Title

Modified single-patch repair for atrioventricular septal defects results in good functional outcomes in the absence of deep ventricular septal defects

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Glossary of Abbreviations

CAVSD = complete atrioventricular septal defect

CI = confidence interval

HR = hazard ratio

ICR = intracardiac repair

LAVV = left atrioventricular valve

LAVVR = left atrioventricular valve regurgitation

LVOT = left ventricular outflow tract

LVOTO = left ventricular outflow tract obstruction

MSP = modified single-patch repair

PAB = pulmonary artery banding

ROC = receiver operating characteristic

TP = two-patch repair

VSD = ventricular septal defect

Central Picture Legend

Modified single-patch repair-deep ventricular septal defect group showed the worst result.

Central Message

Moderate or greater left atrioventricular valve regurgitation after modified single-patch repair for patients with complete AVSD is comparable to two-patch repair unless deep VSD is present.

Perspective Statement

One surgical technique may not always be superior because each technique is best suited to specific anatomical configurations. Applying the right technique to the right anatomy will result in the best functional outcomes. The incidence of postoperative left atrioventricular valve regurgitation can still be reduced. Our findings provide guidance in choosing the optimal repair approach in such cases.

Abstract (250 words)

Objectives: We compared two-patch repair (TP) with modified single-patch repair (MSP) for complete atrioventricular septal defects (CAVSD) and evaluated their impact on the left atrioventricular valve (LAVV) competence. We also identified risk factors for unfavorable functional outcomes.

Methods: This retrospective study included 118 patients with CAVSD who underwent intracardiac repair (ICR) from 1998–2020 (MSP: 69, TP: 49). The median follow-up period was 10.4 years. The functional outcome of freedom from moderate or greater LAVV regurgitation (LAVVR) was estimated using the Kaplan–Meier method.

Results: The hospital mortality was 1.7% (2/118) and late mortality was 0.8% (1/118). Eight patients required LAVV-related reoperation (MSP: 4, TP: 4) and none required left ventricular outflow tract-related reoperation. In the MSP group without LAVV anomaly, the receiver operating characteristic curve analysis revealed that the ventricular septal defect (VSD) depth was strongly associated with moderate or greater postoperative LAVVR, with the best cutoff at 10.9 mm. When stratified by the combination of ICR type and VSD depth, the MSP-deep VSD (VSD depth > 11 mm) group demonstrated the worst LAVV competence among the four groups (*P* = .002). According to multivariate analysis, weight <4.0 kg, LAVV anomaly, and moderate or greater preoperative LAVVR were independent risk factors for moderate or greater postoperative LAVVR, while MSP was not a risk factor.

Conclusions: Postoperative LAVVR remains an obstacle to improved functional outcomes. MSP provides similar LAVV competence to TP unless deep VSD is present. The surgical approach should be selected based on anatomical variations, specifically VSD depth.

Keywords: atrioventricular septal defect, modified single-patch repair, left atrioventricular valve regurgitation, ventricular septal defect

INTRODUCTION

Excellent short- and long-term survival rates are usually achieved after surgical repair of balanced complete atrioventricular septal defects (CAVSD). Therefore, attention has shifted from mortality to functional outcomes or residual lesions that influence patients' quality of life. The most notable and troublesome postoperative complication is progressive left atrioventricular valve regurgitation (LAVVR), which sometimes requires surgical reinterventions followed by thorough medical intervention. Its incidence ranges from 7% to 14%.[1-5]

The evolution of surgical techniques includes the modified single-patch repair (MSP) first advocated by Wilcox et al. in 1997 and encouraged by Nicholson and Nunn in 1999.[6,7] Earlier intracardiac repair (ICR) has been facilitated by a distinctive procedure characterized as the "no ventricular septal defect (VSD) patch" technique.[8] This omission of the VSD patch closure, which is the most complicated part of two-patch repair (TP), especially for young infants, removes a potential error related to the VSD patch size and simplifies the entire procedure, contributing to shorter cardiopulmonary bypass and aortic cross-clamp times. However, this feature simultaneously raises a critical issue, as the atrioventricular valve is pulled down to the ventricular septal crest and might impair valve competence in the setting of a deep VSD.

Several reports have compared MSP and TP, including a recently published systematic review. However, no large study has investigated whether VSD depth affects the choice of surgical techniques from the perspective of long-term left atrioventricular valve (LAVV) competence. Therefore, we compared the impact of MSP and TP on the LAVV competence, stratified by VSD depth, over a 20-year period and identified morphological risk factors for moderate or greater postoperative LAVVR.

PATIENTS AND METHODS

This retrospective, nonrandomized, single-institution study included 118 patients with balanced CAVSD who underwent ICR at Okayama University Hospital between June 1998 and September 2020; 69 patients underwent MSP while 49 underwent TP. Patients with an associated diagnosis of tetralogy of Fallot or single papillary muscle were excluded. Our hospital's institutional review board approved this study, and the requirement for written informed consent was waived because of its observational nature (approval number 2009-023; approval date: October 23, 2020). A thorough retrospective review of the medical records was conducted. Preoperative, intraoperative, postoperative (before discharge), and follow-up data were collected from clinical reports.

Follow-up

Follow-up was completed in January 2021 with a median of 10.4 years (interquartile range [IQR], 4.9–14.4 years), which differed according to surgical approach, with a median of 7.1 (3.0–10.9) years in the MSP group and 14.8 (10.5–18.6) years in the TP group. A total of 113 out of 116 (97%) hospital survivors underwent complete follow-up, including echocardiography by a cardiologist in our hospital within a year of the end of the study period.

Study endpoints and measurements

The primary endpoints were survival, reoperation related to LAVVR, and moderate or greater postoperative LAVVR measured by echocardiography. All recordings of two-dimensional, M-mode, and Doppler images were repeatedly obtained by a few cardiologists specializing in echocardiography in conformance with the recommendations of the American Society of Echocardiography guidelines, and Z scores were generated.[9] Left ventricular end-diastolic diameter was measured during diastole in the parasternal short-axis view. The VSD depth was defined as the distance between the ventricular crest and the closed atrioventricular valvular leaflets during diastole in the four-chamber view. The VSD depth index was calculated and divided by the body surface area.

Mechanical ventilatory support was defined as a preoperative need for intubation. LAVV anomaly was defined as the presence of a double orifice LAVV, significant deficient lateral leaflet, or dysplastic leaflet.[10]

Operative technique

Criteria for primary ICR included body weight greater than 4 kg, no association with other cardiac anomalies, and no preoperative shock or other organ dysfunction; otherwise, pulmonary artery banding (PAB) was performed as the first palliation in symptomatic neonates or early infants who had large VSD leading to secondary LAVVR and congestive heart failure. These palliated patients were enrolled on the waiting list when their body weight exceeded 4 kg. All ICRs were performed via a median sternotomy with aortobicaval cannulation and moderate hypothermia. Although TP was performed exclusively by one surgeon (S.S.) until MSP was first introduced at our institution in 2002; thereafter, both techniques have been performed by two surgeons (S.S. and S.K.). The decision regarding the surgical technique was made by the professor of cardiovascular surgery in a multidisciplinary meeting, which included cardiologists, and was mostly determined by the presence of outlet extension VSD rather than VSD depth. The decision made was not reversed during the operation. MSP (Video 1) involved direct closure of the VSD component using multiple interrupted mattress sutures placed on the right side of the interventricular crest, passed through the bridging leaflets, whose division line had a slight shift to the right side, through the autologous pericardial patch that was to close the atrial septal defect, and through a thin felt strip. After these sutures were tied, the zone of apposition between the superior and inferior bridging leaflets in the LAVV was approximated with multiple interrupted simple sutures up to the point where the chordae inserted on the valve leaflet, unless this would have led to LAVV stenosis. The remainder of the pericardial patch was used to close the primum atrial septal defect while the coronary sinus was kept draining into the right atrium. The apposition zone in the right atrioventricular valve was also closed with one or two interrupted simple sutures. In TP, the VSD component was closed with a Dacron (DuPont de Nemours Inc, Wilmington, Delaware, USA) patch. Then a series of sutures were passed through the free edge of the patch, superior and inferior bridging leaflets, and the autologous pericardial patch and finally tied down. The remaining procedures were the same as for MSP.

Statistical analysis

Continuous variables were reported as median (interquartile range) for skewed data or mean (standard deviation) for values with normal distribution. Categorical variables were reported as absolute frequency (percentage). Continuous variables were compared using the *t*-test or Mann–Whitney U test based on the normality of the data. Categorical variables were compared using Pearson's χ^2 test. In cases where the expected frequency was less than 5, Fisher's exact test was used. Receiver operating characteristic (ROC) curves were calculated to determine the best cutoff value of VSD depth for moderate or greater postoperative LAVVR. Accuracy was measured by the area under the ROC curve. A multivariate Cox proportional hazards regression model was used to determine the independent risk factors of moderate or greater postoperative LAVVR, with a backward elimination strategy, beginning with a baseline model including all significant variables in univariate analysis ($P < .05$). Variables were subsequently removed one by one according to P-value (highest to lowest), to only include significant risk factors in the final model. The hazard ratios (HR) and 95% confidence intervals (CI) were reported for significant multivariate risk factors. Estimates of survival, freedom from reoperation, and moderate or greater LAVVR were made using the Kaplan–Meier method. Censoring was performed at the time of the last follow-up or death. The level of statistical significance was set at $P < .05$. All statistical analyses were performed with SPSS version 28 (IBM Corp. Armonk, NY, USA) and GraphPad Prism software version 9 (San Diego, CA, USA).

RESULTS

Demographics

Median age and weight at ICR were 176 (123–330) days and 5.3 (4.2–6.5) kg, respectively. Twenty-one (18%) patients weighed <4.0 kg. Thirty-nine (33%) patients underwent initial PAB for palliation. The characteristics of the patients who underwent MSP and TP were compared (Table 1). Age and weight at ICR were not different between the two groups. Trisomy 21 and Rastelli type C anatomy were more common in the TP group. Preoperative echocardiography before ICR showed that VSD depth in the MSP group was significantly less than that in the TP group. The VSD depth index in the MSP group was also significantly less than that in the TP group. Associated LAVV anomalies presented more often in the MSP group. The left ventricular dimension and proportion of patients with moderate or greater LAVVR were mostly equivalent between the two groups.

Operative data and mortality

Operative data are shown in Table 2. Mean aortic cross-clamp and cardiopulmonary bypass time, excluding 12 patients who underwent a concomitant procedure related to coarctation or interruption of the aorta during ICR, were significantly shorter in the MSP group.

Hospital mortality was 1.7% (2 out of 118). One patient (2 months, 2.8 kg) with preoperative heart failure with intubation who underwent TP as the primary ICR, died of persistent heart failure. Similarly, another patient (neonate, 3.3 kg) with preoperative heart failure with intubation, who underwent MSP as staged ICR, died of persistent heart failure. Late mortality occurred in one patient, who died of cerebral hemorrhage 10 months after discharge. The survival rate was 96.7% (95% CI, 92.2%–100%) overall, 96.7% (95% CI, 92.2%–100%) in the MSP group, and 98.0% (95% CI, 94.1%–100%) and 98.0% (95% CI, 94.1%–100%) in the TP group at 5 and 10 years, respectively (P = .746; Figure 1).

Functional outcomes in MSP and TP groups

Reoperations based on the surgical approach are summarized in Table 2. The criteria for reoperations included severe LAVVR or left ventricular outflow tract (LVOT) peak pressure gradient ≥ 50 mmHg.[11] Among the entire cohort, no reoperation was related to LVOT obstruction (LVOTO), and 8 (7%) patients required LAVV-related reoperations (4 patients each in the MSP and TP groups). Freedom from LAVV-related reoperation was observed in 94.2% (95% CI, 88.7%–99.7%) and 94.2% (95% CI, 88.7%–99.7%) in the MSP group, and 91.7% (95% CI, 83.9%–99.5%) and 91.7% (95% CI, 83.9%–99.5%) in the TP group at 5 and 10 years, respectively (P = .659) (Figure 2A).

All patients underwent postoperative echocardiography at the latest follow-up. The incidence of moderate or greater LAVVR was comparable between the two groups (MSP: 17 of 69 [25%], TP: 10 of 49 [20%]). Other variables, including LAVV inflow peak velocity and LVOT peak velocity, were also comparable. Freedom from moderate or greater LAVVR was 82.9% (95% CI, 73.7%–92.1%) and 76.2% (95% CI, 65.0%–87.4%) in the MSP group, and 91.7% (95% CI, 83.9%–99.5%) and 91.7% (95% CI, 83.9%–99.5%) in the TP group at 5 and 10 years, respectively (*P* = .009; Figure 2B).

Type of procedure and impact of VSD depth on late LAVVR

In the MSP group without LAVV anomaly, the ROC curve analysis revealed that the VSD depth was strongly associated with moderate or greater postoperative LAVVR, with the best cutoff at 10.9 mm (AUC: 0.742; 95% CI: 0.574–0.910; *P* = .013). In the TP group, on the other hand, the VSD depth was only minimally associated with moderate or greater postoperative LAVVR (AUC: 0.598; 95% CI: 0.370–0.827; *P* = .362). The VSD depth was plotted and stratified by the presence of LAVV anomaly, type of ICR, and postoperative LAVVR (Figure 3). Apparently, the calculated best cutoff value was only applicable to the MSP group without LAVV anomaly.

The whole cohort was further divided into four groups stratified by the combination of the type of ICR and VSD depth, defining the VSD depth > 11 mm as deep VSD and ≤ 11 mm as shallow VSD. Freedom from moderate or greater LAVVR at the 10-year follow-up visit was 92.0% (95% CI, 83.2%–100.0%) for the TP-shallow VSD group, 90.0% (95% CI, 71.4%–100.0%) for the TP-deep VSD group, 79.7% (95% CI, 68.7%–90.7%) for the MSP-shallow VSD group, and 50.0% (95% CI, 10.0%–90.0%) for the MSP-deep VSD group (*P* = .002; Figure 4). Thus, the MSP-deep VSD group demonstrated the worst LAVV competence among these four groups, significantly lower than in the other three groups. There was no difference among the three groups except in the

MSP-deep VSD group (P = .238).

Risk factors for moderate or greater postoperative LAVVR

In the whole cohort, multivariate analysis indicated weight <4.0 kg, LAVV anomaly, and moderate or greater preoperative LAVVR as independent risk factors for moderate or greater postoperative LAVVR, while MSP was not detected as a risk factor (Table 3).

DISCUSSION

Considering the current emphasis on better functional outcomes, our study demonstrated excellent surgical outcomes of balanced CAVSD with a low overall mortality rate (2.5%, 3/118), infrequent reoperation related to LAVVR (6.7%, 8/118), and a low proportion of moderate or greater postoperative LAVVR (23%, 27/118) during a postoperative follow-up period of 20 years. Identified risk factors for later LAVV incompetence in the whole cohort did not involve MSP. Further, the VSD depth in the MSP group had a strong association with unfavorable valve competence on ROC analysis. At first glance, the functional outcome of TP appears to be superior to MSP; however, when stratified by the combination of ICR type and VSD depth, only the MSP for the deep VSD group demonstrated the stepwise decline of functional outcome, while the other three groups showed durable LAVV competence (Figure 5, Video Abstract). This implied that the functional outcomes were comparable between the groups if the VSD was relatively shallow (VSD depth ≤ 11 mm). These findings indicate that specific anatomy should be taken into consideration when choosing the surgical technique.

Postoperative LAVVR and its risk factors

Management of recurrent LAVVR in the pediatric population is especially problematic. Far from expected reverse remodeling of the ventricle, moderate LAVVR immediately after operation leads to left ventricular failure from progressive volume overload with various alterations to whole valve complex, such as annular dilatation, dislocation of papillary muscles, and further degenerative changes in the leaflets. Therefore, every effort should be made to avoid postoperative LAVVR before discharge, as this is reportedly a risk factor for recurrent LAVVR.[12] The etiology of postoperative LAVVR could be multifactorial and is typically due to technical issues. However, many articles have reported low body weight as an underlying issue owing to the friable leaflet tissue in its original state.[13-16] St. Louis et al. reviewed 2399 patients with CAVSD from the Society of Thoracic Surgeons Congenital Heart Surgery Database from 2008–2011.[13] They demonstrated that risk factors for poor outcomes (mortality, complications) included early repair (<2.5 months) and low weight (<3.5 kg). Recently, some studies have advocated early repair at less than 3 months of age, but there is a trend toward impaired long-term survival in young patients or patients who had primary ICR.[17, 18] We have been incorporating a staged surgical approach for high-risk patients, including young patients and those with low body weight because they have fragile leaflets and determining the division line of the AVV should be accurate. The PAB does not work for the primary LAVVR but is quite effective for congestive heart failure triggered due to large VSD and the secondary LAVVR. In our cohort, 39 patients underwent primary PAB with employment of a flow probe in addition to the Trusler's formula to increase the blood flow through the ascending aorta by one-and a half times, resulting in no interstage mortality after PAB. With a safe and optimal alternative approach, facing a small and fragile leaflet can be avoided.

Some researchers have demonstrated significant preoperative LAVVR as a predisposing factor, which could be explained by LAVV anomaly or annular dilatation.[5, 19, 20] In our study, the z score of the preoperative left ventricular end-diastolic diameter did not affect postoperative LAVVR. One reason for this may be the tendency to use PAB in most symptomatic neonates or early infants, which dramatically reduces the size of the ventricles. Of the 12 patients with significant preoperative LAVVR, 5 patients had an associated LAVV anomaly. Although primary LAVVR must have resulted from a certain rationale or etiology, which were undetected from clinical reports, preoperative LAVVR was a comprehensive anatomical factor associated with some type of anomaly resulting in unfavorable valve competence.

LAVV anomaly, which has also been recognized as a risk factor for postoperative LAVVR, was identified as a risk factor in our study.[5,21-23] They are relatively uncommon but challenging when present; hence, fine modification in addition to the standard technique is required. Other technical aspects, such as cleft closure, have not been included as a variable in this study because our institutional policy has consistently been to close the cleft. We sometimes encounter a relatively small bridging leaflet. Closing these would lead to a new tethered anterior leaflet, which is similar to the “curtain effect” in the adult cardiac mitral field.[24] In that case, patch augmentation would be one of the options.

Modified single-patch repair vs. two-patch repair

There has long been a debate that MSP is superior to TP. Recent comparative retrospective studies with propensity score matching analysis and a single meta-analysis showed no difference between the two regarding mortality and reoperation.[1, 3, 25] These studies, however, included VSD width as an anatomical variable for the matching cohort, but we identified VSD depth as a critical component for late LAVVR when MSP was used. While direct suturing of the common atrioventricular valve leaflet to the crest of the ventricular septum offers uncomplicated manipulation, therefore minimizing cross-clamp time, this might tether the bridging leaflets to some extent. Theoretically, the sole remaining concern is that coaptation between the left lateral leaflet and sutured bridging leaflets would become shallow regardless of the VSD depth. However, the extent to which the completed valve complex can tolerate distortion of the new annulus and leaflets is of concern. Backer has advocated recommending MSP when the VSD depth is 10 mm or less and that its use should be avoided in cases of VSD depth more than 12 mm.[8, 26] In our study, the best cutoff point of VSD depth for unfavorable valve competence was similarly determined to be 11 mm. Since a scooping VSD (VSD depth > 11 mm) was present in only 15 (13%) of the 118 patients in the present study, the majority of patients with CAVSD can safely benefit from MSP, which provides simpler and shorter manipulation. Since MSP can easily be taught and grasped by trainees, requiring a shorter learning curve, it could become a reproducible standard procedure.[27]

Inadequate coaptation can occur even when TP is utilized with a patch that is larger or smaller than the actual VSD depth. Furthermore, suturing the atrial septal defect from the VSD patch through bridging leaflets enfolds the leaflets, especially when the suture line is reinforced, leading to reduced coaptation length.[27] This multiple suturing becomes particularly critical when the repair is performed for neonates or early infants, whose leaflet tissue can be characterized as flimsy.[27] A jungle of chordae around the crest of the ventricular septum, as seen in Rastelli A anatomy, complicates VSD patch closure and can result in entanglement or injury of the chordae.

There are multiple mechanisms of LAVVR, as mentioned above. Of these, surgical approach and timing of repair still play a key role as convertible factors for better and more durable LAVV competence. We found that functional outcomes were comparable between the two groups unless the VSD was deep. Each technique is best suited to a specific anatomy. Our results suggest that the choice of surgical technique should be determined based on the anatomical suitability of each approach rather than based on a decision made irrespective of structural characteristics. Neither adopting the MSP for scooping VSD nor sticking to the TP for superficial VSD with Rastelli A should be recommended, as each has its role. Applying the appropriate technique for specific anatomical characteristic creates the best functional outcomes.

Finally, the present study comprises another striking finding, a lack of LVOTO-related reoperation, which incidence have been reported from 1.3% to 3.7%[1-3,28]. According to Overman, the “scooped out" interventricular septum was more common in Rastelli type C than in Rastelli type A, and thus the lateral aspect of neo-LVOT tunnel can be squashed to some extent by the MSP[29]. Therefore, our modification that shifts the dividing line of bridging leaflets to the right side contributes to securing more room in the tunnel, as Backer previously mentioned[30]. MSP is not a predisposing factor to LVOTO as long as it incorporates the modification technique and is used with VSD not further extending toward the outlet portion.

Limitations

This study had the typical limitations of any retrospective study: selection bias and lack of randomization. Based only on the data available with a few events, it is not possible to ascertain if the variables that were not included in the multivariate analysis affected the findings. Although all echocardiography had been performed by a few cardiologists specializing in echocardiography, no core labs or examiners reviewed the echocardiographic data in this study. Hence, echocardiography data may be dependent on the skills of the reader. The follow-up length was shorter in the MSP group, which may be insufficient to detect a significant difference between the two groups.

Conclusions

Postoperative LAVVR is still an obstacle to better functional outcomes and quality of life. Unless VSD is deep, MSP and TP provide similar LAVV competence. The appropriate surgical approach should be selected according to the patient's anatomy, specifically VSD depth.

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Table 1. Patient demographics

Characteristics	**Modified single-patch (n = 69)**		**Two-patch (n = 49)**		***P*-value**
Male sex	28	(41)	14	(29)	0.179
Age at ICR (days)	189	(121–327)	167	(121–342)	0.770
Weight at ICR (kg)	5.3	(4.3–6.2)	4.8	(4.0–6.7)	0.592
Trisomy 21	37	(54)	40	(82)	0.002
Patent left superior vena cava	9	(13)	2	(4)	0.119
Coarctation or interruption of aorta	11	(16)	1	(2)	0.014
Mechanical ventilatory support	3	(4)	4	(8)	0.447
Rastelli type					0.019
A	51	(74)	26	(53)	
C	18	(26)	23	(47)	
Initial pulmonary artery banding	24	(35)	15	(31)	0.635
Echocardiographic data before ICR					
VSD depth (mm)	7.3	±2.5	8.9	±2.5	<0.001
VSD depth index (mm/m^2)	25.1	±10.0	30.8	±8.7	0.002
LVEDD (mm)	22.7	±4.0	22.3	±4.2	0.644
LVEDD Z score	-0.7	±2.1	-0.8	±2.5	0.820
Moderate or greater LAVVR	12	(17)	6	(12)	0.444
LAVV anomaly	9	(13)	1	(2)	0.044

Data presented as median (interquartile range) or n (%) or mean (± SD). ICR, intracardiac repair; LAVV, left atrioventricular valve; LAVVR, left atrioventricular valve regurgitation; LVEDD, left ventricular end-diastolic diameter; VSD, ventricular septal defect

Table 2. Perioperative and postoperative results							
Characteristics	**Overall**		**Modified single-patch**		**Two-patch**		***P*-value**
(Limited to) Isolated CAVSD repair	**n = 106**		**n = 58**		**n = 48**		
Aortic cross-clamp time (min)	89	±26	82	±23	100	±28	0.001
Cardiopulmonary bypass time (min)	128	±36	120	±35	137	±38	0.035
Postoperative results	**n = 118**		**n = 69**		**n = 49**		
Surgical reintervention							
LAVV-related	8	(7)	4	(6)	4	(8)	0.717
RAVV-related	1	(1)	1	(1)	0	(0)	1.000
LVOTO-related	0	(0)	0	(0)	0	(0)	-
Pacemaker insertion	2	(2)	1	(1)	1	(2)	1.000
Hospital mortality	2	(2)	1	(1)	1	(2)	1.000
Late mortality	1	(0)	1	(1)	0	(0)	1.000
Long-term follow-up echocardiography							
Moderate or greater LAVVR	27	(23)	17	(25)	10	(20)	0.590
LAVV inflow peak velocity (m/s)	1.2	±0.3	1.2	±0.3	1.2	±0.3	0.743
LVOT peak velocity (m/s)	1.2	±0.3	1.2	±0.3	1.2	±0.3	0.405

Data presented as median (interquartile range) or n (%) or mean (± SD). CAVSD, complete atrioventricular septal defect; ICR, intracardiac repair; LAVV, left atrioventricular valve; LAVVR, left atrioventricular valve regurgitation; LVOT, left ventricular outlet tract; LVOTO, left ventricular outlet tract obstruction; RAVV, right atrioventricular valve

Table 3. Univariate and multivariate analysis of risk factors for moderate or greater preoperative LAVVR in the whole cohort (n = 118)

Characteristics	**N**	**%**	**Univariate analysis**			**Multivariate analysis**		
			HR	**(95% CI)**	***P*-value**	**HR**	**(95% CI)**	***P*-value**
Weight <4.0 kg	21	(18)	3.435	(1.539–7.667)	0.003	7.375	(2.953–18.42)	<0.001*
Trisomy 21	77	(65)	0.364	(0.167–0.792)	0.011			
Patent left superior vena cava	11	(9)	0.706	(0.382–1.305)	0.267			
Coarctation or interruption of aorta	12	(10)	2.657	(0.771–9.153)	0.121			
Rastelli type A	77	(65)	1.774	(0.714–4.411)	0.217			
Initial pulmonary artery banding	39	(33)	1.560	(0.688–3.537)	0.287			
VSD depth > 11 mm	15	(13)	2.959	(1.301–6.732)	0.010	2.363	(0.954–5.853)	0.063
LAVV anomaly	10	(9)	9.555	(3.742–24.40)	<0.001	6.773	(2.409–19.04)	<0.001*
Moderate or greater preoperative LAVVR	18	(15)	6.760	(3.067–14.90)	<0.001	5.367	(2.242–12.85)	<0.001*
Modified single-patch	69	(58)	3.621	(1.326–9.888)	0.012	2.633	(0.966–7.175)	0.058

HR, hazard ratio; CI, confidence interval; LAVV, left atrioventricular valve; LAVVR, left atrioventricular valve regurgitation; VSD, ventricular septal defect

* *P*-value < 0.05 (multivariate)

Figure legends

Figure 1. Kaplan–Meier curves for overall survival stratified by the type of ICR. Color shading shows the 95% confidence intervals.

ICR, intracardiac repair; MSP, modified single-patch repair; TP, two-patch repair

Figure 2. Kaplan–Meier curves for functional outcomes stratified by the type of ICR.

(A) Freedom from LAVV-related reoperation. (B) Freedom from moderate or greater LAVVR. Color shading shows the 95% confidence intervals.

ICR, intracardiac repair; LAVV, left atrioventricular valve; LAVVR, left atrioventricular valve regurgitation; MSP, modified single-patch repair; TP, two-patch repair

Figure 3. Scatter plots of the VSD depth stratified by presence of LAVV anomaly, type of ICR, and postoperative LAVVR. Solid and dashed lines show the best cutoff value (11 mm) of the VSD depth, which is only applicable to the MSP group without LAVV anomaly.

ICR, intracardiac repair; LAVV, left atrioventricular valve; LAVVR, left atrioventricular valve regurgitation; MSP, modified single-patch repair; TP, two-patch repair; VSD, ventricular septal defect

Figure 4. Kaplan–Meier curves for freedom from moderate or greater LAVVR stratified by the combination of the type of ICR and VSD depth. The dotted line shows the 95% confidence intervals.

ICR, intracardiac repair, LAVVR, left atrioventricular valve regurgitation; MSP, modified single-patch repair; TP, two-patch repair; VSD, ventricular septal defect

Figure 5. When stratified by the combination of ICR type and VSD depth, the MSP-deep VSD group demonstrated the worst LAVV competence among the four groups (*P* = .002). The surgical approach should be selected based on anatomical variations, specifically VSD depth.

ICR, intracardiac repair, LAVV, left atrioventricular valve; MSP, modified single-patch repair; TP, two-patch repair; VSD, ventricular septal defect

Video 1. Modified single-patch repair for atrioventricular septal defect.

Video Abstract. A summary of the principal findings of the present study.