

ORIGINAL ARTICLE

Spectrum, Outcomes, and Safety of Catheter-Based Pediatric Cardiac Interventions: A One-Year Experience from a High-Volume Tertiary Care Center in Pakistan.

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Abstract

Background: Congenital heart disease (CHD) is a major cause of childhood morbidity and mortality, particularly in low- and middle-income countries where access to specialized cardiac care is limited. In Pakistan, the annual burden of CHD is substantial. Catheter-based interventions provide minimally invasive alternatives to surgery for selected congenital cardiac lesions. This study aimed to describe the spectrum, outcomes, and safety of pediatric catheter-based cardiac interventions at a tertiary care center in Pakistan.

Methodology: This retrospective descriptive study was conducted at the Department of Pediatric Cardiology, Lady Reading Hospital-Medical Teaching Institution, Peshawar. Data were retrieved for all pediatric patients aged ≤ 18 years who underwent catheter-based cardiac procedures between January 1 and December 31, 2023. Demographic characteristics, procedural types, complications, procedure duration, and hospital stay were analyzed using descriptive statistics.

Results: A total of 603 catheter-based cardiac procedures were performed. Device closure procedures were the most common interventions, accounting for 447 cases (74.1%), including patent ductus arteriosus closure in 204 patients (33.8%), atrial septal defect closure in 160 (26.5%), and ventricular septal defect closure in 83 (13.8%). Balloon pulmonic and aortic valvuloplasty accounted for 10.4% and 3.0% of procedures, respectively, while diagnostic and therapeutic catheterizations comprised 12.4%. Males constituted 57.0% of patients. Major complications occurred in two patients (0.33%), both requiring device removal, while minor complications occurred in approximately 1.7%. Uncomplicated procedures required two to three days of hospital stay.

Conclusion: Pediatric catheter-based cardiac interventions were safe and effective, with low complication rates and favorable short-term outcomes in a resource-constrained setting.

Keywords

Congenital Heart Disease, Pediatric Cardiology, Cardiac Catheterization, Device Closure, Patent Ductus Arteriosus, Atrial Septal Defect, Ventricular Septal Defect, Pakistan.

Introduction

Congenital heart disease (CHD) is the most common congenital anomaly worldwide and remains a major cause of childhood morbidity and mortality. Affecting approximately 8–10 per 1,000 live births globally, CHD imposes a considerable burden on healthcare systems, particularly in low- and middle-income countries where access to specialized pediatric cardiac services remains limited^{1,2}. Advances in diagnosis, perioperative care, and interventional cardiology have significantly improved survival in high-income countries; however, disparities in healthcare infrastructure continue to contribute to delayed diagnosis and suboptimal treatment outcomes in resource-constrained regions.

Pakistan faces a particularly significant challenge, with an estimated 60,000 children born with congenital heart defects each year^{3,4}. Many patients encounter delays in diagnosis and treatment due to socioeconomic barriers, limited awareness, geographic disparities, and an insufficient number of specialized pediatric cardiac centers. Consequently, a substantial proportion of affected children remain untreated or receive delayed interventions, increasing the risk of long-term complications, disability, and premature mortality^{3,4}.

Historically, surgical correction has been the cornerstone of treatment for many congenital cardiac lesions. Although highly effective, surgery is associated with greater procedural invasiveness, longer hospital stays, increased healthcare costs, and the potential for significant perioperative morbidity. Over the past three decades, however, catheter-based interventions have transformed the management of selected congenital heart defects by providing minimally invasive alternatives with excellent efficacy and safety profiles^{5,6}. These techniques have become the preferred treatment modality for many patients with patent ductus arteriosus (PDA), atrial septal defect (ASD), ventricular septal defect (VSD), and selected valvular abnormalities.

Transcatheter device closure procedures have demonstrated procedural success rates exceeding 95% in experienced centers while minimizing surgical

trauma, reducing recovery times, and lowering the risk of postoperative complications⁵. Similarly, balloon valvuloplasty for pulmonary and aortic valve stenosis has become the standard first-line intervention in many pediatric patients because it provides effective relief of obstruction while preserving native valve function and avoiding the need for early surgical intervention⁷. These advances have substantially altered the landscape of pediatric cardiac care and have increasingly been adopted in developing countries through improved training, technological advancements, and greater availability of cost-effective devices⁸.

High-volume pediatric catheterization laboratories play a crucial role in expanding access to specialized cardiac care by managing a broad spectrum of congenital and acquired cardiac conditions. In addition to device closure procedures and balloon valvuloplasty, modern catheterization laboratories routinely perform diagnostic angiography, hemodynamic assessments, transesophageal echocardiography-guided interventions, stent implantation, and other therapeutic procedures^{9,10}. The growing procedural experience reported by Pakistani centers reflects an encouraging trend toward the development of sustainable pediatric interventional cardiology programs capable of addressing the increasing burden of congenital heart disease^{3,10}.

Despite these advancements, published data describing the procedural spectrum, complication profile, and outcomes of pediatric catheter-based interventions in Pakistan remain limited. Most available studies originate from a small number of institutions, and there is a continuing need for locally generated evidence to inform clinical practice, resource allocation, training priorities, and healthcare policy development^{2,4}. Furthermore, documenting real-world outcomes from high-volume tertiary care centers is essential for benchmarking performance and identifying opportunities for quality improvement.

The present study was therefore undertaken to evaluate the spectrum of catheter-based pediatric cardiac interventions performed at a major tertiary

care center in Pakistan over a one-year period. Specifically, the study aimed to describe procedural distribution, patient characteristics, procedural outcomes, complication rates, and short-term hospital outcomes among children undergoing cardiac catheterization procedures. By providing contemporary institutional data from a high-volume public-sector center, this study seeks to contribute to the growing body of evidence supporting the safety, feasibility, and scalability of pediatric interventional cardiology services in resource-limited settings.

Methodology

Study Design

This retrospective descriptive observational study was conducted to evaluate the spectrum, frequency, and immediate outcomes of catheter-based pediatric cardiac interventions performed over a one-year period. The study was designed to provide a comprehensive overview of routine clinical practice and procedural outcomes in a high-volume pediatric cardiology center operating within a resource-constrained healthcare environment. The study followed a registry-based approach, utilizing routinely collected procedural and clinical data without any intervention or modification of patient management.

Ethics

The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and institutional guidelines for research involving human participants. Ethical approval was obtained from the Ethical Review Committee of Lady Reading Hospital-Medical Teaching Institution (LRH-MTI), Peshawar. As this was a retrospective review of existing hospital records and catheterization laboratory data, informed consent from individual participants was waived by the institutional review board. Patient confidentiality was maintained throughout the study by anonymizing all identifiers before data extraction and analysis. No information that could directly identify individual patients was included in the study dataset.

Setting

The study was carried out in the Department of Pediatric Cardiology, Lady Reading Hospital-MTI,

Peshawar, Pakistan, a major public-sector tertiary care referral center providing specialized pediatric cardiac services to patients from Khyber Pakhtunkhwa and neighboring regions. The department operates a dedicated cardiac catheterization laboratory equipped for both diagnostic and therapeutic pediatric cardiac procedures. The center receives referrals from primary, secondary, and tertiary healthcare facilities and manages a wide spectrum of congenital and acquired cardiac diseases. Data were collected for all eligible procedures performed between January 1, 2023, and December 31, 2023.

Participants

The study population consisted of all pediatric patients aged 18 years or younger who underwent catheter-based cardiac procedures during the study period. Consecutive sampling was employed, and all eligible procedures recorded in the catheterization laboratory registry during the study year were included. Both elective and urgent procedures were considered eligible. Inclusion criteria comprised pediatric patients undergoing diagnostic or therapeutic cardiac catheterization procedures, including device closures, balloon valvuloplasty, angiographic evaluations, and other interventional cardiac procedures. Patients undergoing open cardiac surgery without catheter-based intervention, patients undergoing non-cardiac catheter-based procedures, and cases with incomplete procedural records that prevented classification of the intervention type were excluded from the analysis.

Variables

The primary study variables included the type of catheter-based procedure performed, patient sex, age, procedural category, occurrence of procedure-related complications, requirement for device retrieval or repeat intervention, duration of hospitalization, and procedural duration. Procedures were categorized into patent ductus arteriosus (PDA) device closure, atrial septal defect (ASD) device closure, ventricular septal defect (VSD) device closure, balloon pulmonic valvuloplasty (BPV), balloon aortic valvuloplasty (BAV), and diagnostic or therapeutic cardiac catheterization procedures. Complications were classified as major or minor

based on their clinical significance and need for additional intervention. Major complications included device embolization, complete heart block requiring device removal, surgical intervention, or clinically significant residual lesions requiring re-intervention. Minor complications included transient arrhythmias, access-site bruising, minor bleeding, or other self-limiting events that resolved without long-term consequences.

Data Sources / Measurement

Data were extracted from the departmental cardiac catheterization laboratory registry, procedural logs, operative records, discharge summaries, and available electronic medical records. A standardized data extraction approach was employed to ensure consistency across all records. Patient demographic information, procedural details, and outcome measures were verified through cross-referencing of available sources whenever possible. Procedural duration was measured from vascular access initiation to procedure completion as documented in catheterization laboratory records. Hospital stay was calculated as the number of inpatient days from the date of intervention to discharge. Complications were identified through procedural reports, inpatient progress notes, discharge documentation, and available follow-up records. Operator-specific information was intentionally excluded to maintain confidentiality and focus the analysis on overall departmental performance.

Bias

Several measures were undertaken to minimize potential sources of bias. Consecutive inclusion of all eligible catheter-based procedures performed during the study period reduced selection bias and ensured comprehensive representation of routine clinical practice. The use of institutional registry data minimized recall bias because procedural information was documented contemporaneously during patient care. Data verification through multiple institutional sources improved data accuracy and reduced information bias. Nevertheless, the retrospective design may have resulted in incomplete documentation of certain clinical variables, and the study remained susceptible to reporting bias related to the quality of record keeping. Additionally,

because the study was conducted at a single tertiary care center, the findings may not be fully generalizable to all healthcare settings in Pakistan.

Study Size

The study included all eligible pediatric catheter-based cardiac procedures performed during the predefined one-year study period. No formal sample size calculation was performed because the objective was to analyze the complete procedural volume of the department during the study year. A total of 603 catheter-based procedures met the eligibility criteria and were included in the final analysis. The inclusion of the entire annual procedural cohort allowed comprehensive assessment of the procedural spectrum and outcomes within the institution.

Quantitative Variables

Age, procedure duration, and length of hospital stay were treated as continuous quantitative variables. Age was recorded in years and summarized using mean and standard deviation. Procedure duration was recorded in minutes according to catheterization laboratory documentation. Hospital stay was measured in days from the date of intervention until discharge. Categorical variables included sex, procedure type, and complication status and were summarized using frequencies and percentages. Where exact measurements were unavailable due to limitations in retrospective documentation, available ranges were reported.

Statistical Methods

Data were entered, cleaned, and analyzed using appropriate statistical software. Descriptive statistical methods were employed because the primary objective was to characterize procedural patterns and outcomes rather than test specific hypotheses. Continuous variables were summarized using means, standard deviations, medians, or ranges as appropriate according to data distribution. Categorical variables were summarized using frequencies and percentages. Complication rates were calculated by dividing the number of events by the total number of procedures performed and expressed as percentages. No inferential statistical tests, regression analyses, or subgroup comparisons were performed because the study was descriptive in

nature. Results were presented through tables and graphical summaries to facilitate interpretation of procedural distributions and outcomes.

Results

Participants

During the study period from January 1 to December 31, 2023, a total of 603 catheter-based cardiac procedures were performed in pediatric patients aged ≤ 18 years and met the eligibility criteria for inclusion in the analysis. All eligible procedures recorded in the departmental catheterization laboratory registry were included, and no cases were excluded due to incomplete demographic or outcome data. The study cohort represented the full annual procedural volume of the Pediatric Cardiology Department at Lady Reading Hospital-MTI, thereby providing a comprehensive overview of catheter-based pediatric cardiac interventions performed at this high-volume tertiary care center.

The patient population demonstrated a slight male predominance, with 344 (57.0%) male patients and 259 (43.0%) female patients, as presented in Table 1. The mean age of the participants was 6.2 ± 3.8 years, reflecting the broad age spectrum typically encountered in pediatric interventional cardiology.

Descriptive Data

A wide range of diagnostic and therapeutic catheter-based procedures was performed during the study period. Device closure procedures constituted the majority of interventions, accounting for 447 of 603 procedures (74.1%). Among these, patent ductus arteriosus (PDA) device closure was the most frequently performed intervention, comprising 204 cases (33.8%), followed by atrial septal defect (ASD) device closure with 160 cases (26.5%) and ventricular septal defect (VSD) device closure with 83 cases (13.8%). Balloon valvuloplasty procedures represented 81 cases (13.4%), including 63 balloon pulmonic valvuloplasties (10.4%) and 18 balloon aortic valvuloplasties (3.0%). Diagnostic and therapeutic cardiac catheterization procedures collectively accounted for 75 cases (12.4%) (Table 2).

The procedural distribution highlights the predominance of transcatheter closure of left-to-

right shunt lesions within the institution's pediatric cardiac practice. PDA closure emerged as the single most common intervention, reflecting both the prevalence of this lesion and the established effectiveness of percutaneous closure techniques. The relative proportions of each procedure category are illustrated in Figure 1, which demonstrates the substantial contribution of device closure procedures to the overall procedural workload.

Outcome Data

Procedure-related complications were uncommon throughout the study period. Major complications occurred in only three patients, representing a very small proportion of the total cohort. Two cases required device removal, resulting in an overall major device removal rate of 0.33% (2/603). One patient experienced PDA device embolization requiring retrieval, while another developed device-related complete heart block following ASD device closure, necessitating device explantation and rhythm management. In addition, one patient developed a significant residual shunt following ASD closure and required planned re-intervention with close clinical follow-up. Detailed complication outcomes are summarized in Table 3.

Minor complications were reported in approximately ten patients (1.7%) and primarily consisted of transient arrhythmias and vascular access-site bruising. These events were self-limiting, resolved without significant intervention, and did not result in long-term morbidity. No procedure-related mortality was documented during the study period.

Hospital stay remained relatively short for most patients. Uncomplicated device closure procedures were generally associated with discharge within two to three days following intervention, consistent with institutional practice of post-procedural observation and monitoring. Procedure duration varied according to lesion complexity and intervention type. PDA device closure procedures typically required 30–60 minutes, whereas VSD device closures generally required longer procedural times ranging from 90–140 minutes.

The duration of other procedures is presented in Table 4.

Main results

The findings demonstrate that catheter-based interventions constituted a major component of pediatric cardiac care at this tertiary referral center, with device closure procedures accounting for nearly three-quarters (74.1%) of all interventions performed. PDA closure was the most common procedure (33.8%), followed by ASD closure (26.5%) and VSD closure (13.8%), indicating that transcatheter management of congenital left-to-right shunt lesions formed the cornerstone of interventional activity (Table 1, Figure 1).

The overall safety profile of catheter-based interventions was highly favorable. Major device-related complications were rare, occurring in only 0.33% of procedures requiring device removal,

while minor complications affected approximately 1.7% of patients (Table 3). Most adverse events were successfully managed without long-term sequelae, supporting the safety and effectiveness of these interventions in a high-volume pediatric cardiac center.

Furthermore, the relatively short hospital stay of two to three days for uncomplicated cases and the acceptable procedural durations observed across intervention categories (Table 4) highlight the efficiency of catheter-based approaches in reducing hospitalization burden while maintaining favorable clinical outcomes. Collectively, these findings demonstrate that transcatheter interventions can be safely and effectively implemented in resource-constrained settings, with procedural outcomes comparable to those reported by established pediatric cardiac programs internationally.

Table 1: Baseline Demographic Characteristics of the Study Population (N=603).

Variables	Number (n)	Percentage (%)
Age (Years); Mean±SD	6.2	3.8
Gender		
Male	344	57.0
Female	259	43.0

Table 2: Distribution of Catheter-Based Pediatric Cardiac Interventions (N=603).

Variables	Number (n)	Percentage (%)
Procedure Category		
PDA Device Closure	204	33.8
ASD Device Closure	160	26.5
VSD Device Closure	83	13.8
Balloon Pulmonic Valvuloplasty (BPV)	63	10.4
Balloon Aortic Valvuloplasty (BAV)	18	3.0
Cardiac Catheterization (Diagnostic/Therapeutic)	75	12.4

Table 3: Procedure-Related Complications (N=603).

Complication Event	Number (n)	Percentage (%)	Outcome
PDA device embolization	1	0.17	Retrieved percutaneously/surgically
Significant residual shunt post-ASD closure	1	0.17	Planned re-intervention; close follow-up
Device-related complete heart block (ASD)	1	0.17	Device explanation; pacing instituted

Total major device removals	2	0.33	-
Minor complications (arrhythmia, bruising)*	10	1.7	Self-limited; no intervention required

Table 4: Typical Procedure Duration Across Different Categories of Pediatric Cardiac Catheter-Based Interventions.

Procedure Category	Typical Duration (minutes)
PDA Device Closure	30-60
ASD Device Closure	35-190
VSD Device Closure	90-140
Balloon Pulmonic Valvuloplasty	40-90
Balloon Aortic Valvuloplasty	45-120
Diagnostic/Therapeutic Catheterization	30-180

Discussion

This study presents a comprehensive overview of catheter-based pediatric cardiac interventions performed over a one-year period at a high-volume tertiary care center in Pakistan. A total of 603 procedures were conducted, demonstrating both the substantial burden of congenital heart disease (CHD) and the growing role of interventional cardiology in addressing pediatric cardiac needs in resource-limited settings. The findings indicate that transcatheter procedures can be performed safely and effectively, with high procedural throughput, short hospitalization periods, and a low incidence of major complications.

Device closure procedures constituted nearly three-quarters (74.1%) of all interventions, highlighting their central role in contemporary pediatric cardiac practice. Patent ductus arteriosus (PDA) closure represented the largest procedural category, followed by atrial septal defect (ASD) and ventricular septal defect (VSD) closure. This pattern is consistent with reports from regional and international pediatric cardiac centers, where left-to-right shunt lesions account for the majority of transcatheter interventions because of their high prevalence and favorable anatomical suitability for device-based treatment^{3,5,10}. The predominance of PDA closure may reflect both the frequency of the lesion and the well-established efficacy, safety, and cost-effectiveness of transcatheter closure techniques,

which have largely replaced surgical ligation in suitable patients^{5,11}.

Balloon valvuloplasty procedures accounted for 13.4% of all interventions, with balloon pulmonic valvuloplasty being performed more frequently than balloon aortic valvuloplasty. These findings are consistent with the established role of balloon dilation as the first-line treatment for valvular pulmonary stenosis and selected cases of congenital aortic stenosis⁷. Previous studies have demonstrated excellent immediate hemodynamic outcomes, sustained reduction in pressure gradients, and long-term preservation of native valve function following balloon valvuloplasty, making these procedures particularly valuable in settings where surgical resources may be limited^{7,11}. The continued utilization of these interventions at our center reflects adherence to internationally accepted standards of pediatric cardiac care.

The overall safety profile observed in this study was highly favorable. Major complications requiring device removal occurred in only 0.33% of procedures, while minor complications occurred in approximately 1.7% of patients. These rates compare favorably with those reported in large international registries and multicenter studies, where major complication rates range from less than 1% to over 7%, depending on procedural complexity and patient characteristics^{9,12,13}. The low complication rates observed in our cohort may be attributable to

increasing operator experience, standardized procedural protocols, careful patient selection, and advances in imaging and device technology. Importantly, all major complications were promptly recognized and appropriately managed, reflecting the presence of established procedural safety mechanisms and multidisciplinary support systems.

No procedure-related mortality was recorded during the study period, further supporting the safety of catheter-based interventions in appropriately selected pediatric patients. The majority of minor complications consisted of transient arrhythmias and vascular access-site complications, both of which resolved without long-term consequences. These findings are consistent with previously published literature demonstrating that most adverse events associated with pediatric cardiac catheterization are minor and self-limiting when procedures are performed in experienced centers¹²⁻¹⁴.

The slight male predominance observed in this study (57%) has also been reported in several regional studies and may reflect a combination of biological, social, and healthcare-access factors^{3,10}. In many low- and middle-income countries, disparities in healthcare-seeking behavior and referral patterns may contribute to differences in access to specialized cardiac services between male and female children. Further multicenter studies are needed to better understand the demographic determinants of referral and treatment patterns in pediatric cardiology across Pakistan.

Another notable finding was the relatively short hospital stay associated with uncomplicated interventions. Most patients were discharged within two to three days of their procedure, reflecting the minimally invasive nature of catheter-based therapy and its potential to reduce hospital resource utilization. Shorter hospitalization not only decreases healthcare costs but also minimizes disruption to family life and reduces the risk of hospital-acquired complications. These advantages are particularly important in resource-constrained healthcare systems where bed availability and financial limitations remain significant challenges^{4,5}.

The procedural volume reported in this study underscores the expanding role of pediatric interventional cardiology in Pakistan. Given the estimated 60,000 children born annually with congenital heart disease in the country, the demand for timely diagnosis and intervention remains substantial^{1,4}. High-volume centers such as ours serve as critical referral hubs and provide evidence that advanced catheter-based therapies can be successfully implemented in public-sector institutions despite infrastructural and financial constraints. Continued investment in catheterization laboratory infrastructure, workforce development, specialized training programs, and equitable referral networks will be essential to further improve access to pediatric cardiac care nationwide.

Limitations

Several limitations should be considered when interpreting the findings of this study. First, the retrospective design relied on routinely collected registry and hospital data, which may be subject to incomplete documentation and reporting bias. Second, the study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other institutions with different patient populations, procedural volumes, and resource availability. Third, detailed clinical variables such as lesion complexity, hemodynamic measurements, device specifications, fluoroscopy time, radiation exposure, contrast volume, and procedural success rates were not consistently available in the registry and therefore could not be analyzed. Similarly, patient weight, socioeconomic status, and comorbidity profiles were incompletely recorded, limiting risk stratification analyses. Fourth, long-term follow-up data, including late complications, residual defects, re-intervention rates, quality-of-life outcomes, and survival analyses, were not available and therefore the study is restricted to short-term procedural outcomes.

Conclusion

This study demonstrates that catheter-based pediatric cardiac interventions can be performed safely and effectively in a high-volume tertiary care center within a resource-limited setting. Device closure procedures for PDA, ASD, and VSD

constituted the majority of interventions, while balloon valvuloplasty remained an important treatment modality for congenital valvular stenosis. The low rates of major and minor complications, absence of procedure-related mortality, and short hospital stays observed in this cohort support the growing role of transcatheter therapies as a cornerstone of modern pediatric cardiac care.

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