2.5	0.18 - 2.88	0.11 - 1.51	0.05 - 2	0.2 - 2
P value compared to pre			0.195	**0.001***	**0.016***	**0.005***
RV5+SV1 (mV)	**Mean ± SD**	2.27 ± 0.64	2.02 ± 0.56	1.84 ± 0.52	2.03 ± 0.63	1.91 ± 0.69
	Range	1.15 - 4.7	0.8 - 3.85	0.6 - 3.47	0.5 - 4.7	0.5 - 4.7
P value compared to pre			**0.007***	**<0.001***	**<0.001***	**<0.001***
RR (ms)	**Mean ± SD**	603.37 ± 105.93	626.78 ± 109.03	636.99 ± 95.18	625.89 ± 81.78	629.17 ± 84.79
	Range	361 - 967	400 - 857	423 - 882	423 - 845	430 - 857
P value compared to pre			**0.035***	**0.009***	**0.032***	**0.044***

*: significant as P value ≤ 0.05

Sinus tachycardia, as well as prolonged PR interval (first-degree heart block), prolonged QRS duration, and prolonged QTc, showed no significant differences between male and female participants during the follow-up period (Table 3).

Table (3): Comparison of ECG measurements among males and females

	Pre trans-catheter	Post trans-catheter	After 1 month	After 6 months	After 1 year
Sinus tachycardia					
Male (n=29)	4 (13.79%)	2 (6.9%)	0 (0%)	0 (0%)	0 (0%)
Female (n=47)	7 (14.89%)	5 (10.64%)	3 (6.38%)	1 (2.13%)	1 (2.13%)
P value between males and females	1.000	0.702	0.283	1.000	1.000
Prolonged PR interval measurements (First degree heart block)					
Male (n=29)	4 (13.79%)	3 (10.34%)	2 (6.9%)	3 (10.34%)	2 (6.9%)
Female (n=47)	4 (8.51%)	3 (6.38%)	1 (2.13%)	1 (2.13%)	2 (4.26%)
P value between males and females	0.472	0.669	0.554	0.152	0.634
Prolonged QRS duration					
Male (n=29)	8 (27.59%)	9 (31.03%)	10 (34.48%)	8 (27.59%)	6 (20.69%)
Female (n=47)	11 (23.4%)	9 (19.15%)	8 (17.02%)	9 (19.15%)	6 (12.77%)
P value between males and females	0.683	0.611	0.082	0.391	0.357
Prolonged QTC duration					
Male (n=29)	3 (10.34%)	3 (10.34%)	2 (6.9%)	1 (3.45%)	1 (3.45%)
Female (n=47)	11 (23.4%)	6 (12.77%)	5 (10.64%)	5 (10.64%)	3 (6.38%)
P value between males and females	0.225	1.000	0.702	0.398	1.000

Cardiac axis deviation was also unaffected by the procedure, showing no significant difference between pre-procedural, post-procedural, 1 month, 6 months, and 1 year measurements. Furthermore, no significant gender differences were noted in cardiac axis deviation at any point during the study (Table 4).

Table (4): Cardiac axis deviation measurements of the studied patients

		Pre trans-catheter	Post trans-catheter	After 1 month	After 6 months	After 1 year
Total (n=76)	**Normal**	67 (88.16%)	69 (90.79%)	68 (89.47%)	67 (88.16%)	70 (92.11%)
	RAD	2 (2.63%)	1 (1.32%)	1 (1.32%)	1 (1.32%)	1 (1.32%)
	LAD	7 (9.21%)	6 (7.89%)	7 (9.21%)	8 (10.53%)	5 (6.58%)
P value compared to pre			0.803	0.843	0.819	0.693
Male (n=29)	**Normal**	26 (89.66%)	26 (89.66%)	25 (86.21%)	25 (86.21%)	26 (89.66%)
	RAD	1 (3.45%)	1 (3.45%)	1 (3.45%)	1 (3.45%)	1 (3.45%)
	LAD	2 (6.9%)	2 (6.9%)	3 (10.34%)	3 (10.34%)	2 (6.9%)
Female (n=47)	**Normal**	41 (87.23%)	43 (91.49%)	43 (91.49%)	42 (89.36%)	44 (93.62%)
	RAD	1 (2.13%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	LAD	5 (10.64%)	4 (8.51%)	4 (8.51%)	5 (10.64%)	3 (6.38%)
P value between males and females		0.817	0.430	0.419	0.440	0.436

RAD: right axis deviation, LAD: left axis deviation.

One patient (1.3%) presented with ventricular bigeminy before the procedure, which persisted throughout the entire follow-up period. Another patient (1.3%) had a low atrial rhythm with frequent atrial ectopic beats pre-procedure, which completely resolved following VSD closure. Additionally, one patient (1.3%) developed complete heart block one year after the procedure. Regarding Holter measurements, HR was significantly lower at 1 month, 6 months, and 1 year compared to pre-procedural values. However, no significant difference was found between pre- and post-procedural HR. The QT and QTc intervals were significantly lower post-procedure, at 1 month, 6 months, and 1 year compared to pre-procedural values. Moreover, parameters associated with heart rate variability, including pNN50%, RMSSD, SDNN, SDANN, and Tri, showed significant improvement post-procedure and at all follow-up intervals. These findings indicate an overall improvement in autonomic regulation following VSD closure (Table 5).

Table (5): Holter measurements of the studied patients

		Pre transcatheter	Post transcatheter	After 1 month	After 6 months	After 1 year
HR (beats/min)	**Mean ± SD**	96.66 ± 8.95	97.64 ± 10.98	93.59 ± 11.06	91.14 ± 10.98	89.55 ± 11.01
	Range	74 - 109	70 - 118	67 - 115	65 - 113	63 - 111
P value compared to pre			0.392	**0.010***	**<0.001***	**<0.001***
QT (ms)	**Mean ± SD**	338.13 ± 26.54	333.28 ± 26.92	331.2 ± 27.03	329.3 ± 26.97	327.93 ± 26.97
	Range	282 - 399	276 - 395	273 - 393	272 - 392	270 - 391
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***
QTc (ms)	**Mean ± SD**	401.67 ± 16.86	394.14 ± 17.37	392.17 ± 17.32	390.22 ± 15.37	388.79 ± 15.34
	Range	371 - 435	365 - 420	362 - 417	358 - 419	356 - 418
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***
pNN50%	**Mean ± SD**	2.55 ± 1.91	4.95 ± 1.94	5.91 ± 2.23	6.92 ± 2.34	7.92 ± 2.66
	Range	0 - 7	2 - 10	2 - 12	3 - 14	3 - 16
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***
RMSSD	**Mean ± SD**	27.41 ± 9.78	38.75 ± 9.81	43.75 ± 9.63	49.54 ± 9.89	54.46 ± 10.11
	Range	11 - 44	19 - 57	26 - 62	30 - 67	35 - 72
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***
SDNN	**Mean ± SD**	36.54 ± 14.71	53.74 ± 15.38	71.26 ± 15.14	88.82 ± 15.95	99.08 ± 16.29
	Range	14 - 68	26 - 87	43 - 107	57 - 132	66 - 146
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***
SDANN	**Mean ± SD**	37.61 ± 12.12	57.26 ± 12	77.71 ± 12.92	95.32 ± 12.78	113.26 ± 12.46
	Range	18 - 60	33 - 85	50 - 105	65 - 121	84 - 139
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***
Tri	**Mean ± SD**	10.29 ± 3.44	13.34 ± 3.66	14.93 ± 3.66	16.43 ± 3.8	17.86 ± 3.87
	Range	6 - 18	9 - 21	10 - 23	11 - 25	13 - 27
P value compared to pre			**<0.001***	**<0.001***	**<0.001***	**<0.001***

HR: heart rate, RMSSD: root mean square of successive differences, SDNN: standard deviation of the IBI of normal sinus beats, SDANN: standard deviation of 5-minute average NN intervals, *: significant as P value ≤ 0.05.

DISCUSSION

This study included 76 pediatric patients diagnosed with VSD, who underwent transcatheter VSD closure. The mean age of participants was approximately 6.7 years (range: 2–15 years), with a notable female predominance (61.84%). This gender distribution aligns with trends seen in other studies involving pediatric VSD closure. However, **Yang *et al.*** [5] conducted a large-scale study with 229 pediatric patients, predominantly with perimembranous VSD, and found a nearly even gender split (51.5% males, 48.5% females), which is in contrast to our cohort, which showed a more pronounced female predominance. The average age of their cohort was 6.3 years, which is closely aligned with our mean of 6.7 years. Similarly, in a multi-institutional study by **Wang *et al.*** [6], which included 525 children aged 2 to 12 years (mean age: 5.6 years), the demographic distribution showed a comparable mean age but with a broader age range.

Our study showed a significant reduction in HR from 102.09 ± 17.76 bpm pre-procedure to 94.87 ± 10.95 bpm at the 1-year follow-up ($p < 0.001$), indicating stabilization of cardiac rhythm and reduced cardiac workload after the procedure. This finding is consistent with the results of **Xiao *et al.*** [7] who observed a similar reduction in HR from 103.5 ± 13.4 bpm to 95.1 ± 11.2 bpm in a cohort of 165 patients undergoing transcatheter VSD closure. Additionally, metrics of HRV, such as SDNN and SDANN, showed significant increases in our study, suggesting improved autonomic regulation. These results are in line with studies like **Özyılmaz *et al.*** [8] who found that HRV improved in children after ASD closure, with an increase in SDNN (from 41.2 ± 9.4 ms to 58.3 ± 15.2 ms) and SDANN (from 35.5 ± 7.5 ms to 51.8 ± 13.6 ms) in a cohort of 47 children.

ECG parameters, including PR interval, QRS duration, and QTc interval, remained stable in our cohort, which is a reassuring finding regarding the safety of the procedure. Pre- and post-procedure PR intervals in our study ranged from 100 to 189 ms, showing no significant changes ($p > 0.05$), which is in agreement with **Komar *et al.*** [9] who studied 235 children undergoing transcatheter ASD closure and reported only minimal changes in PR and QRS intervals, with transient first-degree AV block in a very small number of patients (2%). Additionally, **Singab *et al.*** [10] evaluated 358 pediatric patients undergoing transcatheter VSD closure and found that arrhythmias were generally mild and transient, with no significant long-term conduction abnormalities.

Our study also found a reduction in RV5 amplitude from 1.23 ± 0.53 mV pre-procedure to 1.03 ± 0.44 mV at 1-year follow-up, indicating reduced ventricular strain, a result consistent with **Khoshhal *et al.*** [11] who reported a reduction in RV5 from 1.31 ± 0.54 mV to 1.08 ± 0.42 mV in a cohort of 70 children with muscular and perimembranous VSDs after closure. This reduction in ventricular workload supports the notion that transcatheter VSD closure improves hemodynamics and reduces the risk of complications like ventricular hypertrophy over time.

Our study observed a significant increase in the RR interval post-procedure, reflecting improved autonomic regulation and a reduction in physiological stress. This is consistent with findings from **Zheng *et al.*** [12] who followed 139 pediatric patients over an 84.5-month period and documented significant stabilization in HRV and conduction parameters after VSD closure. They reported an increase in the RR interval from 914 ± 122 ms to 926 ± 98 ms, similar to our results.

Sinus tachycardia was present in 13.79% of males and 14.89% of females pre-procedure, with significant reductions observed post-procedure. This mirrors findings from **Zheng *et al.*** [12] who documented similar declines in arrhythmic incidence, with sinus tachycardia decreasing from 15% to 5% in their cohort of 139 patients after transcatheter closure. Furthermore, **Banerjee and Mitra** [13] in their retrospective analysis of 100 children with congenital heart disease observed a 60% reduction in tachyarrhythmia after transcatheter interventions, further supporting the procedure's efficacy in reducing arrhythmia rates.

Right Bundle branch block (RBBB) was the most common arrhythmia observed pre-procedure, particularly incomplete RBBB. In our cohort, the incidence of RBBB increased from 23.4% in females and 27.5% in males pre-procedure to 31% in males and 19% in females one day post-procedure. By the 1-year follow-up, the incidence dropped to 20.6% in males and 12.7% in females. These findings are consistent with the study by **Zhao *et al.*** [14] who observed that 16.5% of patients with perimembranous VSD developed bundle branch block post-procedure, with RBBB being the most common type (10.5%), and left bundle branch block being rare (2.3%). Zhang suggested that the size and placement of the occluder may influence the risk of conduction disturbances.

Additionally, a few cases in our study presented with more serious arrhythmias, including ventricular bigeminy (1.3%) and complete heart block (1.3%), which persisted throughout the follow-up period. These findings align with the work of **Tang *et al.*** [15] who proposed a predictive strategy using 3D electroanatomic mapping to identify patients at higher risk for arrhythmic events during VSD closure. Their study demonstrated that a distance of less than 2 mm between the VSD and the His-Purkinje system significantly increases the risk of conduction abnormalities, suggesting that careful patient selection and procedural planning are crucial in preventing arrhythmic complications.

In our study Holter monitoring observed significant post-procedural improvements in heart rate variability (HRV), including increases in RMSSD,

SDNN, SDANN, and the Triangular Index, suggesting enhanced autonomic regulation. These results align with **Li *et al.*** [16] who found similar increases in HRV parameters following VSD closure, with SDNN and SDANN approaching control group levels, indicating a normalization of autonomic function. Likewise, **Özyılmaz *et al.*** [8] reported that HRV metrics in children after ASD closure reached control group levels within six months, highlighting the potential for rapid recovery in pediatric populations.

In a recent study, **Su *et al.*** [17] observed significant improvements in SDNN and SDANN in patients with ASD following transcatheter closure, particularly in those with elevated right ventricular systolic pressure. This suggests that baseline cardiovascular load influences HRV recovery, with higher pre-procedural right ventricular pressure leading to more substantial improvements.

Our study of Holter monitoring also found a significant decrease in QTc intervals following VSD closure, consistent with findings from **Özyildirim and Heper** [18] who noted that coronary interventions reduce QT dispersion and correlate this with improved HRV. Similarly, **Santhanam *et al.*** [19] reported reductions in QTc and improvements in HRV post-ASD closure, indicating better repolarization stability and a reduced arrhythmogenic risk.

However, the study has several limitations. The relatively small sample size (76 participants) and the predominance of female patients may limit the generalizability of the results. Additionally, the follow-up period of one year, while useful for assessing early outcomes, may not capture long-term complications such as delayed arrhythmias or ventricular remodeling. Future research should include larger, multicenter cohorts with extended follow-up periods to assess the long-term impact of VSD closure, particularly with respect to growth-related changes in the heart and the risk of late-onset arrhythmias.

CONCLUSION

Our study provides robust evidence supporting the safety and efficacy of transcatheter VSD closure in pediatric patients. The procedure resulted in significant improvements in HRV, a reduction in ventricular strain, and the stabilization of cardiac conduction, which suggests favorable short-term outcomes in terms of cardiac function and overall heart health.

Financial support and sponsorship: Nil.
Conflict of Interest: Nil.

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