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Transcatheter Device Closure of Congenital Ventricular Septal Defects: Procedural Outcomes and Short-Term Experience from a Tertiary Care Center in Pakistan.

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Abstract

Background: Congenital ventricular septal defects (VSDs) are the most common congenital cardiac anomalies and may lead to left ventricular volume overload, pulmonary hypertension, arrhythmias, heart failure, or Eisenmenger syndrome if untreated. While surgery remains the conventional treatment, transcatheter device closure offers a minimally invasive alternative with shorter hospitalization and reduced morbidity.

Methodology: This retrospective observational study was conducted at Lady Reading Hospital-MTI, Peshawar, Pakistan, and included all patients who underwent attempted transcatheter closure of congenital VSDs from January 2023 to January 2026. Patients with hemodynamically significant left-to-right shunts and anatomically suitable defects on echocardiography were included. Clinical, echocardiographic, and catheterization records were reviewed to assess defect characteristics, device selection, procedural success, immediate outcomes, and complications.

Results: A total of 41 patients underwent attempted transcatheter VSD closure, with ages ranging from 12 months to 47 years. Perimembranous VSDs accounted for 70.7% of cases and muscular VSDs for 29.3%. Procedural success was achieved in 90.2% (37/41), with complete or trivial residual shunting on immediate imaging. Partial right coronary cusp prolapse was observed in 34.1% of patients, without progression to significant aortic regurgitation after device deployment. Major complications included device embolization in 4.8%, significant residual shunt in 2.4%, mild left ventricular outflow tract obstruction in 2.4%, and procedure-related mortality in 2.4%. No new significant aortic regurgitation or complete atrioventricular block was observed.

Conclusion: Transcatheter VSD closure showed high procedural success and favorable short-term outcomes, supporting its role as a safe, effective, valve-preserving alternative to surgery in selected patients, including in resource-limited settings.

Keywords

Congenital Ventricular Septal Defect, Transcatheter VSD Closure, Perimembranous Ventricular Septal Defect, Congenital Heart Disease, Device Closure, Cardiac Catheterization.

Introduction

Congenital ventricular septal defects (VSDs) are the most frequently encountered congenital heart defects, accounting for approximately 20–40% of all congenital cardiac anomalies worldwide[1]. VSDs produce abnormal communication between the ventricles, resulting in left-to-right shunting, pulmonary overcirculation, and progressive left ventricular volume overload. If left untreated, significant defects may lead to pulmonary hypertension, arrhythmias, congestive heart failure, infective endocarditis, and irreversible Eisenmenger syndrome[1-3]. The clinical presentation and severity largely depend on the size, location, and hemodynamic significance of the defect.

Surgical patch closure has traditionally been considered the definitive treatment for hemodynamically significant VSDs. Surgical repair provides excellent long-term outcomes; however, it requires sternotomy, cardiopulmonary bypass, prolonged hospitalization, and postoperative recovery[4]. In low- and middle-income countries, limited surgical infrastructure, delayed referrals, increased infection risk, and financial constraints further complicate access to timely surgical care[5,6].

Over the past two decades, transcatheter device closure has emerged as a less invasive and increasingly effective alternative for selected congenital VSDs. Advances in catheter-based technologies, imaging modalities, and low-profile occluder devices have significantly improved procedural safety and success rates[3,4]. Devices such as the Amplatzer VSD occluder systems and LifeTech multifunctional occluders allow precise deployment under fluoroscopic and echocardiographic guidance while minimizing trauma associated with open-heart surgery. Compared with surgery, transcatheter closure offers shorter hospital stay, rapid recovery, improved cosmetic outcomes, and reduced healthcare burden[3,6].

Despite growing global experience, transcatheter closure of VSDs remains technically challenging in anatomically complex defects, particularly perimembranous lesions associated with aneurysmal septum, deficient rims, or right coronary cusp (RCC) prolapse. Concerns regarding conduction disturbances, residual shunting, device embolization, valvular dysfunction, and left ventricular outflow tract obstruction continue to influence patient selection and procedural planning[7–9]. Careful imaging assessment and individualized device selection are therefore essential to optimize outcomes and reduce complications.

In South Asia, and particularly in Pakistan, published data regarding transcatheter VSD closure remain relatively limited despite increasing procedural adoption in tertiary cardiac centers[10]. Regional data are important because patient demographics, referral patterns, anatomical complexity, and healthcare resource availability may differ substantially from high-income countries. Evaluating local procedural outcomes can therefore provide valuable evidence for expanding minimally invasive congenital cardiac interventions in resource-constrained healthcare systems.

The present study aimed to evaluate the procedural success, anatomical characteristics, short-term outcomes, and complications associated with transcatheter device closure of congenital ventricular septal defects at a tertiary care center in Pakistan. Particular emphasis was placed on anatomically challenging lesions, including perimembranous defects associated with aneurysmal tissue and RCC prolapse, to assess the feasibility and safety of transcatheter intervention in real-world clinical practice.

Methodology

Study Design

This retrospective observational study was conducted to evaluate the feasibility, procedural success, and short-term outcomes of transcatheter device closure of congenital ventricular septal defects (VSDs) at a tertiary cardiac care center. The study included all consecutive patients who underwent attempted transcatheter VSD closure between January 2023 and January 2026 at Lady Reading Hospital-MTI Peshawar, Pakistan. The study aimed to assess procedural efficacy, immediate hemodynamic outcomes, and device-related complications in both

pediatric and adult patients undergoing minimally invasive VSD closure procedures.

Ethics

Ethical approval for the study was obtained from the Ethical Review Committee of Lady Reading Hospital-MTI Peshawar prior to data collection. As the study utilized retrospective hospital-based records and procedural data, patient confidentiality and anonymity were maintained throughout the analysis. All procedures had originally been performed according to institutional protocols and internationally accepted standards for congenital cardiac interventions.

Setting

The study was carried out at Lady Reading Hospital-MTI Peshawar, a tertiary care referral center for congenital and structural heart disease interventions in Pakistan. The institution routinely manages pediatric and adult congenital cardiac cases and performs advanced catheter-based interventions using fluoroscopic and echocardiographic guidance. Patients were referred from multiple regions for evaluation and management of hemodynamically significant congenital VSDs.

Participants

The study population consisted of patients with congenital VSDs who underwent attempted transcatheter device closure during the study period. Patients with hemodynamically significant left-to-right shunts associated with evidence of left ventricular volume overload and suitable anatomy on transthoracic echocardiography (TTE), with or without transesophageal echocardiography (TOE), were included. Hemodynamic significance was defined as a Qp/Qs ratio greater than 1.5 in association with echocardiographic evidence of left ventricular volume overload. Patients with irreversible pulmonary hypertension, active infective endocarditis, significant pre-existing aortic regurgitation, or associated cardiac lesions requiring surgical correction were excluded from the study. Patients suspected of having irreversible pulmonary hypertension were excluded on the basis of clinical and echocardiographic assessment, including markedly elevated pulmonary artery pressures and absence of reversibility.

Variables

The primary outcome variable was procedural success, defined as stable device deployment with complete closure or only negligible residual shunting without significant valvular compromise. Secondary variables included demographic characteristics, VSD morphology, anatomical complexity, device type utilized, procedural complications, residual shunt status, valvular dysfunction, left ventricular outflow tract (LVOT) obstruction, device embolization, arrhythmias, and mortality. Additional anatomical variables assessed included the presence of aneurysmal membranous septum and right coronary cusp (RCC) prolapse.

Data Sources / Measurement

Data were collected retrospectively from hospital medical records, procedural reports, catheterization laboratory records, and echocardiographic databases. All patients underwent detailed pre-procedural clinical evaluation and echocardiographic assessment to determine defect type, defect size, relation to adjacent valvular structures, aneurysmal tissue formation, and RCC prolapse. TTE was used routinely, while TOE was utilized in selected complex cases. During the intervention, left ventricular angiography, primarily in the left anterior oblique cranial view, was used to determine defect morphology and dimensions. Device size selection was generally performed by choosing a device 1–2 mm larger than the measured defect diameter. Device deployment was guided by fluoroscopy and echocardiography to confirm optimal positioning, preservation of aortic and tricuspid valve function, absence of significant residual shunting, and acceptable LVOT gradients prior to device release. Post-procedural follow-up included clinical assessment and echocardiography before discharge and during outpatient visits to evaluate residual shunting, valvular function, arrhythmias, and device-related complications.

Bias

As a retrospective single-center observational study, the study was subject to inherent limitations

including selection bias, information bias, and potential documentation bias. Selection bias may have occurred because only patients with anatomically suitable defects and acceptable hemodynamic profiles were selected for transcatheter closure. Additionally, the retrospective nature of data collection relied on the accuracy and completeness of institutional records. To minimize variability, all procedures were performed using standardized institutional interventional protocols and imaging-based assessment strategies.

Study Size

The study included a total of 41 consecutive patients who underwent attempted transcatheter closure of congenital VSDs during the three-year study period. The sample represented all eligible patients meeting the inclusion criteria within the defined timeframe, and no formal sample size calculation was performed because of the retrospective observational design.

Quantitative Variables

Continuous variables such as age, defect size, and LVOT gradients were evaluated as quantitative variables and reported using mean ± standard deviation or range where appropriate. Categorical variables including sex distribution, VSD type, procedural success, and complications were presented as frequencies and percentages. Residual shunts were categorized according to echocardiographic findings as complete closure, trivial residual shunt, or significant residual shunt.

Statistical Methods

Descriptive statistical analysis was performed for all study variables. Continuous variables were summarized using mean ± standard deviation or range according to data distribution, whereas categorical variables were expressed as frequencies and percentages. Due to the relatively small sample size and retrospective observational nature of the study, advanced inferential statistical analyses and multivariable regression modeling were not performed. The analysis primarily focused on procedural outcomes, complication rates, and short-term clinical results following transcatheter VSD closure.

Results

Participants

A total of 41 consecutive patients with congenital ventricular septal defects (VSDs) underwent attempted transcatheter device closure between January 2023 and January 2026 at Lady Reading Hospital-MTI Peshawar. The study population included both pediatric and adult patients, with ages ranging from 12 months to 47 years, demonstrating the applicability of transcatheter intervention across a broad age spectrum. Females represented 56.1% (n=23) of the cohort, while males accounted for 43.9% (n=18). All included patients had hemodynamically significant left-to-right shunting associated with echocardiographic evidence of left ventricular (LV) volume overload, fulfilling the predefined inclusion criteria. Pre-procedural imaging evaluation was performed in all patients using transthoracic echocardiography (TTE), with transesophageal echocardiography (TOE) utilized in selected anatomically complex cases (Table 1).

Descriptive Data

Perimembranous (PM) VSDs constituted the majority of defects, accounting for 70.7% (n=29) of cases, whereas muscular VSDs represented 29.3% (n=12) of the cohort. Among muscular defects, 24.4% (n=10) were high muscular defects and 4.9% (n=2) were mid-muscular defects. Anatomical complexity was frequently observed among patients with PM VSDs. Partial right coronary cusp (RCC) prolapse was identified in 34.1% (n=14) of patients, although none demonstrated significant pre-existing aortic regurgitation. Additionally, aneurysmal transformation of the membranous septum was observed in 12.1% (n=5) of cases. These anatomical findings had important implications for procedural planning, device selection, and preservation of valvular integrity during intervention (Table 2 and Figure 1).

All procedures were performed under general anesthesia using femoral arterial and venous access. Defect morphology and measurements were assessed using left ventricular angiography, predominantly in the left anterior oblique cranial projection. Device selection was individualized according to defect anatomy, size, and proximity to

surrounding valvular structures. The LifeTech Multifunctional Occluder was most frequently used, particularly in anatomically complex or aneurysmal defects, while the Amplatzer Duct Occluder II and Amplatzer PM VSD Occluder were utilized in smaller or less complex lesions.

Outcome Data

Successful device deployment with stable positioning and effective closure was achieved in 37 out of 41 patients, resulting in an overall procedural success rate of 90.2%. Immediate post-procedural imaging demonstrated either complete closure or only trivial residual shunting in the successfully treated patients. Importantly, no cases of new-onset significant aortic regurgitation were observed following device deployment, including among patients with pre-existing RCC prolapse. Baseline hemodynamic evaluation confirmed significant left-to-right shunting in all patients, although catheter-based Qp/Qs measurements were not consistently available due to the retrospective nature of the study. Left ventricular outflow tract (LVOT) hemodynamics remained preserved in the majority of cases. Mild LVOT obstruction occurred in one patient (2.4%), with a peak gradient of 21 mmHg, which was considered clinically non-significant and did not require intervention. Mild tricuspid regurgitation was observed in a few patients; however, none required device retrieval or additional intervention. Overall, procedural outcomes demonstrated favorable short-term safety and efficacy profiles for transcatheter VSD closure (Table 3 and Figure 2).

Main Results

Major adverse events or procedural failure occurred in four patients (9.8%). Device embolization was observed in two patients (4.8%), both involving perimembranous defects. In one patient, the device embolized to the left pulmonary artery, while in the other, migration occurred to the right pulmonary artery. Both embolized devices were successfully retrieved percutaneously using a snare technique without the need for surgical intervention.

One patient (2.4%) developed a significant residual shunt leading to procedural abandonment. Additionally, one procedure-related mortality (2.4%) occurred in a 5-year-old child with a large mid-muscular VSD. During the procedure, repeated entanglement of the delivery sheath within the tricuspid valve chordae resulted in technical difficulty and eventual abandonment of device deployment prior to release.

Following extubation, the patient developed severe hypoxia and refractory pulmonary edema, ultimately progressing to cardiac arrest despite full resuscitative measures. Despite these adverse events, the overall findings indicate that transcatheter closure of congenital VSDs provides a high procedural success rate with acceptable complication rates when performed in appropriately selected patients and anatomically suitable defects (Table 3 and Figure 2).

Table 1: Baseline Demographic and Clinical Characteristics (N = 41).

Variables		Value
Sex	Female	23 (56.1)
	Male	18 (43.9)
Hemodynamically significant left-to-right shunt		41 (100)
LV volume overload on echocardiography		41 (100)
Pre-procedural imaging		TTE +/- TOE (100%)

Table 2: Defect Morphology and Anatomical Characteristics.

Variables		N (%)
Defect Type	Perimembranous (PM) VSD	29 (70.7)
	Muscular VSD	12 (29.3)
Muscular VSD subtype	High muscular	10 (24.4)
	Mid-muscular	2 (4.9)
Anatomical Features	Partial RCC prolapse	14 (34.1)
	Aneurysmal membranous septum	5 (12.1)
	Significant pre-procedural AR	0 (0)

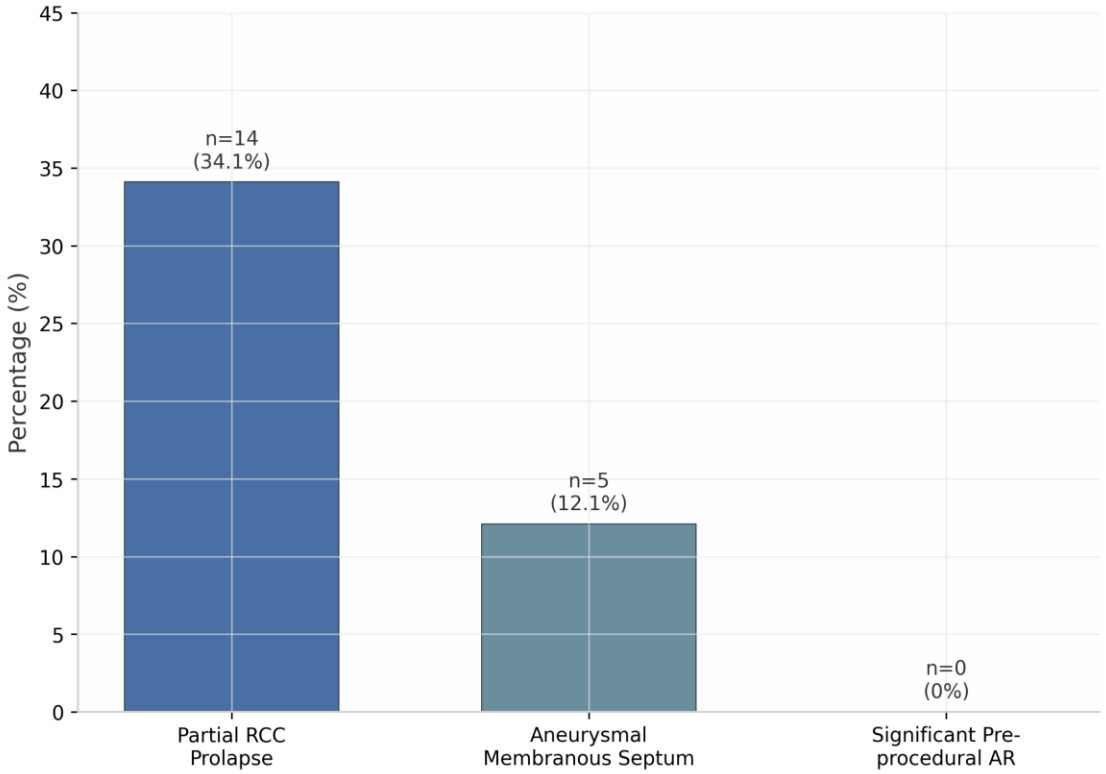

Figure 1: Anatomical Features in Study Population.

Table 3: Procedural Outcomes and Complications

Outcome	N (%)
Procedural success	37 (90.2)
Complete/trivial residual shunt	37 (90.2)
New-onset significant AR	0 (0)
Mild LVOT obstruction	1 (2.4)
Procedural failures / Major adverse events	4 (9.8)
- Device embolization (retrieved)	2 (4.8)
- Significant residual shunt (abandoned)	1 (2.4)
- Procedure-related mortality	1 (2.4)

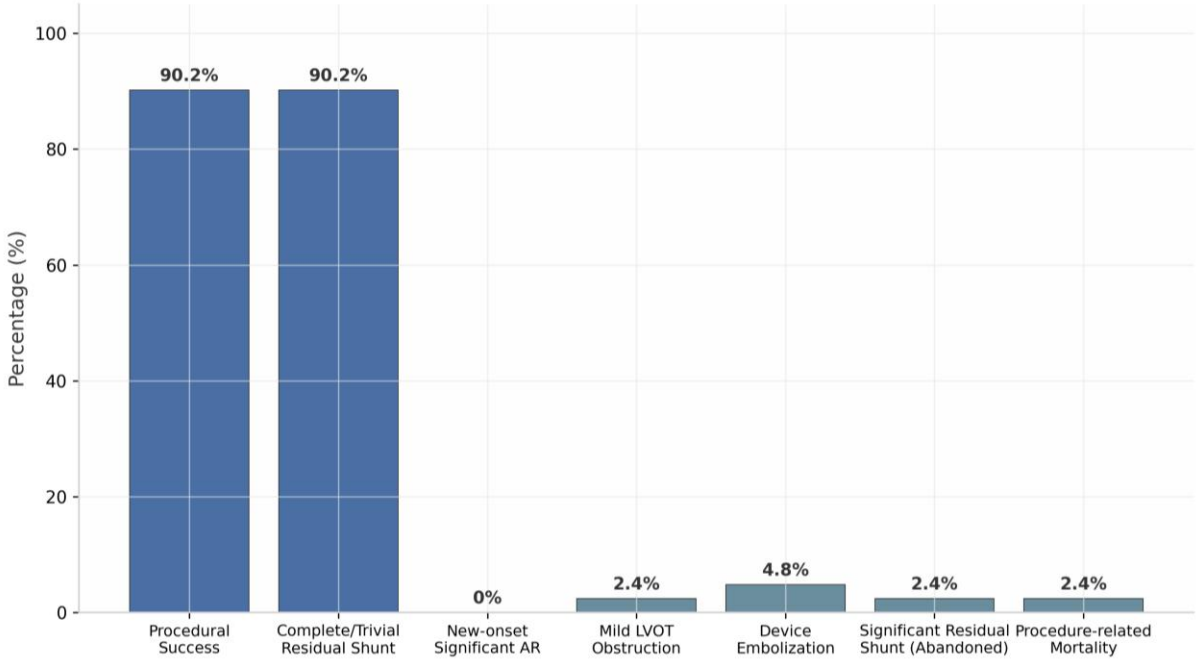

Figure 2: Procedural Outcomes and Complications (N=41).

Discussion

The present study demonstrates that transcatheter device closure of congenital ventricular septal defects (VSDs) is a safe, feasible, and highly effective therapeutic option in appropriately selected patients within a tertiary care setting in Pakistan. An overall procedural success rate of 90.2% was achieved, with most patients demonstrating complete closure or only trivial residual shunting immediately after device deployment. These findings are comparable to internationally reported success rates ranging from 92% to 98% in contemporary transcatheter VSD closure studies and meta-analyses[10-14]. The results support the expanding role of minimally invasive congenital cardiac interventions, particularly in regions where surgical resources may be limited or associated with increased financial and postoperative burden[5,6].

Perimembranous VSDs constituted the majority of cases in the present cohort, reflecting common referral patterns observed in real-world congenital cardiology practice. Anatomical complexity was also frequently encountered, with one-third of patients demonstrating partial right coronary cusp (RCC) prolapse and a subset exhibiting aneurysmal membranous septum. Despite these challenges, successful closure was achieved without the development of new-onset significant aortic regurgitation. This finding is clinically important because valvular compromise remains one of the major concerns associated with transcatheter closure of perimembranous defects[10,11]. Careful pre-procedural echocardiographic assessment, appropriate device oversizing, and imaging-guided deployment likely contributed to preservation of valvular integrity in this cohort.

The use of different occluder systems allowed individualized management according to defect morphology and anatomical characteristics. The LifeTech Multifunctional Occluder was particularly useful in aneurysmal or morphologically complex lesions because of its flexibility and adaptability, while Amplatzer devices were used effectively in smaller and less complex defects. Previous studies have similarly emphasized the importance of tailoring device selection according to defect anatomy to minimize complications such as residual shunting, conduction disturbances, or device embolization[7,11].

Complication rates in the present study were acceptable and largely consistent with previously published literature. Device embolization occurred in 4.8% of patients, which is slightly higher than some large international series but remained manageable, as both embolized devices were successfully retrieved percutaneously using snare techniques without surgical conversion[9,14]. Mild left ventricular outflow tract (LVOT) obstruction occurred in only one patient and remained clinically insignificant. Importantly, no cases of complete atrioventricular block were identified, despite concerns reported in earlier experiences with perimembranous VSD closure devices[15]. The absence of major conduction abnormalities in this study may reflect cautious patient selection, precise imaging guidance, and careful device sizing strategies.

One procedure-related mortality occurred in a patient with a large mid-muscular VSD due to severe procedural complexity and post-extubation pulmonary edema. Although the mortality rate appears higher compared with large-volume international centers reporting mortality rates below 1%, this finding should be interpreted in the context of the relatively small sample size and anatomical complexity of selected cases[12,13]. The event highlights the technical challenges associated with muscular VSD interventions, particularly in younger pediatric patients with difficult catheter manipulation and unstable hemodynamics.

The findings of this study are also relevant within the regional context. Data regarding transcatheter VSD closure from Pakistan and neighboring low- and middle-income countries remain limited [16,17]. The present experience demonstrates that favorable outcomes comparable to international standards can be achieved even in resource-constrained healthcare environments when appropriate imaging, operator expertise, and patient selection are available. Expanding transcatheter congenital cardiac programs may therefore reduce dependence on surgical referrals, shorten hospitalization, and improve accessibility to definitive treatment for congenital heart disease patients in developing healthcare systems.

Furthermore, the inclusion of both pediatric and adult patients reflects the broad applicability of transcatheter VSD closure across different age groups. The study also highlights the growing role of catheter-based therapies in anatomically challenging lesions that were previously considered more suitable for surgical correction. Continued improvements in device technology, low-profile delivery systems, and multimodality imaging are expected to further enhance procedural safety and long-term outcomes in the future.

Limitations

Several limitations of this study should be acknowledged. First, the retrospective observational design inherently carries risks of selection bias and information bias because the analysis depended on existing clinical and procedural records. Second, this was a single-center study with a relatively small sample size, limiting the generalizability of the findings and restricting the ability to perform subgroup or multivariable analyses. Third, follow-up duration was limited primarily to short-term in-hospital and early outpatient assessment; therefore, long-term outcomes such as late arrhythmias, device-related thrombosis, progression of valvular dysfunction, residual shunting, and delayed conduction abnormalities could not be adequately evaluated. Additionally, detailed invasive hemodynamic parameters such as catheter-based Qp/Qs measurements were not consistently available for all patients because of the retrospective nature of data collection. Finally, the study population may have been selectively enriched with anatomically favorable defects suitable for transcatheter intervention, potentially influencing procedural success rates and complication profiles.

Conclusion

Transcatheter device closure of congenital ventricular septal defects demonstrated high procedural success and favorable short-term clinical outcomes in both pediatric and adult

patients. The procedure proved to be an effective minimally invasive alternative to surgical repair, particularly in appropriately selected patients with perimembranous and muscular defects. Careful anatomical evaluation, individualized device selection, and imaging-guided deployment allowed successful management of anatomically challenging lesions, including defects associated with aneurysmal tissue and right coronary cusp prolapse, while preserving valvular function. Although major complications were uncommon, the occurrence of device embolization and procedure-related mortality emphasizes the importance of meticulous patient selection, operator expertise, and procedural planning. Overall, the findings support the growing role of transcatheter VSD closure as a safe, effective, and valve-preserving therapeutic strategy in resource-limited tertiary cardiac centers. Further prospective multicenter studies with long-term follow-up are needed to better evaluate durability, late complications, and long-term functional outcomes.

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