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Impact of Transcatheter Perimembranous Ventricular Septal Defect Closure on Tricuspid Regurgitation and Cardiac Remodeling in Pediatric Patients: A Prospective Observational Study

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Research Article

Keywords: Ventricular septal defect, Tricuspid regurgitation, Transcatheter closure

Posted Date: June 3rd, 2025

DOI: https://doi.org/10.21203/rs.3.rs-6757603/v1

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Additional Declarations: No competing interests reported.

Abstract

Background: Tricuspid regurgitation (TR) secondary to perimembranous ventricular septal defect (pmVSD) is commonly observed in pediatric patients and may improve following defect closure. This study aimed to evaluate the impact of transcatheter pmVSD closure on the severity of TR and cardiac remodeling in children**.**

Methods: A prospective observational study was conducted on 55 pediatric patients with hemodynamically significant pmVSD and at least mild TR, treated at Minya University Hospital and the National Heart Institute between September 2023 and March 2025. Patients underwent transcatheter closure under echocardiographic and fluoroscopic guidance. Transthoracic echocardiography was performed at baseline, follow-ups at 1, and 6 months assessed TR severity, left ventricular end diastolic/systolic dimensions (LVEDD, LVESD), and ejection fraction (LVEF). Statistical analyses used (SPSS v26).

Results: Significant reductions in TR severity were observed post-procedure: The tricuspid regurgitation jet area reduced from 4.63 cm^2 to 1.16 cm^2, mild TR decreased from 2.98 cm^2 to 0.72 cm^2, moderate TR from 6.6 cm^2 to 1.2 cm^2, and severe TR from 10.4 cm^2 to 4.2 cm^2 at 6 months (all $p<0.001$). Left ventricular dimensions improved markedly after 6 months, with LVEDD decreasing from 43.18 mm to 39.4 mm and LVESD from 26.8 mm to 23.8 mm (both $p<0.001$). LVEF increased from 65.3% to 67.1% ($p<0.001$). No residual shunts were reported. Only two patients (3.6%) experienced minor complications.

Conclusion: Transcatheter closure appears to be safe and effective treatment for PmVSD associated with TR, with favorable clinical and functional outcomes.

Introduction

Perimembranous ventricular septal defects (pmVSD) are the most frequently encountered congenital heart anomalies, constituting nearly 70% of all VSDs (1).

The hemodynamic burden posed by these defects often results in functional tricuspid regurgitation (TR), secondary to dilation and dysfunction of both right and left ventricles (2).

Traditionally, surgical intervention has been the standard treatment; however, in recent years, transcatheter closure techniques have emerged as a less invasive and increasingly popular alternative due to their reduced perioperative risks (3).

The pathophysiology of TR in the setting of pmVSD is primarily linked to distortion of the tricuspid valve's anatomy through septal displacement and annular dilation (4). Over time, chronic volume overload can exacerbate these changes, potentially leading to progressive valve insufficiency. Early correction may mitigate permanent myocardial damage and reduce the likelihood of future surgical valve repair (5).

Technological advances in device development—such as the Amplatzer occluder—have significantly enhanced procedural outcomes and minimized complications (6). Recent advances, such as the Lifetech Konar multifunctional occluder, have further improved procedural success rates and reduced complications (7). Nonetheless, questions remain regarding the durability of valve competence post-device closure, especially in patients with severe baseline TR (8).

Evidence suggests that TR associated with pmVSD may improve following defect closure, as geometric normalization of the ventricles relieves stress on the tricuspid valve (9). However, the long-term impact of transcatheter closure on TR severity and cardiac function remains understudied, particularly in pediatric populations. This study addresses this gap by evaluating the efficacy and safety of transcatheter pmVSD closure in reducing TR and improving ventricular performance in children.

Aim of the work

The aim of the present study was to evaluate the impact of ventricular septal defect transcatheter device closure on tricuspid valve function and cardiac remodeling in pediatric patients.

Patients and Methods

Study Design and Participants:

This prospective study was conducted at the Nation Heart institute and Cardiology Unit of the Pediatric Department of Minya University Hospital during the period between September 2023 and March 2025 and included 55 patients.

Inclusion criteria:

- Children (up to 16 years old) and both genders.
- ECHO criteria
- Hemodynamically Significant isolated perimembranous VSD anatomically suitable for transcatheter closure; The rim to the aortic valve must be more than 2 mm.
- The presence of a left-to-right shunt.
- Mean pulmonary artery pressure < 40 mmHg.
- At least mild TR.

Exclusion criteria:

- Body weight less than 6 kg
- Pulmonary vascular resistance index greater than 7 WU/m2 ,
- PMVSD extending to the inlet
- Presence of additional lesions requiring surgical intervention (e.g. TOF).

- Gerbode defect (abnormal shunting between the left ventricle and right atrium) which way mimic severe TR.

Procedural Details:

Transcatheter closure was performed under general anesthesia or local anesthesia. Devices were selected based on defect size and anatomy. The femoral vein and artery were accessed, and intravenous heparin (100 IU/ kg) was administered. Angiography in the left ventricle at a 60°/30° left anterior oblique projection/ cranial was used to profile the VSD and the location and size of the VSD were assessed. The choice of procedure depends on the defect's size and location, and the device being used. Real-time fluoroscopy and transesophageal echocardiograms guided device deployment to ensure optimal positioning and minimize complications. Procedural success was defined as complete defect closure without residual shunting or significant TR progression.

Echocardiographic Protocol:

Comprehensive transthoracic echocardiograms (TTE) were performed pre-procedure and at follow-up visits. The left ventricular end-systolic/ end-diastolic diameters, left atrial maximum anteroposterior diameter, and left ventricular ejection fraction were determined using the modified Simpson's biplane algorithm and M-Mode method.

The severity of TR was assessed based on the spatial distribution of the central regurgitant jet within the right atrium by color- Doppler flow mapping from apical
4-chamber view. In each patient, the TR jet was sought from all available midprecordial and apical positions until a flow signal with the maximum spectral representation of high velocities was recorded. once a signal with a relatively dense high-velocity spectral representation is obtained, the angle between the ultrasound beam and the direction of flow can be assumed to be minimal ***(10)***. The severity of the tricuspid regurgitation (TR) was graded 1 (mild), 2 (moderate) and 3 (severe), using the approach as recommended by the American Society of Echocardiography ***(11)***. These recommendations included color jet area TRJA (cm^3), vena contracta width, and the ratio of the maximal regurgitant area to right atrial area (%).

Outcome Measures:

- Primary : Change in TR gradimg (mild, moderate, severe) and TRJA.
- Secondary : Change in LV dimensions (LVEDD, LVESD) and LVEF at 1 and 6 months.
- Safety : Procedural complications (e.g., device embolization, arrhythmias, valve injury).

Statistical analysis of the data

- All data were collected, tabulated, and statistically analyzed using SPSS 26 for windows (SPSS Inc., Chicago, IL, USA)

- Data were tested for normal distribution using the Shapiro Walk test. Qualitative data were represented as frequencies and relative percentages. Quantitative data were expressed as mean ± SD (Standard deviation) and range.
- Independent t test was used to calculate difference between quantitative variables in 2 groups for parametric variables.
- One way ANOVA test was used to calculate difference between quantitative variables in more than 2 groups for parametric variables.
- Repeated measure ANOVA was used to calculate the difference between more than 2 related variables
- Paired sample t test was used to calculate difference between 2 related variables
- All statistical comparisons were two tailed with significance Level of P-value ≤ 0.05 indicates significant, p <0.001 indicates highly significant difference while, P> 0.05 indicates non-significant difference.
- 95% confidence intervals were calculated for sample sizes.

Ethics:

The aim and nature of this study was explained to parents/care givers of the studied cases before inclusion. Informed consents were obtained before enrollment giving them the right to withdraw from our research avoiding using deceptive practice. This study also was approved by the Pediatrics Department Council and had approval of the ethical committee of Faculty of Medicine Minia- University No. 985/11/2023.

Results

Patients:

All 55 patients with at least mild TR were successfully treated by transcatheter intervention for VSD. There were 31 male and 24 female patients. Characteristics of the studied patients as clinical, operative and post-operative data are summarized in Table 1.
Regarding the clinical data, according to color-Doppler TTE before intervention, the average end-diastolic VSD size was 4.93 ± 1.2 mm, ranged from 2.8 to 7.5 mm with the majority of cases (65.5%) had mild tricuspid resurge, 25.5% had moderate TR and only 9% had severe TR. Regarding the operative data, the mean procedure time was 69.4 min, ranged from 34 to 120 min with the mean device size of 7.39 ± 1.02 and the majority had ADO I device (69.1%) Regarding postoperative data, the mean hospital stay was 1.54 ± 0.63 day, ranged from 1 to 4 days with only 2 cases (3.6%) had complication, one AR and other heart block and a pacemaker was inserted.

TR Reduction and Cardiac Remodeling:

The echocardiographic variables that were determined before, early after percutaneous VSD closure and 6-month follow-up are listed in Table 2. The TRJA, a quantitative marker of TR severity, decreased from 4.63 cm² to 1.16 cm² with mean percentage of decline of 76.1%±15 ($p < 0.001$), indicating substantial improvement in tricuspid valve competence. The mean TRJA decreased significantly after 1 month compared to preintervention value. At 6 months post-closure, TR severity decreased significantly across all grades: mild TR dropped from 2.9–0.72%, moderate TR from 6.6–1.2%, and severe TR from 10.9–4.2% ($p < 0.001$ for all). The results are shown in Fig. 1.

Left ventricular remodeling was evident: LVEDD decreased from 43.18 mm to 39.4 mm, and LVESD from 26.8 mm to 23.8 mm ($p < 0.001$ for both), reflecting reduced ventricular dilation post-defect closure. LVEF improved from 65.3–67.1% ($p < 0.001$), demonstrating enhanced systolic function. Subgroup analyses revealed consistent improvements across all TR grades.

The relation between parameters and TR severity is summarized in Table 3, and the relation between percentage improvement of parameters and TR severity is listed in Table 4.

Table (1): Characteristics of the studied patients as clinical, operative and post-operative data.

	Descriptive statistics (N=55)
VSD size detected by TTE (mm)	
Mean ±SD	4.93±1.2
Range	2.8-7.5
Degree of TR before intervention*	
Mild	36 (65.5%)
Moderate	14 (25.5%)
Severe	5 (9%)
Device type	
ADO I	38 (69.1%)
ADO II	9 (16.4%)
Konar	8 (14.5%)
Device size (mm)	
Mean ±SD	7.39±1.02
Range	4.6-10.12
Procedure time (min)	
Mean ±SD	69.4±24.5
Range	34-120
Hospital stays (Hour)	
Mean ±SD	1.54±0.63
Range	1-4
Complication	
No	53 (96.4%)
Yes	2 (3.6%)

SD=standard deviation, VSD=Ventricular septal defect, TR=tricuspid regurgitation
ADO = Amplatzer duct occluder, TTE = transthoracic echocardiography
*According to American Society of Echocardiography

Table (2)

Comparison of parameters before VSD closure, after 1 month and after 6 months of closure among studied cases.

	A Pre-intervention	B After 1 month	C After 6 months	Percentage change after 6 months %	*P* value		
					A & B	A & C	B & C
LAMD	24.3 ± 2.5	22.4 ± 2.3	21.7 ± 2.2	10.26 ± 3.6	< 0.001	< 0.001	= 0.01
LVEDD	43.18 ± 3.4	40.9 ± 3.2	39.4 ± 3.2	8.6 ± 2.5	< 0.001	< 0.001	< 0.001
LVESD	26.8 ± 1.9	24.6 ± 1.8	23.8 ± 1.9	7.76 ± 3.6	< 0.001	< 0.001	< 0.001
LVEF	65.3 ± 3.6	66.4 ± 3.2	67.1 ± 3.04	2.9 ± 3.2	0.001	< 0.001	= 0.002
TRJA	4.63 ± 2.7	1.49 ± 1.7	1.16 ± 1.49	76.1 ± 15.07	< 0.001	< 0.001	< 0.001
Mild	2.98 ± 1.06	0.98 ± 0.76	0.72 ± 0.54	75.2 ± 12.7	< 0.001	< 0.001	< 0.001
Moderate	6.6 ± 1.09	1.66 ± 1.5	1.2 ± 1.1	83.1 ± 12.5	< 0.001	< 0.001	< 0.001
Severe	10.9 ± 0.51	4.7 ± 3.5	4.2 ± 3.2	62.6 ± 26.7	< 0.001	< 0.001	0.007

LAMD = Left Atrium Maximum Dimension, LVEDD = Left Ventricular End Diastolic Dimension, LVEDD = Left Ventricular End Systolic Dimension, LVEF = Left Ventricular Ejection Fraction, TRJA = Tricuspid Regurgitation Jet Area

Table (3): Relation between different parameters and TR severity

	TR severity			*P* value
	Mild TR (n = 36)	**Moderate TR (n = 14)**	**Severe TR (n = 5)**	
LAMD before	24.8 ± 2.2	23 ± 2.9	23.6 ± 2.3	**0.04***
LAMD after 1 month	22.9 ± 2.04#	21.2 ± 2.7#	21.8 ± 1.9#	**0.04***
LAMD after 6 months	22.3 ± 1.9#	20.5 ± 2.5#	21.4 ± 2.4#	**0.03***
P value	**< 0.001***	**< 0.001***	**0.01***	
LVEDD before	43.9 ± 3.09	41.2 ± 2.9	43 ± 5.5	**0.038***
LVEDD after 1 month	41.7 ± 3.01#	39.1 ± 2.8#	40.4 ± 4.8#	**0.035***
LVEDD after 6 months	40.2 ± 3#	37.6 ± 2.9#	39 ± 4.1#	**0.033***
P value	**< 0.001***	**< 0.001***	**0.008***	
LVESD before	26.1 ± 2.01	25 ± 2.05	26 ± 1.4	**0.25**
LVESD after 1 month	24.9 ± 1.8#	23.9 ± 1.8#	25 ± 1.4#	**0.20**
LVESD after 6 months	24.5 ± 1.8#	22.7 ± 1.8#	23.8 ± 0.83#	**0.03***
P value	**< 0.001***	**< 0.001***	**0.008***	
LVEF before	65.1 ± 2.7	65 ± 5.1	67.8 ± 4.4	**0.28**
LVEF after 1 month	66.1 ± 2.9#	66.7 ± 3.4#	68.4 ± 4.2	**0.32**
LVEF after 6 months	66.7 ± 2.7#	67.3 ± 3.2#	69.4 ± 4.5	**0.19**
P value	**< 0.001***	**0.004***	**0.10**	

TR = tricuspid regurgitation, LAMD = Left Atrium Maximum Dimension,

LVEDD = Left Ventricular End Diastolic Dimension, *LVEDD = Left Ventricular End Systolic Dimension*, *LVEF = Left Ventricular Ejection Fraction*, * significant at p value < 0.05, _# significant difference with baseline.

Regarding the comparison of LAMD and LVEDD before and follow up between cases with mild, moderate and severe TR, the difference was statistically significant (p value < 0.05), but severe TR cases didn't have any significant value with mild TR, however, the mean was higher among mild than severe TR cases.

Regarding the comparison of LVESD and LVEF before VSD closure and after 1 month of closure between cases with mild, moderate and severe TR, the difference was non-statistically significant (p value > 0.05),

On other hand, there is significant difference between mild, moderate and severe TR regarding LVESD at 6 months (p value < 0.05) as the mean was significantly higher among mild TR cases than moderate cases.

Table (4)

Relation between percentage of improvement of parameters and TR severity

Percentage of change	TR severity before			*P* value
	Mild TR	Moderate TR	Severe TR	
LAMD	10.1 ± 3.7	10.7 ± 4	9.4 ± 2.2	0.76
LVEDD	8.5 ± 2.4	8.6 ± 3.05	9.1 ± 2	0.89
LVESD	7.08 ± 3.2	9.2 ± 4.5	8.3 ± 2.9	0.14
LVEF	2.5 ± 2.6	3.9 ± 4.6	2.3 ± 2.4	0.41
TRJA	75.2 ± 12.7	83.1 ± 12.5	62.6 ± 26.7	0.02*

TR = tricuspid regurgitation, LAMD = Left Atrium Maximum Dimension, LVEDD = Left Ventricular End Diastolic Dimension, LVEDD = Left Ventricular End Systolic Dimension, LVEF = Left Ventricular Ejection Fraction, TRJA = Tricuspid Regurgitation Jet Area _ significant at p value < 0.05*

There is significant difference between cases with mild, moderate and severe TR regarding percentage of improvement in TRJA (p value < 0.05) as the mean percentage of improvement was significantly higher among cases with moderate TR (83.1 ± 12.5) than cases with mild TR (75.2 ± 12.7) and both of them were significantly higher than severe TR cases (62.6 ± 26.7). On other hand, there is no significant difference regarding LAMD, LVEDD, LVESD, and LVEF (p value > 0.05).

Discussion

Mechanistic Insights:

The catheter-based approach for VSD has been shown to be an alternative to surgical closure with encouraging results although it still carries risks, such as complete atrioventricular block (cAVB), residual shunt, and interference with the aortic and tricuspid valves (12). TR complicated by VSD was observed in some reports early. However, to our knowledge, few studies have addressed the fate of TR caused by VSD and the outcome of ventricular performance after VSD closure so far. This study was designed to investigate the outcome of varying degrees of TR and improving ventricular parameters in children.

Historical literature provides limited insights into the mechanisms behind TR in patients with perimembranous VSD. In 1978, Earlier reports noted aneurysm formation but did not clarify how it

caused TR (13). Some studies suggested that involvement of the septal leaflet in aneurysm formation could impair tricuspid valve function (14).

Pathological findings have indicated that spontaneous closure of VSDs can occur through tricuspid valve adherence, often producing septal aneurysms. This process can distort the tricuspid apparatus and contribute to valvular insufficiency (15).

Finally, Winslow et al. reported transesophageal echocardiographic findings

of tricuspid valve anomalies linked with spontaneous closure of perimembranous VSD in adults. They concluded that tricuspid valve deformity coupled with VSD closure was responsible for at least mild tricuspid insufficiency in their patients, but they did not explain the specific process or explanation for TR (16).

Functional TR in pmVSD is caused by ventricular septal displacement and annular dilatation, which impair tricuspid valve coaptation. Transcatheter closure mitigates this by restoration of normal ventricular anatomy and reduction of septal dyskinesia, which in turn alleviates stress on the tricuspid valve (17).

In the current study, evident TR (at least moderate) was seen in 10.9% of patients (55/504) with congenital perimembranous VSD, although the majority of TR was dramatically reduced after transcatheter VSD closure. This extraordinary amelioration of TR supports the hypothesis that TR in pmVSD cases is largely functional, reversible, and may be connected to defect.

We align with Abdelnabi and Almaghraby's proposed mechanisms for tricuspid regurgitation in perimembranous ventricular septal defects. The first mechanism involves high-velocity flow through the VSD, which displaces the anterior tricuspid leaflet. This redirects blood flow toward the right atrium, disrupting normal valve dynamics. The second mechanism relates to septal leaflet aneurysm formation, triggered by the Venturi effect of the left-to-right shunt. While this aneurysm may partially occlude the VSD, it compromises tricuspid valve coaptation during systole. The resulting incomplete leaflet closure leads to regurgitation, as the valve fails to achieve proper sealing during ventricular contraction (18).

Severe TR associated with PMVSD necessitated surgical closure combined with tricuspid valve repair or replacement. However, recent clinical trends favor transcatheter closure as a primary intervention, potentially circumventing the need for valve surgery (19). In fact, our results demonstrated complete or near-complete resolution of TR in most patients, even in those with moderate or severe regurgitation.

Clinical Implications:

Regarding the operative data, the mean procedure time was 69.4 min, ranged from 34 to 120 min, we contributed this to system lag not to skills of interventionists. Only two patients (3.6%) had complications, one had heart block and a pacemaker was inserted, and there was a significant increase

in aortic regurgitation (AR) seen in the other patient. In contrast to Xu et al (20) and Shah et al (21) which the incidence of complication was 10.4% and 8.5% respectively.

Transthoracic echocardiography post-transcatheter closure revealed significant improvements in tricuspid regurgitation (TR) severity across all categories. Among 5 patients with pre-existing severe TR, 4 (80%) improved to mild TR and 1 (20%) to moderate TR.

Of 14 patients with moderate TR, 5 (35.7%) decreased to mild TR, 8 (57.1%) resolved to trivial/absent TR, and 1 (7.1%) persisted with moderate TR. In the mild TR group

(36 patients), 29 (80.6%) showed a resolution to trivial/absent TR, while 4 (11.1%) remained unchanged.

These findings highlight the efficacy of transcatheter closure in reducing TR severity, with most patients achieving at least one grade improvement and only a minority exhibiting residual regurgitation.

There is significant difference between cases with mild, moderate and severe TR regarding percentage of improvement in TRJA ($p < 0.05$). Moderate TR cases exhibited the highest mean percentage reduction, followed by mild TR, with both groups showing significantly greater improvement compared to severe TR. This result agreed with (20)

which found that the improvement of TR is weaker in severe TR than mild or moderate cases.

Recently, other reported progressive increase in tricuspid insufficiency with significant diminution of VSD size and an association with aneurysm formation

(22). Our findings corroborate with the association between TR severity and aneurysmal remodeling of the interventricular septum. However, no statistically significant correlation was identified between TR severity and baseline VSD dimensions ($p > 0.05$), suggesting that TR pathogenesis in this context may be mechanistically independent of defect size.

Considering other correlations with VSD size, there is mild negative significant correlation between VSD size before closure and Percentage of change in LVEDD after 6 months ($r = -0.25$, $p = 0.02$), suggesting that smaller defects may exert disproportionate hemodynamic effects on ventricular geometry. Conversely, baseline VSD size exhibited a weak positive correlation with the relative improvement in left ventricular ejection fraction post-closure ($r = 0.26$, $p = 0.01$), potentially reflecting enhanced ventricular unloading and contractile efficiency following closure of larger shunts.

Comparison with Surgical Outcomes :

Our findings corroborate existing evidence demonstrating tricuspid regurgitation reduction following ventricular septal defect closure. However, while prior investigations have predominantly focused on surgical cohorts (23), this study establishes transcatheter closure as a clinically equivalent alternative, achieving 91% overall reduction in TR severity (with 67.2% resolution to trivial/absent TR) through a minimally invasive approach.

Notably, the transcatheter cohort demonstrated comparable TR improvement to surgical benchmarks (90–95%) but transcatheter methods offer shorter hospital stays

Notably, the transcatheter cohort demonstrated comparable TR improvement to surgical benchmarks (90–95%) but transcatheter methods offer shorter hospital stays (2.1 ± 1.3 days vs. 7.8 ± 2.5 days for surgery) and faster functional recovery (median return to normal activity: 5 days vs. 21 days) ***(24)*** with significantly reduced perioperative morbidity
(3.6% vs. 12.4% in surgical controls) ***(23)***. These results suggest that percutaneous techniques may offer dual benefits: hemodynamic correction equivalent to surgery and enhanced procedural safety, particularly in pediatric populations.

Limitations and Future Directions :

- First, A key limitation of this study is its modest sample size, particularly the subgroup of five patients with severe TR, which may limit the generalizability of findings to broader populations. While the majority of outcomes achieved statistical significance, validation in larger, multicenter cohorts is warranted to confirm these results, especially for severe TR.
- Second, A critical limitation of this study is the limited follow-up duration post- VSD closure, which precludes assessment of the long-term trajectory of TR persistence or potential late-onset valvular sequelae. The median follow-up of 6 months may inadequately capture chronic remodeling processes, such as progressive tricuspid annular dilation or iatrogenic valve injury due to device erosion. Furthermore, the durability of TR improvement beyond this timeframe remains uncertain, particularly in patients with baseline severe TR or borderline pulmonary vascular resistance. Large-scale longitudinal multicenter studies with extended surveillance periods (≥ 5 years) are required to delineate the temporal dynamics of TR resolution, identify predictors of late recurrence, and establish sufficient reference data for evidence-based clinical decision-making.
- Additionally, To further refine clinical decision-making, prospective comparative trials directly contrasting transcatheter and surgical cohorts are essential. Such studies should employ standardized endpoints to elucidate the comparative efficacy (e.g., TR reduction rates, ventricular remodeling) and safety profiles (e.g., procedural morbidity, reintervention rates) of the two approaches. Particular attention should be paid to long-term outcomes in pediatric populations, including the invasive burden of open-heart surgery versus transcatheter techniques, as well as patient-reported quality of life metrics. This evidence is critical to establishing risk-stratified treatment algorithms.

Conclusion

Transcatheter pmVSD closure effectively reduces functional TR and improves cardiac function in pediatric patients, with a favorable safety profile. These findings support its role as a first-line therapy for select patients, though larger studies are needed to confirm long-term outcomes.

Declarations

Conflict of interest: None declared

Ethics approval and consent to participate
This study was approved by the Faculty of Medicine, Minia University Ethics Committee (Approval No. 985/11/2023). Informed consent was obtained from all parents/caregivers.

Consent for publication
Not applicable.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

Funding
No specific funding was received for this study.

Authors' contributions
All authors contributed to the study's conception, design, data collection, and manuscript preparation. All authors read and approved the final manuscript.

Acknowledgements
The authors would like to thank the staff of Minya University Hospital and the National Heart Institute for their support.

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Figures



Figure 1

line chart represents change in TRJA among studied cases regarding TR severity