Surgical closure of ventricular septal defect: Contemporary results and risk factors for electrophysiological changes

Original Article

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ABSTRACT

Background: The surgical closure of a ventricular septal defect (VSD) is a commonly performed procedure. Postoperative ECG changes are common findings that need a proper assessment to provide valuable insights into the outcomes of the patients. In this study, we investigate the potential risk factors associated with electrophysiological changes following surgical closure of VSD.

Patients and Methods: A prospective, nonrandomized study was conducted from October 2020 to December 2022 on patients scheduled for VSD closure. Patients with prior abnormal congenital electrophysiological disturbances, internal pacemaker, Ebstein's anomaly, associated subaortic membrane or hypertrophic obstructive cardiomyopathy, iatrogenic VSD, and need aortic root dilatation with VSD closure were excluded. 12-lead ECG was reported on ICU admission and daily after that till discharge. Various demographic and perioperative data were recorded, and their correlation to the presence of electrophysiological changes and outcomes were analyzed.

Results: Two hundred patients who underwent surgical VSD closure were included. Arrhythmias occurred in 41 (20.5%) patients. The encountered arrhythmias were sinus bradycardia with junctional escape in 24 patients, junctional ectopic tachycardia in 10 patients, supraventricular tachycardia in two patients, premature complex in two patients, second-degree heart block in four patients, and third-degree block in two patients. Mother's hypertension, preoperative mechanical ventilation, associated cardiac anomalies, Down syndrome, size of VSD, type of VSD, total bypass time, aortic cross-clamp time, concomitant procedures, intraoperative pacing, and residual VSD were identified in univariate analysis as risk factors for occurrence of arrhythmias.

Conclusion: Surgical VSD closure is a safe procedure with low mortality and morbidity rates. Younger age and lower body weight are risk factors for prolonged hospitalization, ICU stay, and mechanical ventilation. Longer cross-clamp and cardiopulmonary bypass times were significant predictors of postoperative ECG changes and associated complications with prolonged ICU and hospital stay.

Key Words: ECG changes, outcome predictors, risk factors, surgical closure, ventricular septal defect.

Received: 30 June 2024, **Accepted:** 14 July 2024, **Published:** 4 October 2024

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ISSN: 1110-1121, October 2024, Vol. 43, No. 4: 1571-1578, © The Egyptian Journal of Surgery

INTRODUCTION

Ventricular septal defect (VSD) is the most common congenital heart anomaly, accounting for 40% of congenital heart diseases, and occurs in 0.34–2.68 per 1000 live births[1,2]. Surgical closure of VSD, first successfully performed by Lillehei and colleagues in 1954, remains the most common pediatric cardiac procedure[3,4]. Complications and outcomes differ between developed and developing countries. While mortality and morbidity have significantly decreased in Western countries, surgical outcomes remain poor for younger patients and those with low body weight at the time of surgery[5]. Recent studies have evaluated risk factors such as low body weight, severe pulmonary artery hypertension, and syndromic children as causes of high morbidity and mortality of VSD closure[6]. A contemporary study published after 2017 showed excellent results with low morbidity and no mortality. However, low body weight is still associated with increased ventilation duration but not adverse outcomes[5].

Even with the advancements in perfusion methods, surgical techniques, and intensive care management, arrhythmias remain a significant contributor to postoperative mortality and morbidity. The incidence of arrhythmia in the immediate postoperative phase has been reported at varying rates in the literature. Studies by Jain and colleagues, Pfammatter and colleagues, and Valsangiacomo and colleagues, have documented the occurrence of postoperative arrhythmias at 14.4, 27, and 48%, respectively[7–9].

Arrhythmia is usually caused by a direct trauma and ischemic or stretch injury to the atrioventricular (AV)

DOI: 10.21608/EJSUR.2024.300499.1111

conduction system during surgical repair of congenital heart defects. It has been suggested that being younger than 6 months old, prolonged cardiopulmonary bypass and aortic cross-clamp time, myocardial ischemia/injury, postoperative use of arrhythmogenic drugs, acidosis, electrolyte disturbance (hypomagnesemia, hypokalemia, or hypocalcemia), and hypovolemia may be possible risk factors. The type of cardiac surgery is another factor, especially those involving the crux of the heart including tetralogy of Fallot (TOF), AV canal, and VSD repair[10,11].

Arrhythmia is the most common cause of extended durations of ventilation, ICU stay, and hospital stay till patients become stable.

In this study, we are going to detect early electrophysiological changes after the closure of VSD and investigate the risk factors for these electrophysiological changes.

PATIENTS AND METHODS:

After approval of the local ethics committee, a cross-sectional prospective, nonrandomized study was carried out during the period from October 2020 to December 2022. All patients who were scheduled for surgical closure of VSD were included. Informed consent has been obtained for all patients or their guardians to participate in the study.

VSD closure was an isolated VSD or a VSD with concomitant cardiac defects like patent ductus arteriosus or mildly stenotic/regurgitant semilunar valves. Patients with prior pulmonary artery banding were also included. Patients with cardiac anomalies, including AV septal defect, severe stenosis or insufficiency of the semilunar valves, and , redo VSD post Fallot repair were also included, VSD closure was the main indication for surgical intervention in all patients.

Patients with prior abnormal congenital electrophysiological disturbances, internal pacemaker, Ebstein's anomaly, subaortic membrane with VSD, hypertrophic obstructive cardiomyopathy with VSD, iatrogenic VSD, need aortic root dilatation with VSD closure were excluded.

Preoperative data, including demographic data, mothers' related pregnancy disorders, any NICU admission, full history taking, full laboratories, 12-lead ECG, echocardiography reports, and medications, were recorded. In addition, postoperative continuous hemodynamic monitoring during the ICU period and 12-lead ECG were done during ICU admission and daily during the hospitalization time.

Transthoracic conventional echocardiography assessment for residual lesions and cardiac functions was done for all patients using GE (1 Neumann Way, Cincinnati, OH 45215,USA) IBM SPSS (Armonk, NY: IBM Corp) (vivid S5) with probe S3 or S6 according to patient age to get the best images.

All operations were done via the routine median sternotomy under a moderate hypothermic cardiopulmonary bypass with aortic and bicaval cannulations and antegrade blood cardioplegia. All VSD closures were accomplished through the right atrium by polytetrafluoroethylene patch, autologous pericardium, bovine pericardium, or Dacron patch, using continuous or interrupted suture technique.

Statistical analysis

Data were collected, revised, coded, and entered into the Statistical Package for Social Science (IBM SPSS), version 23. The quantitative data were presented as median with interquartile range and range when data were found to be nonparametric. Also, qualitative variables were presented as numbers and percentages.

The comparison between groups with qualitative data was done by using χ^2 test. The comparison between two independent groups with quantitative data and nonparametric distribution was done by using the Mann–Whitney test.

Univariate and multivariate logistic regression analysis was done to assess the principal factors associated with the occurrence of ECG changes with their odds ratio (OR) and 95% confidence interval (CI).

The CI was set to 95%, and the margin of error accepted was set to 5%. So, the *P value* was considered significant as the following: *P value* more than 0.05: nonsignificant, *P value* less than 0.05: significant, *P value* less than 0.01: highly significant.

RESULTS:

Two hundred patients have been included in the study. The median age of the patients was 22.5 months (range, 5–216 months), and the median body weight of the patients at the time of the operation was 10 kg, with a range of 4–60 kg. (Table 1) presents their demographic characteristics.

Two (1.0%) patients had an antenatal history of hypertension during pregnancy. Three (1.5%) patients were admitted to the NICU before surgery, and two (1.0%) required mechanical ventilation. The most frequent complex cardiac defects that need concomitant procedures were CAVC (n=58, 29%), followed by TOF (n=29, 14.5%), valvular pulmonary stenosis (n=2, 1.0%), redo VSD post Fallot repair (n=2, 1.0%), small pulmonary artery (n=2, 1.0%), patent ductus arteriosus (n=2, 1.0%), cleft mitral (n=2, 1.0%), and double outlet right ventricle (n=2, 1.0%). Down syndrome was the most common genetic anomaly (n=29, 14.5%). (Table 2) presents preoperative data for the studied patients.

The preoperative echocardiography showed the median size of the VSD was (6.25 mm; range, 5–9 mm), and types of VSD were 49 (24.5%) inlet-type VSD, 48 (24%) outlet-type VSD, and 103 (51.5%) perimembranous VSD (Table 3).

Continuous suture technique was used in 179 (89.5%) patients, while 21 (10.5%) patients were closed by interrupted technique. One hundred fifteen (57.5%) patients closed by polytetrafluoroethylene patch, 69 (34.5%) by autologous pericardium, 10 (5.0%) by bovine pericardium, six (3.0%) by dacron patch.

The median duration of cardiopulmonary bypass was 65 min (range, 38–200 min), the median aortic cross-clamp time was 45 min (range, 33–60 min), and 26 (13%) patients needed intraoperative cardiac pacing (Table 4).

At the postoperative time, the median mechanical ventilation time was 8 h (range, 5–120), median ICU stay was 48 h (range, 30–192), median hospital stay 5 days (range, 4–14).

Forty-one (20.5%) patients had postoperative ECG changes. The encountered arrhythmias included sinus bradycardia with junctional escape in 24 patients, junctional ectopic tachycardia in 10 patients, supraventricular tachycardia in two patients, premature complex in two patients, second-degree heart block four patients, and third-degree heart block two patients (Table 5).

Eleven (5.5%) patients showed residual VSD postsurgery, and they were treated conservatively as they were small (mean size was 3 mm and mean gradient was 90 mmHg).

In the hospital, mortality was four (2.0%) patients, first mortality occurred in a 6-month infant with large perimembranous VSD and severe pulmonary artery hypertension resulting in right-sided heart failure; second mortality occurred in 5 month Fallot tetralogy case with transannular patch due uncontrolled pulmonary hemorrhage, third mortality occurred in 4 month CAVC due to sepsis and DIC, fourth mortality occurred in 7 month Fallot tetralogy with total repair due to right-sided heart failure.

The univariate logistic regression analysis shows that associated cardiac cong., anomalies, extra-cardiac cong., anomalies, size more than 5.7 mm, inlet, outlet, and perimembranous types of VSD, resection of subpulmonary stenosis, pulmonary augmentation, ASD closure, mitral valve repair, total bypass more than or equal to 120 min, aortic cross-clamp time more than 45 min, residual VSD were found significantly associated with occurrence of ECG changes among the studied patients.

The multivariate logistic regression analysis shows that the risk factors associated with the occurrence of ECG changes were outlet VSD type with OR (95% CI) of 6.345 (2.411–16.699), and *P value* less than 0.001, mitral valve repair as a concomitant procedure with OR (95% CI) of 3.831 (1.421–10.327) and *P value* of 0.008, and aortic cross-clamp time more than 45 min with OR (95% CI) of 2.270 (1.013–5.090) and *P value* of 0.047.

Table 1: Relation between presence of ECG changes and patient demographics

	N=200
Patient demographics	
Age (month)	
Median (IQR)	22.5 (11–36)
Range	5–216
Sex [*n* (%)]	
Female	111 (55.5)
Male	89 (44.5)
Body weight (kg)	
Median (IQR)	10 (7–17.5)
Range	4–60
Mother’s data	
Pregnancy HTN [*n* (%)]	
No	198 (99.0)
Yes	2 (1.0)

IQR, interquartile range.

Table 2: Relation between presence of ECG changes and preoperative data

Preoperative data	No ECG changes [*n* (%)] *N*=159	ECG changes [*n* (%)] *N*=41	Test value	*P* value	Significance
NICU admission					
No	157 (98.7)	40 (97.6)	0.308*	0.579	NS
Yes	2 (1.3)	1 (2.4)			
Mechanical ventilator					
No	159 (100.0)	39 (95.1)	7.834*	0.005	HS
Yes	0	2 (4.9)			

Associated cardiac Cong. anomalies					
No	92 (57.9)	11 (26.8)	12.567*	0.000	HS
Yes	67 (42.1)	30 (73.2)			
CAVC	41 (25.8)	17 (41.5)	3.891*	0.049	S
Tetralogy of Fallot	21 (13.2)	8 (19.5)	1.045*	0.307	NS
Pulmonary stenosis	0	2 (4.9)	7.834*	0.005	HS
Redo VSD S/P Fallot	1 (0.6)	1 (2.4)	1.079*	0.299	NS
Small pulmonary artery	0	2 (4.9)	7.834*	0.005	HS
PDA	2 (1.3)	0	0.521*	0.470	NS
Cleft mitral	2 (1.3)	0	0.521*	0.470	NS
DORV	2 (1.3)	0	0.521*	0.470	NS
Extra-cardiac Cong. anomalies					
No	143 (89.9)	28 (68.3)	12.317*	0.000	HS
Down syndrome	16 (10.1)	13 (31.7)			

VSD, ventricular septal defect.

Table 3: Relation between presence of ECG changes and ventricular septal defect variables

		No ECG changes	ECG changes			
VSD variables	*N*=200	*N*=159	*N*=41	Test value	*P* value	Significance
Size (mm)						
Median (IQR)	6.25 (5–9)	6 (5–8)	8 (5.9–11)	–3.164≠	0.002	HS
Range	3–28	3–28	3–16			
Type [*n* (%)]						
Inlet	49 (24.5)	34 (21.38)	15 (36.6)	4.072*	0.044	S
Outlet	48 (24.0)	30 (18.87)	18 (43.9)	11.200*	0.001	HS
Perimembranous	103 (51.5)	95 (59.75)	8 (19.5)	21.127*	0.0001	HS
Restrictivity [*n* (%)]						
Nonrestrictive	180 (90.0)	141 (88.7)	39 (95.1)	1.503*	0.220	NS
Restrictive	20 (10.0)	18 (11.3)	2 (4.9)			

IQR, interquartile range; VSD, ventricular septal defect.

Table 4: Relation between presence of ECG changes and intraoperative data

	No ECG changes [*n* (%)]	ECG changes [*n* (%)]			
Intraoperative data	*N*=159	*N*=41	Test value	*P* value	Significance
Technique of closure					
Continuous	144 (90.6)	35 (85.4)	0.938*	0.333	NS
Interrupted	15 (9.4)	6 (14.6)			
Patch					
Gortex patch	92 (57.9)	23 (56.1)			
Autologous pericardium	54 (34.0)	15 (36.6)			
Bovine pericardium	9 (5.7)	1 (2.4)	1.365*	0.714	NS
Dacron patch	4 (2.5)	2 (4.9)			
Concomitant procedures					
No	90 (56.6)	8 (19.5)	17.945*	<0.001	HS
Yes	69 (43.4)	33 (80.5)			
Resection of subpulmonary stenosis	19 (11.9)	10 (24.4)	4.069*	0.044	S

Pulmonary augmentation	21 (13.2)	12 (29.3)	6.103*	0.013	S
ASD closure	41 (25.8)	19 (46.3)	6.558*	0.010	S
Mitral valve repair	43 (27.0)	19 (46.3)	5.675*	0.017	S
Aortic valve replacement	5 (3.1)	0	1.322*	0.250	NS
Pulmonary valve replacement	2 (1.3)	2 (4.9)	2.180*	0.140	NS
Debanding of pulmonary artery and augmentation	6 (3.8)	0	1.595*	0.207	NS
Transannular pulmonary patch	0	2 (4.9)	7.834*	0.005	HS
PDA ligation	2 (1.3)	0	0.521*	0.470	NS
Total bypass (min)					
Median (IQR)	60 (45–90)	90 (60–120)	–4.397≠	<0.001	HS
Range	38–200	50–175			
Aortic cross-clamp time (min)					
Median (IQR)	40 (30–60)	50 (45–65)	–3.841≠	<0.001	HS
Range	25–140	30–140			
Intraoperative cardiac pacing					
No	159 (100.0)	15 (36.6)	115.896*	<0.001	HS
Yes	0	26 (63.4)			

IQR, interquartile range.

Table 5: Relation between presence of ECG changes and postoperative data

Postoperative data	*N*=200
Ventilation (h)	
Median (IQR)	8 (8–12)
Range	5–120
ICU stay (h)	
Median (IQR)	48 (48–72)
Range	30–192
Hospital stay (days)	
Median (IQR)	5 (5–7)
Range	4–14
ECG changes [*n* (%)]	
No	159 (79.5)
Yes	41 (20.5)
Sinus bradycardia with junctional escape	24 (12.0)
Premature complexes	2 (1.0)
Supraventricular tachycardia	2 (1.0)
AV block II	4 (2.0)
AV block III	2 (1.0)
Junctional ectopic tachycardia	10 (5.0)

IQR, interquartile range.

DISCUSSION

Nowadays, surgical VSD closure is generally successful, with low mortality and complication rates. However, complications like ECG changes would still happen, leading to prolonged ICU and hospital stay[12,13].

The perimembranous VSD remains the most common location of VSD with 51.5%, which is supported by many studies being most common in location followed by inlet VSD 24.5%[14,15].

Saurav and colleagues and Scully and colleagues, reported that lower body weight and younger age are associated with postoperative ECG changes, while in our study, age and weight are insignificant factors that may be due to younger age and weight in Scully and colleagues, the median age was 10 months, and median weight was 7 kg[16,17].

The technique of closure and patch used in the closure of VSD had no role in ECG changes that occur in the early postoperative period, while concomitant procedures that lead to increased cardiac bypass time and aortic cross-clamp time had a significant effect on postoperative complications[6,18,19].

The incidence of arrhythmia is variable for each surgical procedure. In the study of Jain and colleagues, the complete AV block rate was the highest after AVSD, TOF, and Fontan surgery. On the other hand, the rate of JET was the highest after AVSD operation, intraventricular tunnel, and TOF surgeries[8]. In another study, Sahu *et al*.[20] reported that the most frequent postoperative arrhythmia was JET, and it was most commonly seen after AVSD and TOF operations. Alp *et al*.[21] also reported that different types of arrhythmias were seen in 41% of patients after VSD operation, in 25% of patients after atrial septal defect closure, in 11.4% of patients after TOF operation, and in 9.5% of AVSD cases. In our study, arrhythmias occurred in 41 (20.5%) patients sinus bradycardia with junctional escape and junctional ectopic tachycardia after TOF and AVSD surgeries were found to be significantly higher. Sinus bradycardia with junctional escape in 24 (12%) patients, junctional ectopic tachycardia in 10 (5%) patients, supraventricular tachycardia in two (1%) patients, premature complex in two (1%) patients, second-degree heart block in four (2%) patients and third-degree block in two (1%) patients while in Sahu *et al*.[20] the most common type of arrhythmias was junctional ectopic tachycardia[7].

Out of 24 patients who developed sinus bradycardia with junctional escape, 20 patients returned to normal sinus rhythm after correction of electrolytes and intravenous steroids, with three patients who showed sick euthyroid syndrome and needed thyroxin to be added.

For the other four patients, first case was CAVC, developed second-degree heart block and needed temporary pacing for 5 days, then returned to normal sinus rhythm, second case was Fallot with transannular patch developed JET with sudden drops in hemodynamics and pulmonary hemorrhage (second mortality case), third case was CAVC developed SVT needed amiodarone infusion and maintaining good preload, after 24 h returned to normal sinus rhythm, fourth case was perimembranous VSD developed a junctional rhythm with an accepted rate of 100 BPM.

Of 10 patients who developed JET, eight returned to normal sinus rhythm after different maneuvers like (decreasing inotropes if possible, optimizing electrolytes, correction of anemia, acidosis, hypoxia, adequate sedation, adequate analgesia, maintaining good preload, cooling the core temperature to 34–35°C and amiodarone infusion[10].

In the other two patients, first case was Fallot, with total repair, developed second-degree heart block and needed a permanent pacemaker in follow-up, second case was Fallot with transannular patch developed JET with sudden drops in hemodynamics and pulmonary hemorrhage (second mortality case).

Two patients who developed SVT returned to normal sinus rhythm after correction of electrolytes, maintaining good preload and amiodarone infusion. Two patients developed premature complex control after the correction of electrolytes.

Four patients developed second-degree heart block, three cases needed a permanent pacemaker, and only one case returned to normal sinus rhythm, while two patients developed third-degree heart block and needed a permanent pacemaker in follow-up.

Transient intraoperative cardiac pacing occurred in 26 (13%) patients, 11 patients after total repair of Fallot tetralogy, nine patients after CAVC repair, and six patients after isolated perimembranous VSD while in Gupta *et al*.[22], it was 30% of patients.

Patients who developed postoperative arrhythmias showed longer ventilation time that reached 96 h in some cases, longer ICU stays that reached 168 h, and longer hospital stay that reached 14 days[23].

CONCLUSION

VSD closure operations are safe surgical procedures with low mortality and morbidity rates. Young age and lower body weight are risk factors for prolonged hospitalization, prolonged pediatric ICU stay, and prolonged mechanical ventilation so VSD surgery should not be delayed due to weight or age. Early intervention prevents left-to-right shunt morbidity and mortality.

Although the presence of genetic syndrome did not affect the complication rates, it affected the length of hospital and PICU stays and mechanical ventilation duration.

Greater cross clamp time and cardiopulmonary bypass time were significant predictors of postoperative ECG changes and associated complications with prolonged ICU and hospital stay.

Limitation of study

(1) No genetic investigations were performed to evaluate the genetic contribution of arrhythmias associated with VSD closure.

(2) A single-center study with six surgeons and different teams involved in postoperative care was conducted.

CONFLICT OF INTEREST

There are no conflicts of interest.

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