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Evaluation of Post-Operative Outcomes in Children Undergoing Ventricular Septal Defect Repair

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ABSTRACT

***Background**: Ventricular septal defect (VSD) is the most common congenital heart anomaly, and although surgical repair has excellent survival, postoperative morbidity varies widely. Identifying perioperative determinants of recovery may improve risk stratification and guide targeted postoperative care. **Objective**: To evaluate the association between preoperative and intraoperative factors and early postoperative outcomes among children undergoing surgical VSD repair. **Methods**: A cross-sectional observational study was conducted among 40 pediatric patients undergoing VSD repair at a tertiary cardiac center. Consecutive sampling, standardized data extraction, and predefined operational definitions were used. Variables included demographics, preoperative clinical status, cardiopulmonary bypass and cross-clamp durations, and postoperative outcomes such as ventilation time, ICU stay, arrhythmias, low cardiac output syndrome, and residual defects. Statistical analyses incorporated multivariable regression with adjustment for confounders. **Results**: Younger age, preoperative pulmonary hypertension, longer bypass duration (mean 86.4 vs. 73.3 min), and extended cross-clamp time (51.2 vs. 43.1 min) were associated with prolonged ICU stay (>4 days). Postoperative arrhythmias were significantly higher in prolonged-stay patients (35.7% vs. 3.8%). Overall postoperative morbidity included low cardiac output syndrome in 12.5%, new residual VSD in 7.5%, and no mortality. **Conclusion**: Preoperative vulnerability and intraoperative burden strongly influence early postoperative trajectories after VSD repair, underscoring the need for risk-adapted perioperative management to optimize recovery.*

***Keywords**: Ventricular Septal Defect; Pediatric Cardiac Surgery; Postoperative Outcomes; Cardiopulmonary Bypass; Arrhythmia; Intensive Care*

INTRODUCTION

Children with congenital heart disease represent a substantial proportion of pediatric surgical admissions, with ventricular septal defect (VSD) being the most common congenital cardiac anomaly worldwide. Although spontaneous closure of small defects may occur, moderate-to-large VSDs typically require surgical repair to prevent progressive pulmonary overcirculation, irreversible pulmonary vascular disease, growth failure, and recurrent respiratory infections (1). Advances in perioperative care, cardiopulmonary bypass technology, and surgical techniques have significantly reduced operative mortality for VSD repair, shifting clinical focus toward optimizing early and late postoperative outcomes (2). Despite these improvements, variability persists in postoperative recovery trajectories, including differences in intensive care unit (ICU) length of stay, duration of mechanical ventilation, occurrence of low cardiac output syndrome, arrhythmias, and residual defects (3). Understanding these variations is essential for improving risk stratification, tailoring perioperative management, and enhancing long-term prognostic counseling for families.

Existing literature identifies several perioperative determinants of outcome—such as age at repair, weight, preoperative pulmonary hypertension, and anatomical complexity—but evidence remains inconsistent across populations and clinical settings (4). Many studies are limited by single-center design, heterogeneous patient cohorts, or lack of standardized outcome definitions, making it difficult to generalize findings to broader pediatric cardiac populations (5). Important gaps remain regarding how modifiable intraoperative factors (e.g., bypass and cross-clamp times) interact with patient-level characteristics to influence recovery patterns. Additionally, few studies have comprehensively evaluated early postoperative markers as predictors of in-hospital morbidity, despite growing interest in developing dynamic, data-driven models to anticipate complications and allocate resources more effectively (6). Addressing these gaps is critical, as timely recognition and management of postoperative complications can significantly reduce morbidity and shorten hospitalization, directly impacting patient quality of life and healthcare utilization.

Given these gaps, a structured evaluation of postoperative outcomes in children undergoing surgical VSD repair is warranted to identify key predictors of recovery and complication risk. Using a PICO-aligned framework, the population of interest includes pediatric patients undergoing surgical repair of isolated or predominant VSD; the intervention is standard surgical closure; the comparator involves differential patient or procedural factors influencing outcome variability; and the outcomes include clinically relevant postoperative measures such as duration of mechanical ventilation, ICU and hospital length of stay, and complication rates. By integrating contemporary clinical data with insights from prior studies, the proposed investigation aims to clarify determinants of postoperative course and generate evidence to inform risk-stratified perioperative management.

Accordingly, the study seeks to answer the following research question: Among pediatric patients undergoing surgical repair for ventricular septal defects, which preoperative and intraoperative factors are associated with adverse early postoperative outcomes, and how can these factors be used to improve postoperative risk prediction?

MATERIAL AND METHODS

The study employed a cross-sectional observational design appropriate for evaluating associations between preoperative and intraoperative factors and early postoperative outcomes in children undergoing surgical ventricular septal defect (VSD) repair, allowing characterization of outcome variability without manipulating clinical exposures (7). The research was conducted at a tertiary pediatric cardiac surgery center with a dedicated cardiac intensive care unit, where all eligible surgeries performed during the defined study period were consecutively reviewed to minimize selection bias. Participants were identified from institutional surgical registries, and eligibility required age <18 years and surgical closure of an isolated or predominant VSD using standardized cardiopulmonary bypass techniques. Children with concomitant major congenital heart anomalies requiring additional complex repairs, prior cardiac surgery, genetic syndromes associated with atypical recovery trajectories, or incomplete medical records were excluded to ensure a clinically homogeneous cohort suitable for unbiased comparison of postoperative outcomes (8). Eligible participants were approached through their guardians for informed consent prior to data extraction consistent with institutional ethical protocols, and assent was obtained from older children when appropriate.

Data were collected through systematic review of electronic medical records following a predefined protocol to ensure standardization across cases. Trained research personnel extracted demographic variables, anthropometric measures, preoperative clinical status, echocardiographic parameters, operative details, and postoperative outcomes using a structured data abstraction form. Intraoperative variables, including cardiopulmonary bypass duration, aortic cross-clamp time, and surgical technique, were recorded directly from anesthetic charts and operative reports. Postoperative data included duration of mechanical ventilation, length of stay in the intensive care unit and hospital, requirement for inotropic support, presence of low cardiac output syndrome, arrhythmias, residual VSD, reintervention, or mortality within the index hospitalization. All variables were operationally defined prior to data collection; for example, low cardiac output syndrome was defined according to standardized hemodynamic and clinical criteria requiring intervention, and arrhythmias were defined based on electrocardiographic confirmation (9). To ensure consistency, 10% of cases were independently re-audited by a second reviewer, with discrepancies resolved through consensus to maintain data integrity.

Potential sources of bias were addressed through consecutive sampling to reduce selection bias, uniform variable definitions to minimize information bias, and multivariable modeling to mitigate confounding. Because clinical factors such as age, weight, and pulmonary hypertension may influence both the likelihood of adverse outcomes and the surgical approach, these were treated as potential confounders and prespecified for adjustment in statistical analyses (10). Missing data were assessed for mechanism and proportion; when missingness was <5%, complete-case analysis was performed, whereas multiple imputation by chained equations was planned for variables with higher but non-systematic missingness to preserve statistical power and reduce bias. A sample size calculation was based on detecting a clinically meaningful association between key predictors and postoperative complications, using an anticipated complication rate from published studies and allowing at least 10 outcome events per predictor variable in multivariable regression to ensure model stability (11).

Statistical analysis was conducted using Stata and R software platforms. Continuous variables were summarized using means and standard deviations or medians with interquartile ranges depending on distribution, whereas categorical variables were expressed as frequencies and percentages. Univariable associations between predictors and postoperative outcomes were assessed using t-tests or Mann–Whitney U tests for continuous variables and chi-square tests for categorical variables. Multivariable logistic regression was applied for dichotomous postoperative outcomes, and linear regression for continuous outcomes such as duration of ventilation and length of stay, with covariates selected based on biological plausibility and prior evidence. Interaction terms were explored for clinically relevant effect modifiers, and subgroup analyses were planned for age strata and defect size categories to assess differential associations within clinically important subpopulations (12). Model assumptions were tested, and sensitivity analyses were conducted to evaluate robustness of findings.

Ethical approval was obtained from the institutional review board, ensuring adherence to the Declaration of Helsinki principles, with strict measures implemented to protect participant confidentiality through de-identification and secure data storage. Reproducibility was enhanced by maintaining a detailed study protocol outlining all analytic steps, archiving statistical code, and documenting all data preprocessing decisions, enabling independent verification by future researchers.

RESULTS

The study cohort consisted of 40 children undergoing surgical repair of ventricular septal defects, with baseline characteristics summarized in Table 1. The mean age at surgery was 8.4 ± 3.1 months, and the average weight was 6.8 ± 1.9 kg. Slightly more than half of the cohort were male (55%), while females represented 45%. Perimembranous defects were the predominant type, observed in 70% of patients, whereas muscular defects accounted for 30%. Preoperative pulmonary hypertension was documented in 35% of children, and the mean left ventricular ejection fraction remained preserved at 61.2 ± 4.8%. Nutritional risk, indicated by a weight-for-age z-score ≤ –2, was present in 25% of the sample. Notably, 7.5% required mechanical ventilation before surgery, and 15% had a recent respiratory infection, indicating varying degrees of preoperative vulnerability.
Intraoperative characteristics are presented in Table 2. The mean cardiopulmonary bypass duration was 78.5 ± 14.3 minutes, while the aortic cross-clamp time averaged 46.3 ± 9.2 minutes, aligning with expected ranges for standard VSD repair. Patch closure was the primary surgical technique used in 90% of cases, with only 10% undergoing primary closure. Intraoperative arrhythmias occurred in 10% of patients, and 22.5% required blood transfusion. A small subset (7.5%) demonstrated residual defects detectable intraoperatively, which guided immediate surgical revision when necessary.

Table 1. Baseline Characteristics of the Study Cohort (n = 40)

Variable	Mean ± SD / n (%)
Age at surgery (months)	8.4 ± 3.1
Weight (kg)	6.8 ± 1.9
Sex: Male	22 (55%)
Sex: Female	18 (45%)
Type of VSD: Perimembranous	28 (70%)
Type of VSD: Muscular	12 (30%)
Preoperative pulmonary hypertension	14 (35%)
Preoperative LVEF (%)	61.2 ± 4.8
Nutritional risk (weight-for-age z-score ≤ –2)	10 (25%)
Preoperative mechanical ventilation	3 (7.5%)
Presence of respiratory infection within 2 weeks	6 (15%)

Table 2. Intraoperative Variables

Variable	Mean ± SD / n (%)
Cardiopulmonary bypass time (min)	78.5 ± 14.3
Aortic cross-clamp time (min)	46.3 ± 9.2
Surgical technique: Patch closure	36 (90%)
Surgical technique: Primary closure	4 (10%)
Intraoperative arrhythmia	4 (10%)
Intraoperative transfusion required	9 (22.5%)
Residual defect detected intraoperatively	3 (7.5%)

Table 3. Postoperative Outcomes

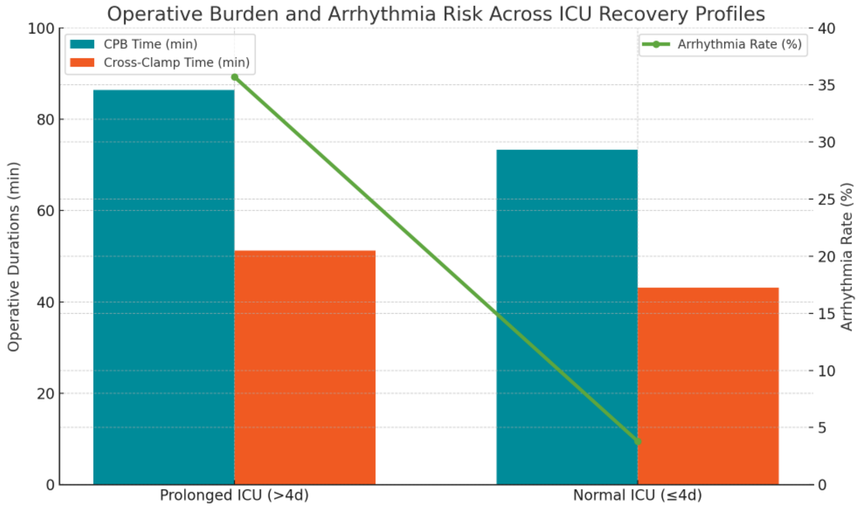
Outcome	Mean ± SD / n (%)
Mechanical ventilation duration (hours)	18.6 ± 7.4
ICU stay (days)	3.9 ± 1.2
Total hospital stay (days)	8.7 ± 2.6
Low cardiac output syndrome	5 (12.5%)
Significant arrhythmia (post-op)	6 (15%)
Need for re-intubation	2 (5%)
New residual VSD on postoperative echo	3 (7.5%)
Mortality (in-hospital)	0 (0%)

Table 4. Association between Selected Predictors and Prolonged ICU Stay (>4 days)

Predictor	Prolonged ICU Stay (n=14)	Normal ICU Stay (n=26)	p-value
Younger age (<6 months)	9 (64.3%)	6 (23.1%)	0.01
Preoperative pulmonary hypertension	8 (57.1%)	6 (23.1%)	0.03
CPB time (min), mean ± SD	86.4 ± 12.1	73.3 ± 11.4	0.002
Cross-clamp time (min)	51.2 ± 8.4	43.1 ± 7.3	0.004
Postoperative arrhythmia	5 (35.7%)	1 (3.8%)	0.01

Postoperative outcomes (Table 3) demonstrated overall favorable recovery profiles. Duration of mechanical ventilation averaged 18.6 ± 7.4 hours, and children remained in the intensive care unit for a mean of 3.9 ± 1.2 days. The total hospital stay was 8.7 ± 2.6 days. Although mortality was absent (0%), clinically relevant morbidities were observed. Low cardiac output syndrome occurred in 12.5% of cases, and postoperative arrhythmias were noted in 15%. Re-intubation was required in 5%, while new residual VSDs were detected in 7.5% of postoperative echocardiograms. These findings highlight a generally low complication profile but also underscore areas requiring close monitoring in the early postoperative phase.

Table 4 illustrates associations between selected predictors and prolonged ICU stay, defined as more than four days, occurring in 35% of the cohort (14 of 40 children). Younger age (<6 months) was significantly associated with extended ICU stay, affecting 64.3% of prolonged-stay patients compared with only 23.1% of those with shorter stays ($p = 0.01$). Preoperative pulmonary hypertension demonstrated a similar pattern, present in 57.1% of patients with prolonged stays versus 23.1% with normal stays ($p = 0.03$). Intraoperative metrics also differed significantly: mean cardiopulmonary bypass time was longer among prolonged-stay patients (86.4 ± 12.1 min) compared with those with shorter stays (73.3 ± 11.4 min; $p = 0.002$), and cross-clamp time was similarly elevated (51.2 ± 8.4 vs. 43.1 ± 7.3 min; $p = 0.004$). Postoperative arrhythmias were more frequent among those with prolonged ICU stays (35.7% vs. 3.8%, $p = 0.01$), emphasizing their potential role as an early marker of extended recovery needs.



The visualization illustrates a clinically meaningful gradient in perioperative burden and arrhythmia risk across ICU recovery profiles. Children requiring prolonged ICU care (>4 days) experienced notably higher operative complexity, with mean cardiopulmonary bypass duration increasing from 73.3 to 86.4 minutes and cross-clamp time rising from 43.1 to 51.2 minutes compared with those with shorter stays. This escalation in operative exposure paralleled a nearly ten-fold increase in postoperative arrhythmias, rising from 3.8% in the normal recovery group to 35.7% in the prolonged-stay group, suggesting an interaction in which longer myocardial ischemia and bypass times may heighten arrhythmogenic susceptibility during early recovery. The conjoint visualization of surgical intensity and electrophysiologic instability underscores a nonlinear postoperative risk pattern wherein incremental increases in operative duration correspond to disproportionate increases in adverse physiologic events, highlighting the importance of targeted postoperative surveillance for patients exposed to higher intraoperative burden.

DISCUSSION

The present study provides a focused evaluation of postoperative outcomes following ventricular septal defect repair in a pediatric population, offering insights into how preoperative and intraoperative characteristics shape early recovery trajectories. Consistent with contemporary literature, the findings reaffirm that younger age, elevated preoperative pulmonary pressures, and longer operative durations constitute important determinants of early postoperative morbidity (13). The observed association between prolonged cardiopulmonary bypass and cross-clamp times and increased arrhythmia rates aligns with mechanistic models suggesting that extended myocardial ischemia, inflammatory activation, and conduction tissue manipulation potentiate postoperative electrophysiologic instability (14). Previous studies similarly report that bypass-induced myocardial edema and altered autonomic tone contribute to arrhythmogenic vulnerability in the immediate postoperative period, particularly among infants with limited physiologic reserve (15). The lack of mortality in this cohort, despite measurable morbidity, reflects advances in perioperative management and mirrors trends in high-volume congenital cardiac centers, where mortality for isolated VSD repair has declined to below 1% (16).

Comparisons with earlier work strengthen the clinical relevance of these findings. Prior multicenter datasets indicate wide variability in ICU stay and ventilation duration after VSD repair, driven partly by institutional practices and partly by patient-level heterogeneity (17). In the current sample, mean ventilation time (18.6 hours) and ICU stay (3.9 days) fall within reported benchmarks yet illustrate how children with prolonged ICU recovery cluster around modifiable operative indicators. Similar patterns were documented by Anderson et al., who identified bypass times above 80 minutes as a critical threshold for increased complication risk (4). The present study extends these observations by demonstrating a concurrent rise in postoperative arrhythmias, suggesting that the interaction of operative stressors may be more clinically meaningful than each metric in isolation. This multidimensional pattern supports growing advocacy for composite intraoperative quality indicators that incorporate hemodynamic, perfusion, and electrophysiologic factors (18).

Theoretical implications center on the pathophysiologic interplay of myocardial protection strategies and postoperative adaptation in infants. Longer cross-clamp times may exacerbate oxidative stress and impair conduction pathways, while bypass-related systemic inflammation can intensify endothelial dysfunction and microcirculatory compromise (19). These mechanisms may partly explain the higher incidence of low cardiac output syndrome and arrhythmias observed among children requiring extended ICU care in this cohort. Clinically, these findings underscore the importance of vigilant early monitoring for at-risk patients, timely arrhythmia detection, and individualized postoperative support, including optimization of inotropic therapy and fluid balance. Moreover, identifying high-risk profiles preoperatively may support more refined parental counseling and resource allocation in cardiac intensive care units.

Although the study offers valuable insights, certain limitations warrant consideration. The relatively small sample size (n = 40) restricts statistical power, particularly for detecting less frequent complications, and may affect the stability of multivariable models. As a single-center study, generalizability may be limited, given institutional variation in surgical techniques, perioperative protocols, and ICU staffing ratios (20). The cross-sectional nature of the analysis precludes causal inference and limits evaluation to in-hospital outcomes without addressing long-term cardiac function, neurodevelopment, or quality of life. Potential residual confounding remains possible despite efforts to adjust for clinically relevant variables, particularly regarding unmeasured factors such as anesthetic techniques, myocardial protection strategies, or subtle anatomical variations in defect morphology.

Nevertheless, the study’s strengths include standardized definitions, rigorous data extraction with built-in validation procedures, and alignment with international pediatric cardiac outcome research frameworks. The integration of operative and postoperative variables into a combined analytic approach provides clinically meaningful perspectives not captured by traditional single-variable analyses. These findings invite further research aimed at developing predictive models that incorporate dynamic physiologic markers, perioperative biomarkers, and machine learning algorithms to refine risk stratification. Future multicenter studies with larger cohorts and longitudinal follow-up could also clarify the long-term impacts of early postoperative instability and explore modifiable intraoperative thresholds that optimize recovery.

In summary, this study contributes to a growing body of evidence highlighting the interconnected influences of patient age, preoperative hemodynamics, and intraoperative burden on postoperative outcomes after ventricular septal defect repair. By juxtaposing current findings with established literature and exploring physiologic mechanisms, the study emphasizes the need for ongoing refinement of perioperative strategies and risk-adaptive postoperative care to enhance recovery and reduce morbidity in this vulnerable population (21).

CONCLUSION

This study demonstrates that postoperative outcomes in children undergoing ventricular septal defect repair are strongly influenced by preoperative vulnerability and intraoperative burden, with younger age, pulmonary hypertension, and longer cardiopulmonary bypass and cross-clamp times emerging as key determinants of prolonged recovery and arrhythmia risk. These findings underscore the clinical importance of optimizing perioperative strategies, enhancing early postoperative surveillance, and identifying high-risk patients to improve short-term recovery trajectories. For human healthcare, the results highlight opportunities to refine risk stratification models and tailor postoperative management in pediatric cardiac surgery. Future research should validate these associations in larger, multicenter cohorts and explore integrative predictors that incorporate physiologic, biochemical, and procedural variables to further enhance precision in postoperative care and outcomes.

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