

Right Vertical Infra-Axillary Minithoracotomy Versus Median Sternotomy for Doubly Committed Subarterial Ventricular Septal Defect: A Retrospective Cohort Study of 689 Patients

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Abstract

Background:

Minimally invasive approaches are increasingly used for surgical repair of congenital heart defects. However, evidence for right vertical infra-axillary minithoracotomy (RVIAT) in doubly committed subarterial ventricular septal defect (dcVSD) remains limited. This study compared the perioperative outcomes of median sternotomy and RVIAT in patients with dcVSD and evaluated the safety, feasibility, and overall incision-related satisfaction of RVIAT.

Methods:

This single-center retrospective study included 689 consecutive patients with dcVSD who underwent primary surgical repair between January 2021 and October 2025. Patients were classified into two groups according to the incision type: the median sternotomy group (Mid group, $n = 222$) and the right thoracic incision group (Right group, $n = 467$). Perioperative outcomes, postoperative complications, follow-up findings, and a five-level overall incision-related satisfaction rating were compared between groups. Age-stratified analyses and propensity score matching (PSM) were performed to reduce the impact of baseline differences.

Results:

Compared with the Mid group, patients in the Right group had significantly shorter hospital stay and mechanical ventilation duration (both $P < 0.001$). Cardiopulmonary bypass (CPB) time and cardiac intensive care unit (CICU) stay were comparable between groups. Age-stratified analyses showed subgroup-specific differences, whereas PSM confirmed shorter hospital stay and mechanical ventilation duration in the Right group. The incidence of residual shunt remained low and comparable both postoperatively and at 6-month follow-up (all $P > 0.05$). Similarly, no significant differences were observed in the progression of aortic regurgitation or reoperation rates. No in-hospital mortality occurred. Overall incision-related satisfaction was significantly higher in the Right group than in the Mid group (84.3% vs. 36.0%, $P < 0.001$).

Conclusions:

In patients with dcVSD, the RVIAT approach provides perioperative safety and clinical outcomes comparable to those of median sternotomy, and higher reported overall incision-related satisfaction at six months. It provides a feasible alternative to median sternotomy.

Trial registration

Clinical trial number: Not applicable.

Background

Doubly committed subarterial ventricular septal defect (dcVSD) is a type of ventricular septal defect located in the outlet (infundibular) septum. It is characterized by fibrous continuity between the aortic and pulmonary valves because of absence or deficiency of the subpulmonary infundibulum¹. Median sternotomy has long been the standard surgical approach for this condition because it provides excellent exposure and facilitates operative manipulation. However, in pediatric and adolescent patients, the perioperative and long-term drawbacks associated with median sternotomy should not be overlooked. These include greater bleeding, longer hospitalization, a higher risk of surgical site infection, and psychological burden and cosmetic concerns related to visible scarring^{2,3}.

In recent years, the right vertical infra-axillary minithoracotomy(RVIAT) approach has shown promising early outcomes in the treatment of dcVSD. It offers less surgical trauma and improved cosmetic results^{4,5}. As shown in Fig. 1, the use of RVIAT increased steadily over the study period. However, existing studies are largely limited to small sample sizes or preliminary reports. Robust evidence regarding perioperative safety, technical reproducibility, and mid- to long-term outcomes in large consecutive cohorts remains limited. This study therefore systematically evaluated the safety, feasibility, and overall incision-related satisfaction of RVIAT in dcVSD repair. It also aimed to provide stronger clinical evidence for its standardized application.

Methods

A retrospective review was performed on 689 patients with dcVSDs who underwent primary surgical repair at our center between January 2021 and October 2025. The inclusion criteria were as follows: (1) diagnosis of dcVSD confirmed by preoperative echocardiography; and (2) first-time definitive surgical repair. The exclusion criteria included: (1) complex congenital heart disease requiring concomitant complex procedures; and (2) previous cardiac surgery. Patients were categorized according to the surgical approach into the median sternotomy group (Mid group, n = 222) and the right thoracic incision group (right group, n = 467).

All patients underwent repair of dcVSD under general anesthesia with endotracheal intubation and cardiopulmonary bypass (CPB). The repair strategy was determined by the operating surgeon based on intraoperative anatomical findings. No case in the right group required conversion to median sternotomy. Perioperative variables, including hospital stay, CPB time, cardiac intensive care unit (CICU) stay, and mechanical ventilation time, as well as follow-up outcomes such as residual shunt and aortic valve function, were compared between the two groups.

The study was approved by the institutional ethics committee. Owing to the retrospective design and the use of de-identified data, the requirement for written informed consent was waived.

Continuous variables were presented as median (interquartile range, IQR) and compared using the Wilcoxon rank-sum test because of non-normal distribution. Categorical variables are expressed as counts (percentages) and compared using the Pearson χ^2 test or Fisher's exact test, as appropriate. All statistical tests were two-tailed, and a P value < 0.05 was considered statistically significant. Statistical analyses were performed using R software (version 4.5.2).

Operative technique

In the Right group, patients were placed in the left lateral decubitus position. After routine skin preparation and draping, a longitudinal incision was made along the right mid-axillary line. The thoracic cavity was entered through the fourth intercostal space. The pericardium was opened and suspended to provide adequate exposure of the heart and great vessels. Purse-string sutures were placed on the ascending aorta, superior vena cava, and right atrial appendage. After systemic heparinization, CPB was established by cannulation of the ascending aorta and superior vena cava. Inferior vena cava cannulation was subsequently performed under parallel circulation, and caval snares were applied to both the superior and inferior venae cavae.

After aortic cross-clamping, cold blood cardioplegia was administered through the aortic root to achieve cardiac arrest. The ventricular septal defect was exposed through an incision in the right ventricular outflow tract or the pulmonary artery. Intraoperative assessment confirmed the diagnosis of dcVSD. After measuring the defect size, closure was performed with an autologous pericardial patch or a synthetic patch using continuous suturing. A saline test of the tricuspid valve after repair showed no significant regurgitation.

Subsequently, intracardiac de-airing was performed, and the aortic cross-clamp was removed to restore coronary perfusion. The heart resumed beating spontaneously in most cases, usually with sinus rhythm. Intraoperative transesophageal echocardiography confirmed the absence of residual shunt and significant aortic regurgitation. CPB was weaned gradually once hemodynamic stability was achieved. After decannulation of the ascending aorta and venae cavae, heparin was neutralized with protamine. A right pleural drainage tube was placed, and the incision was closed in layers after meticulous hemostasis. Patients were transferred to the intensive care unit with endotracheal intubation.

In the Mid group, a standard midline sternotomy was performed. CPB was established routinely. After aortic cross-clamping and cardiac arrest, the defect was exposed through the pulmonary artery or right ventricular outflow tract. It was then closed with a patch using continuous suturing. The remaining procedures were similar to those described for the Right group.

Transthoracic echocardiography was routinely performed postoperatively and at 6 months of follow-up, with additional assessments conducted as clinically indicated.

Results

Demographic and baseline clinical characteristics are summarized in Table 1. Age and body weight differed between the two surgical groups. In the Mid group, the median age was 268.00 (119.00–1085.75) days and the median weight was 9.15 (6.50–13.35) kg. In the Right group, the median age was 444.00 (202.50–1243.50) days and the median weight was 10.30 (8.00–15.50) kg. The proportion of male patients was 68.9% in the Mid group and 63.4% in the Right group, indicating a comparable sex distribution between groups.

Table 1
Demographic and clinical data of patients

Variable	Mid	Right	P value
Weight (kg)	9.15 (6.50-13.35)	10.30 (8.00-15.50)	< 0.001
Age (days)	268.00 (119.00-1085.75)	444.00 (202.50-1243.50)	< 0.001
Male, n (%)	153 (68.9)	296 (63.4)	0.18
Female, n (%)	69 (31.1)	171 (36.6)	

Because significant baseline differences in age and body weight were observed between the two groups (Figs. 4 and 5), age-stratified analyses were conducted to minimize the potential confounding effect on perioperative outcomes. As shown in Table 2, body weight remained generally comparable between the Mid and Right groups within most age strata. Overall, age stratification substantially reduced the baseline imbalance in age between groups, although a residual difference in body weight persisted in the 3–6 months subgroup.

Table 2
Age-stratified baseline body weight comparison between the Mid and Right groups

Age group	Mid, n	Right, n	Weight (kg), Mid	Weight (kg), Right	P value
0–3 months	25	11	5.0 (4.5–5.6)	5.3 (4.85–5.9)	0.388
3–6 months	55	75	6.5 (5.45–7.15)	6.8 (6.05–7.65)	0.008
6–12 months	41	127	8.4 (7.5–9.3)	8.5 (7.5–9.5)	0.327
> 1 year	101	254	14.0 (11–20)	15.0 (12–20.08)	0.437

Perioperative outcomes are summarized in Table 3. Compared with the Mid group, the Right group had a significantly shorter hospital stay and mechanical ventilation time (both $P < 0.001$). CPB time and CICU stay did not differ significantly between groups (both $P > 0.05$). These findings may suggest that the RVIAT approach may facilitate postoperative recovery without prolonging CPB time and CICU time.

Table 3
Perioperative outcomes

Variable	Mid	Right	P value
Hospital stay (days)	10.00 (8.00–12.00)	8.00 (7.00–11.00)	< 0.001
CPB time (min)	57.00 (49.00–65.75)	55.00 (44.50–68.00)	0.178
CICU stay (days)	2.00 (1.00–3.00)	2.00 (2.00–2.00)	0.153
Mechanical ventilation (h)	6.88 (4.60–23.25)	5.50 (4.17–16.25)	< 0.001

Because significant differences in age and body weight were observed between the Mid and Right groups at baseline, age-stratified analyses were performed to further evaluate perioperative outcomes.

As shown in Table 4, age-stratified analyses revealed shorter CPB time in the Right group among patients younger than 6 months. Hospital stay was significantly shorter in the Right group in the 3–6 month and 6–12 month subgroups. CICU stay differed between groups in the 6–12 month and > 1 year subgroups, whereas mechanical ventilation time was comparable across all age strata.

Table 4
Age-stratified comparison of perioperative outcomes (Mid vs Right)

Age group	Hospital stay (days)	P value	CPB time (min)	P value	CICU stay (days)	P value	Mechanical ventilation (h)	P value
0–3 months	12 (10–15) vs 15 (12–21)	0.224	62 (56–70) vs 45 (42–55)	0.002	4 (3–5) vs 3.5 (2.25–4.75)	0.926	40.23 (24.38–48.53) vs 26.26 (20.72–43.02)	0.547
3–6 months	11 (10–14) vs 9 (8–12)	< 0.001	56 (45.5–64.5) vs 49 (38.5–59)	0.013	3 (2–4.75) vs 2 (2–3)	0.12	20.88 (6.71–43.79) vs 21.32 (5.62–27.1)	0.271
6–12 months	9 (8–12) vs 8 (7–10.75)	0.032	55 (47–62) vs 56 (43.5–68)	0.934	2 (1–2) vs 2 (2–2)	0.023	6.29 (4.48–18.03) vs 6.17 (4.68–15.07)	0.82
> 1 year	8 (7–10) vs 8 (7–10)	0.83	58 (50–66) vs 57 (46–72.75)	0.806	1 (1–2) vs 2 (2–2)	< 0.001	5.18 (3.8–7.1) vs 4.95 (3.8–7)	0.79

Although age-stratified analyses reduced the impact of age-related heterogeneity, residual baseline differences between the two groups could not be completely excluded. Therefore, propensity score matching (PSM) was performed to minimize potential selection bias and confounding effects.

Patients were matched in a 1:1 ratio based on age, body weight, and sex, resulting in a matched cohort of 444 patients (222 patients in each group). Perioperative outcomes in the matched cohort are summarized in Table 5. No significant differences were observed between the Mid and Right groups in CPB time ($P = 0.494$) or CICU stay ($P = 0.643$). After PSM, patients in the Right group had a shorter hospital stay ($P < 0.001$) and shorter duration of mechanical ventilation ($P < 0.001$) compared with those in the Mid group.

These findings suggest that RVIAT achieves perioperative outcomes comparable to median sternotomy while offering potential advantages in postoperative recovery.

Table 5
PSM-matched comparison of outcomes

Variable	Mid	Right	P value
Hospital stay (days)	10.00 (8.00–12.00)	8.00 (7.00–10.00)	< 0.001
CPB time (min)	57.00 (49.00–65.75)	58.00 (46.00–71.75)	0.494
CICU stay (days)	2.00 (1.00–3.00)	2.00 (2.00–2.00)	0.643
Mechanical ventilation (h)	6.88 (4.60–23.25)	5.13 (4.00–9.49)	< 0.001

The median follow-up duration was 6 months. No perioperative or late mortality occurred during follow-up. No evidence of cardiac function deterioration was observed, and all patients were classified as New York Heart Association (NYHA) functional class I at follow-up.

The incidence of residual shunt immediately after surgery was low in both groups. It occurred in 0.21% (1/467) of the Right group and 0.45% (1/222) of the Mid group, with no significant difference between groups ($P = 0.541$). At 6-month follow-up, the incidence of residual shunt remained low. It was 0.86% (4/465) in the Right group and 0.90% (2/222) in the Mid group ($P = 1.000$). All residual shunts were trivial and presented as small jet flows.

During follow-up, aortic regurgitation was predominantly absent, trivial, or mild, with no cases of severe regurgitation observed. Progression of aortic regurgitation occurred in 1 patient (0.49%) in the Mid group and 1 patient (0.22%) in the Right group. No significant difference was found between groups ($P = 0.455$). Reoperation rates were low in both groups. They occurred in 0.45% (1/222) and 0.43% (2/467), respectively ($P = 1.000$).

Overall, RVIAT demonstrated comparable rates of residual shunt, aortic regurgitation progression, and reoperation to the median sternotomy approach, without an increased risk of adverse outcomes.

Table 6
Comparison of postoperative and follow-up clinical outcomes

Variable	Mid	Right	P value
Residual shunt (postoperative)	1 (0.45%)	1 (0.21%)	0.541
Residual shunt (follow-up)	2 (0.90%)	4 (0.86%)	1
Aortic regurgitation progression	1 (0.49%)	1 (0.22%)	0.455
Reoperation	1 (0.45%)	2 (0.43%)	1
Overall satisfaction(very good and excellent)	76 (36.02%)	380 (84.26%)	< 0.001

Overall satisfaction with the surgical incision/scar was recorded at the six-month follow-up using a single five-level item (poor, fair, good, very good, or excellent). Ratings of very good or excellent were grouped as high overall satisfaction for the reported comparison. The item was study-specific and was not a validated scar assessment scale. Ratings were available for 211 of 222 patients in the Mid group and 451 of 467 patients in the Right group; analyses of this outcome used available responses. The English presentation of the analyzed item is provided in Supplementary File 1.

During follow-up, no chest wall deformity or breast asymmetry was observed. Scars in the Right group were typically located in the axillary region and were relatively well concealed. Patients in the Right group reported higher overall incision-related satisfaction than those in the Mid group at 6-month follow-up (84.3% vs. 36.0%, $P < 0.001$).

Discussion

The present study represents one of the largest single-center analyses comparing RVIAT with conventional median sternotomy for dcVSD repair. The principal findings were threefold. First, RVIAT achieved perioperative and mid-term outcomes comparable to those of median sternotomy, with no increase in residual shunt, progression of aortic regurgitation, reoperation, or mortality. Second, patients undergoing RVIAT experienced faster postoperative recovery, reflected by shorter hospital stay and mechanical ventilation. Third, the minimally invasive approach was associated with substantially greater overall incision-related satisfaction at six months.

DcVSD remains a unique subtype of ventricular septal defect because of its close anatomical relationship to the aortic valve. Progressive aortic cusp prolapse and aortic regurgitation may occur if the defect is left untreated, emphasizing the importance of timely and technically precise surgical repair. Median sternotomy has been the standard approach for correcting congenital heart defects for decades because it provides unrestricted exposure of the great vessels and ventricular outflow tracts, resulting in reliable surgical outcomes. However, the visible anterior chest scar and the potential risk of breast asymmetry may impose a psychological burden and cosmetic concerns, particularly in children, adolescents, and female patients^{6–8}. With the advancement of minimally invasive cardiac surgery, RVIAT

approaches have been increasingly applied in the treatment of various congenital heart diseases, demonstrating potential advantages in reducing surgical trauma and improving cosmetic outcomes^{9–11}.

Previous studies have demonstrated that the RVIAT approach yields favorable clinical outcomes in a variety of congenital heart defects, including ventricular septal defect, tetralogy of Fallot, and partial atrioventricular septal defect, with superior cosmetic results and better scar concealment^{12–14}. Various exposure strategies have been reported for minimally invasive repair of dcVSD, including approaches via the tricuspid valve, pulmonary artery, right ventricular outflow tract, or a left anterior minithoracotomy, all of which have shown good reproducibility with increasing surgical experience^{11,15–18}. However, closure through the tricuspid valve may be limited by suboptimal exposure, often requiring additional maneuvers to improve visualization^{19–21} and the left anterolateral thoracotomy approach may result in noticeable breast or pectoral muscle asymmetry²². In the present study, we preferentially adopted a fourth intercostal approach with exposure through the pulmonary artery or right ventricular outflow tract, which provided satisfactory visualization while maintaining the minimally invasive nature of the procedure.

A notable finding of the present study is the use of both age-stratified analyses and propensity score matching. Patients selected for RVIAT were generally older and heavier than those undergoing median sternotomy, reflecting the practical tendency of surgeons to favor minimally invasive approaches in patients with more favorable anatomical characteristics. Such baseline differences could potentially confound outcome comparisons. After adjustment through age stratification and propensity score matching, the observed advantages of RVIAT in postoperative recovery remained consistent. These findings suggest that the shorter hospital stay and reduced duration of mechanical ventilation are unlikely to be solely attributable to differences in patient characteristics and may instead reflect the intrinsic benefits of avoiding median sternotomy. Although some subgroup differences in CICU stay were observed, the absolute magnitude of these differences was small and was not accompanied by prolonged mechanical ventilation or hospitalization, suggesting limited clinical significance.

An additional strength of the current study was the comparable procedural safety between surgical strategies. Cardiopulmonary bypass duration did not differ significantly between groups after adjustment for baseline differences, indicating that the minimally invasive approach did not increase operative complexity. More importantly, postoperative and follow-up echocardiographic assessments demonstrated similarly low rates of residual shunt and aortic regurgitation progression. Given the anatomical proximity of dcVSD to the aortic valve, preservation of aortic valve competence represents a critical measure of surgical quality. Our findings suggest that RVIAT can achieve the same degree of repair completeness and valve protection as conventional sternotomy when performed in appropriately selected patients.

Several factors may account for the enhanced postoperative recovery observed in the Right group. Compared with median sternotomy, the axillary approach preserves sternal integrity and reduces disruption of the anterior chest wall, potentially resulting in less surgical trauma and earlier postoperative mobilization. The limited incision and reduced tissue dissection may also contribute to a

lower physiological stress response, facilitating recovery after surgery. Consistent with these potential advantages, patients undergoing RVIAT experienced shorter durations of mechanical ventilation and hospital stay. Similar findings have been reported in previous studies of minimally invasive approaches for congenital cardiac surgery, supporting the concept that reduced surgical invasiveness may translate into improved early postoperative recovery.

Incision-related satisfaction represents another important consideration, particularly in pediatric patients with an expected long lifespan after repair. The RVIAT incision is concealed within the axillary region and is generally less visible during routine activities. In the present study, the proportion reporting very good or excellent overall satisfaction with the incision/scar was higher in the Right group than in the Mid group. However, the single study-specific rating does not quantify scar appearance, symptoms, or function separately. Longer-term evaluation with a validated scar-specific patient-reported measure would provide a more complete assessment. These findings suggest that RVIAT can provide higher overall incision-related satisfaction without compromising surgical safety, which may be particularly valuable for female patients and families with greater cosmetic expectations.

The present study has several limitations. First, its retrospective and single-center design inherently introduces the possibility of selection bias despite the application of age-stratified analyses and propensity score matching. Second, unmeasured confounding variables may still have influenced surgical selection and clinical outcomes. Third, the median follow-up duration of six months limits assessment of long-term durability. This is particularly relevant for late aortic valve function, chest wall development, and patient-reported quality of life. Finally, incision-related satisfaction was assessed using a single study-specific item rather than a validated scar-specific patient-reported outcome measure. Future prospective multicenter studies with longer follow-up are warranted to validate these findings and further define the role of RVIAT in the management of dcVSD.

Conclusions

Overall, the findings of the present study indicate that RVIAT provides a safe and effective alternative to conventional median sternotomy for dcVSD repair. By combining excellent surgical outcomes with faster recovery and higher overall incision-related satisfaction, this approach may represent an increasingly attractive strategy in contemporary congenital cardiac surgery.

Abbreviations

RVIAT: right vertical infra-axillary minithoracotomy

dcVSD: doubly committed subarterial ventricular septal defect

PSM: propensity score matching

CPB: cardiopulmonary bypass

CICU: cardiac intensive care unit

NYHA: New York Heart Association

Declarations

Ethical approval and consent to participate

The present study was approved by the Ethics Committee of Shanghai Children's Medical Center (SCMCIRB-K2026232-1) and was conducted in accordance with the Declaration of Helsinki. The requirement for informed consent to participate was waived by the Ethics Committee of Shanghai Children's Medical Center because of the retrospective nature of the study and the use of de-identified data.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

XL and WB collected and analyzed the clinical data, performed the statistical analyses, and drafted the manuscript. MY and YP conceived and designed the study, participated in the surgical procedures, supervised the study, and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Trial registration

Clinical trial number: Not applicable.

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Figures

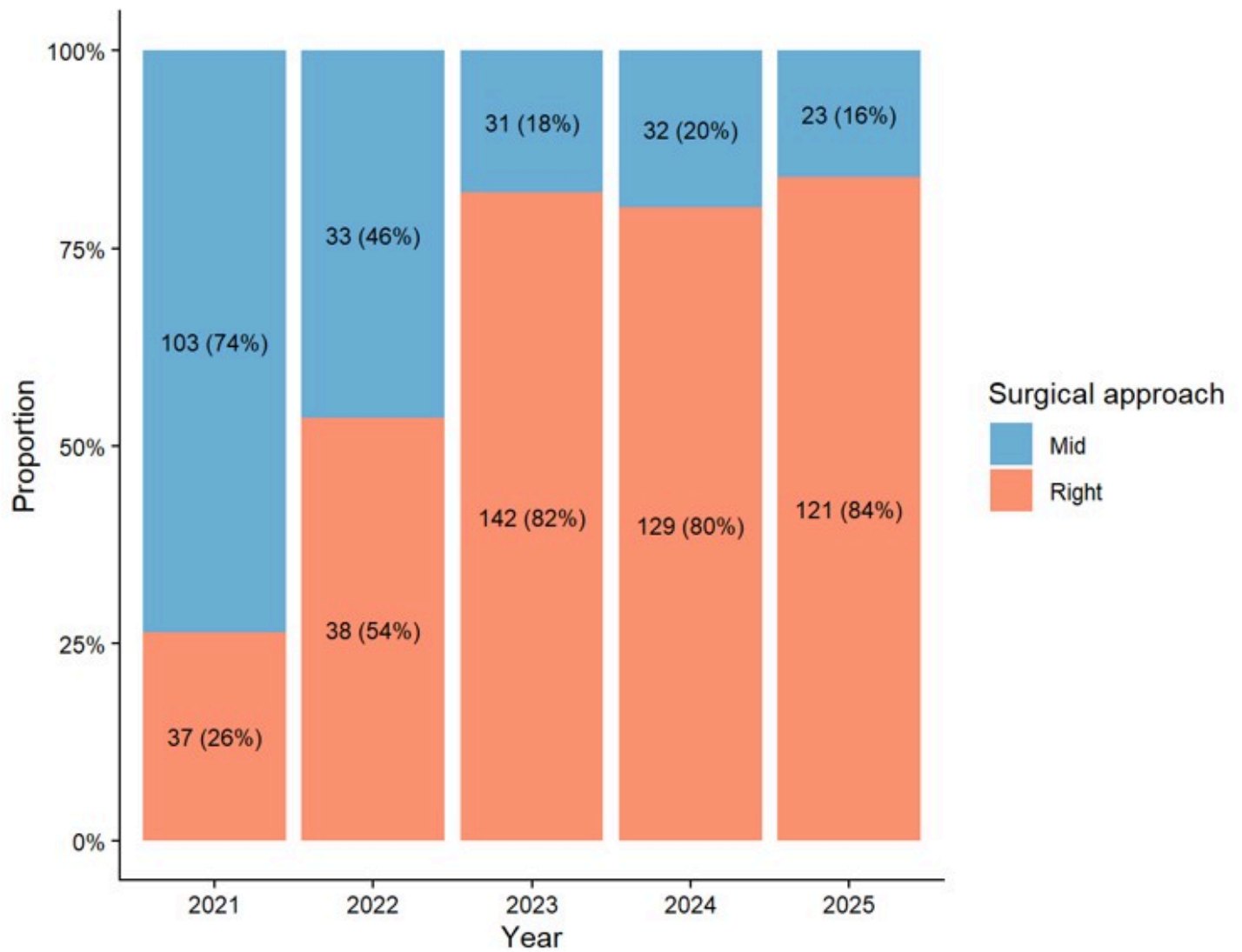


Figure 1

Trends in the use of the median sternotomy and the RVIAT approach from 2021 to 2025



Right mid-axillary line

Figure 2

Preoperative localization of the right mid-axillary line for RVIAT

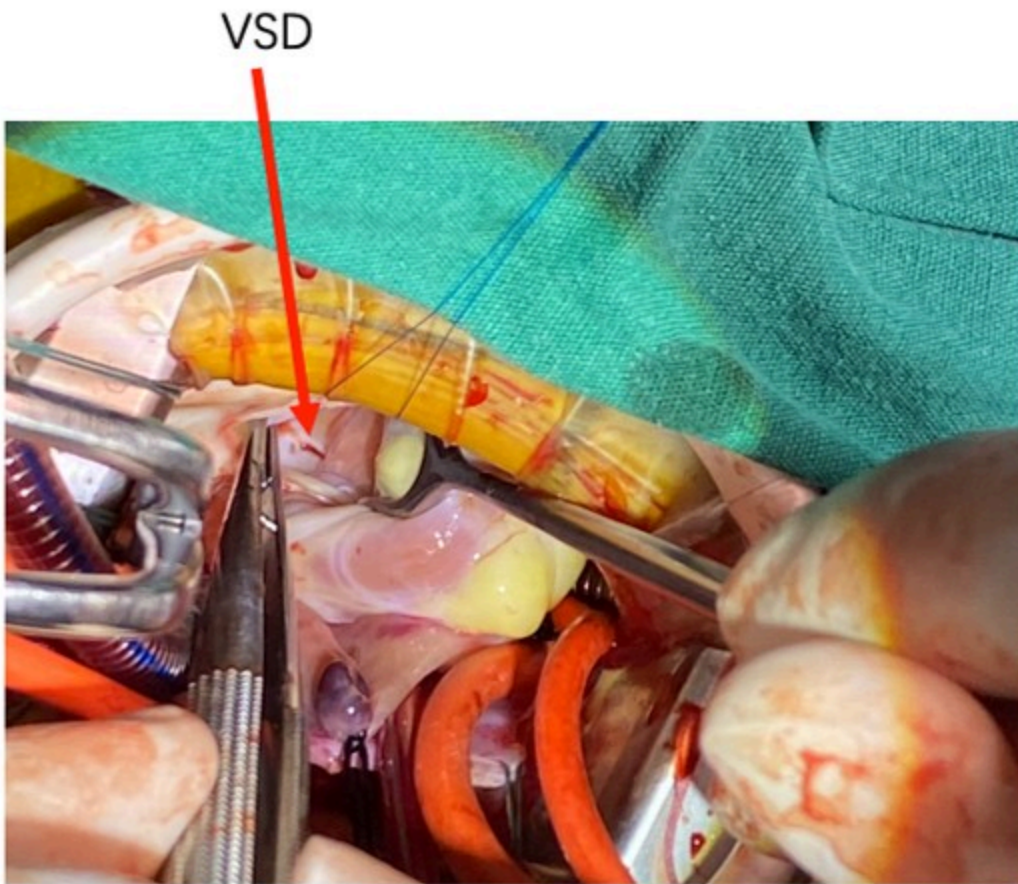


Figure 3

Exposure of dcVSD through an incision in the right ventricular outflow tract or the pulmonary artery.

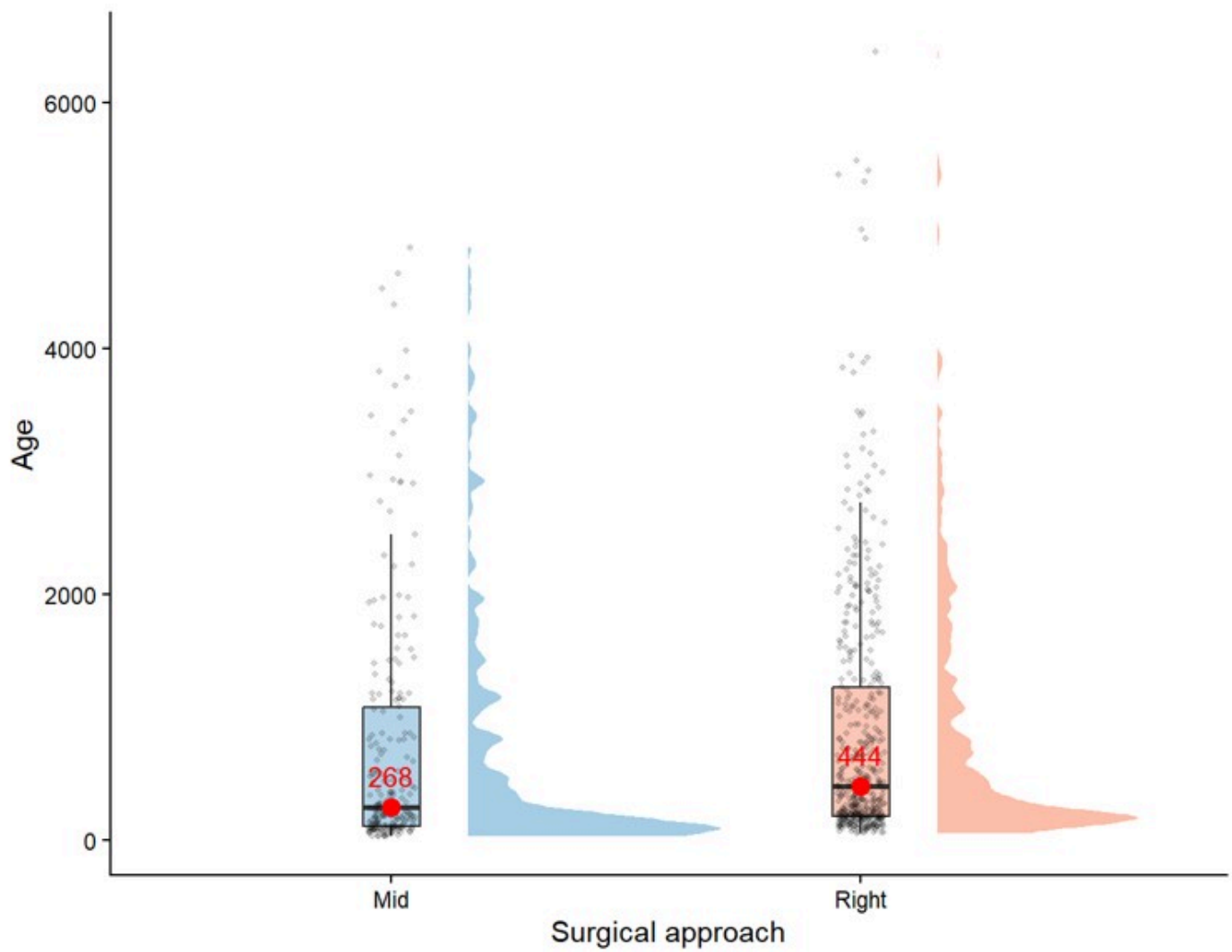


Figure 4

Age distribution according to surgical approach

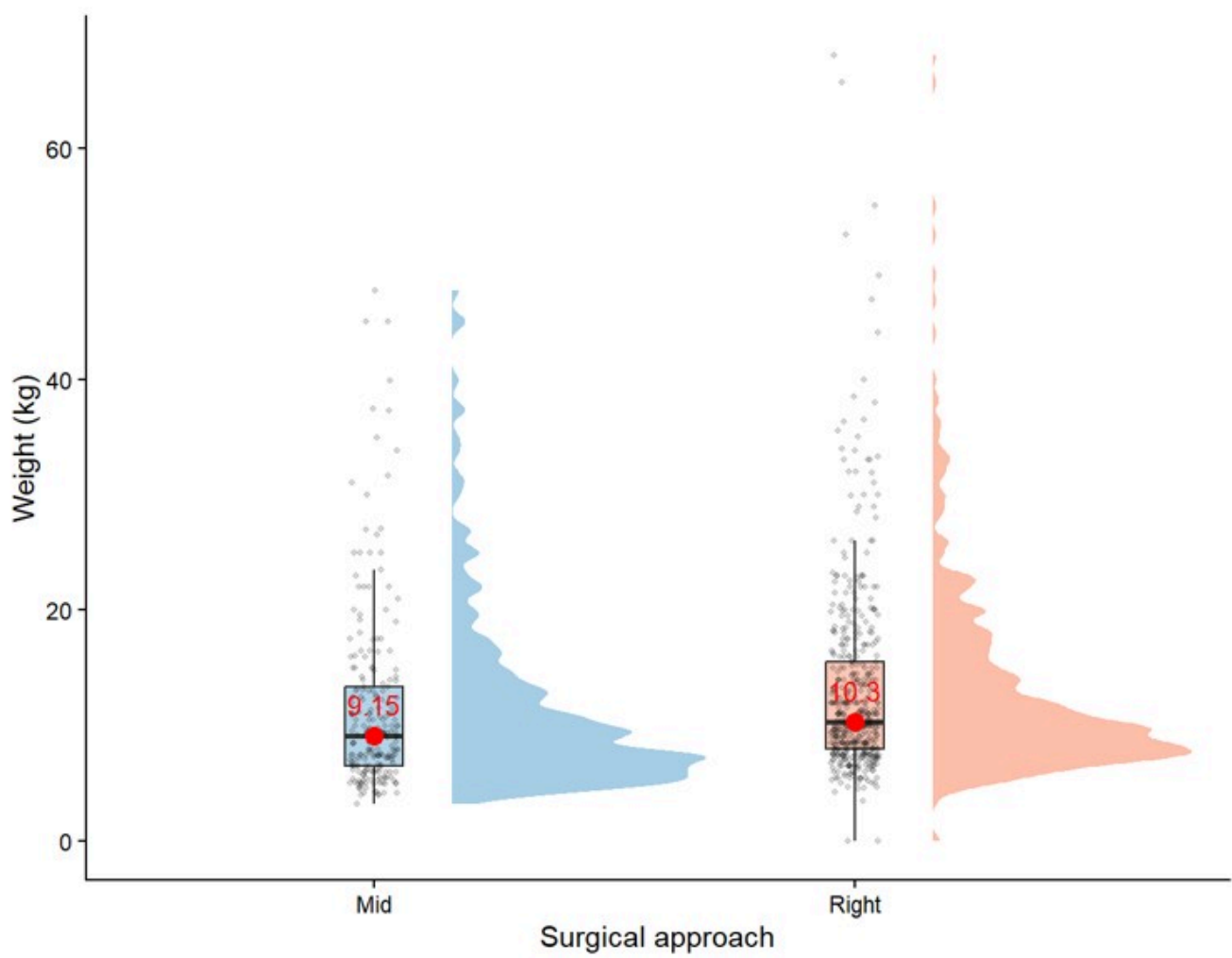


Figure 5

Weight distribution according to surgical approach

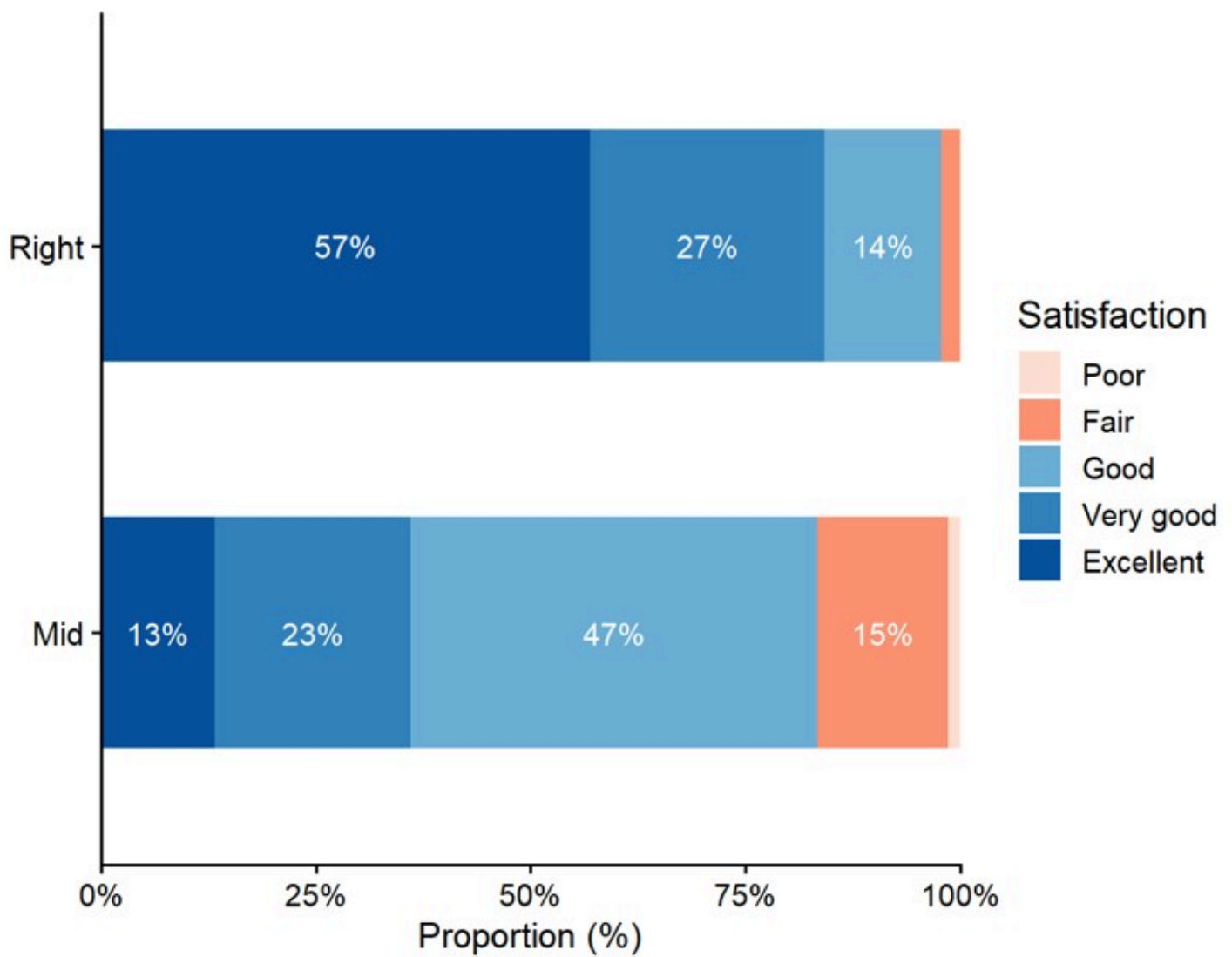


Figure 6

Distribution of the five-level overall incision-related satisfaction ratings at six months in the Mid and Right groups

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryFile1.docx](#)