Doubly committed ventricular septal defect: Is it safe to perform surgical closure through the pulmonary trunk approached by right vertical axillary thoracotomy?

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Is it safe to perform trans-pulmonary closure for doubly committed ventricular septal defect via right vertical axillary mini-thoracotomy?

- **RVIAT approach (N=37)**
  - Bypass time (P=0.21), aortic cross clamp time (P=0.09), operation time (P=0.59)
  - No conversion from RVIAT group to MSA group

- **Median sternotomy approach (N=37)**
  - Mechanical ventilation time (P=0.006) are shorter in RVIAT group, but not the duration of hospital stay (P=0.09)
  - Temporary postoperative arrhythmia fully recovered in RVIAT group

**DCVSD closure via RVIAT approach is safe and does not increase bypass-related complications**

**DCVSD**: doubly committed ventricular septal defect
**MSA**: Median sternotomy approach
**RVIAT**: Right vertical infra-axillary mini-thoracotomy
Doubly committed ventricular septal defect: Is it safe to perform surgical closure through the pulmonary trunk approached by right vertical axillary thoracotomy?

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ARTICLE WORD COUNT. 4143 words

ETHICS APPROVAL: This study was approved by the Vietnam National Children’s Hospital

INFORMED CONSENT: According to our National Legislation and the Institutional Requirements, written informed consent was not required for this retrospective study.
GLOSSARY OF ABBREVIATIONS

DCVSD: Doubly committed ventricular septal defect
RVIAT: Right vertical infra-axillary mini-thoracotomy
MSA: Median sternotomy approach
CHD: Congenital heart defect
VSD: Ventricular septal defect

CENTRAL PICTURE: DCVSD closure via the RVIAT approach

CENTRAL MESSAGE
The RVIAT approach is feasible and safe for DCVSD closure through the pulmonary trunk and does not increase the risk of bypass-related complications.

PERSPECTIVE STATEMENT
In this study, investigators found that patients who underwent the RVIAT technique for DCVSD closure had shorter mechanical ventilation times than the MSA group. The RVIAT method is workable and less intrusive when bypass is utilized.
ABSTRACT

Objective: This study investigated the safety of performing surgical repair for doubly committed ventricular septal defects (DCVSDs) by right vertical infra-axillary mini-thoracotomy (RVIAT).

Methods: A retrospective comparative study was performed to evaluate the outcomes of patients who underwent DCVSD closure from January 2019 to May 2022. Seventy-four patients were enrolled in the study and treated with either the median sternotomy approach (MSA: n=37) or the RVIAT approach (RVIAT: n=37).

Results: The median weight and age in the MSA group were significantly lower than those in the RVIAT group (MSA: 6.0 kg [interquartile range (IQR), 5.2-8.7 kg] vs. RVIAT: 7.5 kg (IQR, 5.6-14 kg), p=0.034 and MSA: 4.9 months (IQR, 3.6-9.4 months) vs. 9.6 months (IQR, 5.0-60.4 months), p=0.0084). No patients died, and no patients in the RVIAT group required conversion to the MSA approach. The mean pre-bypass surgical time was longer in the RVIAT group (36.1 ± 8.2 minutes vs. 31.8 ± 5.6 minutes, p=0.03). There were no significant differences between the two groups in the cardiopulmonary bypass time, aortic cross-clamp time, or operation time. Significantly shorter ventilation times were observed in the RVIAT group (11.9 ± 8.2 hours vs. 15.4 ± 6.3 hours, p=0.006).

Conclusions: Closure of DCVSDs through the pulmonary trunk by the RVIAT approach is feasible and safe, and does not increase the risk of bypass-related complications.

KEYWORDS: doubly committed ventricular septal defect, right vertical axillary mini-thoracotomy, congenital heart defect
INTRODUCTION

The median sternotomy approach (MSA) is considered a standard procedure for open heart surgery involving congenital heart defects (CHDs). Conventionally, surgical closure of a doubly committed ventricular septal defect (DCVSD) has been performed through the pulmonary artery trunk using a patch with continuous sutures or interrupted sutures with pledgets.\(^1,2\) The objective of a surgical technique to close a DCVSD is to repair the shunt and to avoid damage to the aortic valve beneath the VSD.

Recent developments in surgical techniques and devices combined with increasing demand for improved post-surgery cosmetic results presents an opportunity for the use of minimally invasive methods for treating various common CHDs.\(^3-7\) Numerous minimally invasive surgical techniques have been introduced to repair various CHDs, including mini sternotomy, right anterior mini-thoracotomy, right vertical infra-axillary mini-thoracotomy (RVIAT), and total endoscopy.\(^8-13\) However, the RVIAT approach is considered unsuitable for DCVSD closure due to the difficulty associated with exposing lesions in the left side of the chest using this technique, especially in adolescents and adults, and is quite different from the right thoracotomy approach.\(^5\) In this study, we investigated the feasibility and safety of surgical closure of DCVSDs using the RVIAT approach in a single institution.

METHODS

From January 2019 to May 2022, 74 patients who were diagnosed with DCVSD and underwent surgical closure at Vietnam National Children’s Hospital were consecutively enrolled in this study (2606/QD-BVNTU-HDDD, 12/27/2021). Since minimally invasive open-heart surgery via the RVIAT approach was introduced at our hospital with the support of Okayama University
Hospital in August 2019, the first patient with DCVSD who underwent VSD closure via RVIAT was treated in January 2020. Therefore, data from patients diagnosed with DCVSD who underwent RVIAT were collected from January 2020 to May 2022 (n=37). Data from patients who underwent MSA were collected retrospectively from January 2019 to December 2019 as a control group (n=37). According to our National Legislation and the Institutional Requirements, written informed consent was not required for this retrospective study.

Indications for surgical repair were left ventricular enlargement, progressive congestive heart failure, prolapse of the aortic valve, and recurrent respiratory infections. DCVSD closure is indicated for patients with a weight of more than 4 kg and an age older than 2 months. The presence of a patent ductus arteriosus or a left superior vein cava was not considered a contraindication for performing the RVIAT approach.

Surgical techniques

RVIAT group

Patient were placed in a left lateral decubitus position with the right side elevated by 70–80 degrees. The right arm was slung with a wrapped soft cloth and positioned over the head. The pelvis was elevated 45 degrees, and the shoulder joint was approximately 100-120 degrees. A marker was used to make the anterior axillary line, the middle axillary line, the posterior axillary line, and the fourth to the fifth intercostal line. A middle axillary incision of 5 cm to 7 cm was performed, and the thorax was entered regularly through the fifth intercostal space and recently through the fourth intercostal space. The standard Finochietto rib spreader was used, and the lung
was retracted posteriorly with a wet sponge in patients weighing less than 7-8 kg; single left lung 
ventilation was applied in patients weighing more than 8 kg. Direct vision was used without a 
port at the thoracotomy site. Local anesthesia was introduced routinely using intercostal nerve 
block with a single dose of levobupivacaine 0.25% (0.5-1.5 mg/kg) and then a programmed 
intermittent epidural bolus every 3 hours through the epidural catheter placed intrapleural by the 
surgeon via the mini-thoracotomy. The pericardium was opened 2 cm anterior to the phrenic 
nerve and retracted with stay traction sutures to expose the aorta, the superior vein cava, and the 
inferior vein cava. Cardiopulmonary bypass was conducted with a Livanova 135 degree curved 
tip arterial cannula, two venous cava cannulas, and a vent tube inserted via the right superior 
pulmonary vein. The aortic cannula was inserted into the lateral side of the aorta with the support 
of Babcock intestinal forceps. More recent practice has been to introduce the IVC venous 
cannula through a separate incision (5-7 mm) in the sixth intercostal space, which is 
subsequently used for chest tube placement. If a patent ductus arteriosus was present, it was 
dissected and ligated after starting the cardiopulmonary bypass, and a vessel loop retracted at the 
right pulmonary artery was used to help expose the patent ductus arteriosus. The bypass was 
maintained at 32°C, and both vena cavae were snared. The instruments used for aortic cross-
clamping were the DeBakey ductus clamp (for infants) or the DeBakey aortic aneurysm clamp 
(for adolescents). A simple set of endoscopic instruments was used for the included adolescent 
patients: forceps, needle holders and knot pushers. Cold crystalloid HTK cardioplegia was 
induced through the aortic root after aortic cross clamping. A small hole was opened at the right 
atrium to remove the crystalloid cardioplegia solution to reduce hemodilution. In cases where a 
left superior vein cava was present, a sump sucker was placed at the coronary sinus without
snaring the left superior vein cava. The cardioplegic cannula was removed for improved visualization after finishing the cardioplegia infusion.

The main pulmonary artery trunk was retracted, and a longitudinal incision was made up to the base of the pulmonary sinus. A Cushing Vein retractor and two stay traction sutures along the border of the pulmonary incision were used to expose the ventricular septal defect.

Interrupted polypropylene sutures with pledget support were inserted, and the DCVSD was closed with a bovine pericardial patch (Figure 1). The suture was started at “5 o’clock” from the surgeon’s perspective as the deepest of the VSD border and was retracted to the left side for better visualization of the next suture at 6 o’clock. The subarterial border of the DCVSD is easily seen through the opening of the pulmonary trunk, with interrupted pledget sutures passing through the pulmonary annulus, and aortic valve injuries are totally prevented. In 3 patients that presented with total conal septum insufficiency resulting in a large DCVSD that extended to the perimembranous septum, a combination of the right atrial approach and main pulmonary artery trunk approach was used to close the defect. No right ventricular outflow tract incision has been used thus far, and direct closure of the defect was avoided. Additional procedures, which included atrial septal defect closure, tricuspid valve repair, and resection of the jet lesion in the right ventricular outflow tract, were performed if needed.

After completely closing the defect, the pulmonary artery trunk was closed with running sutures, the heart was filled for deairing via the cardioplegia catheter hole, and the aortic cross-clamp was released. The cardiopulmonary bypass was weaned off, the pericardium was left open, and a single chest tube drainage was used through the hole at the sixth intercostal space. Transesophageal echocardiography was performed to confirm the result of surgery in the operating room before transferring the patient to the intensive care unit. Sedation was not used
after the operation, and early extubation in the operating room, whenever reasonable, was considered for all patients.

**MSA group**

Patients were placed in a supine position, and a midline mini-sternotomy approach was used. Standard cardiopulmonary bypass was introduced with arterial cannula and bicaval venous cannulation. After aortic cross clamping, a cold crystalloid HTK cardioplegia solution was introduced through the aortic root cardioplegic cannula. The procedure for DCVSD closure in the MSA group is described as for the RVIAT group. The sternum was closed after two drainages were inserted into the pericardium cavity and the mediastinal cavity.

**Statistical analysis**

Categorical variables are presented as absolute values and as percentages. Continuous variables are described as median and interquartile range, and categorical variables are expressed as frequencies and percentages. All statistical tests were two-tailed, and a p value of less than 0.05 was considered statistically significant. Categorical variables were compared using Pearson’s chi-square test. In cases in which the expected frequency was <5, Fisher’s exact test was used. Continuous variables were compared using the t test or Wilcoxon test based on the normality of the data. Data were collected and analyzed by R studio 2022.02.1 software.

**RESULTS**

The patient demographics of both groups are shown in Table 1. The median age of the MSA group was significantly lower than that of the RVIAT group (4.9 months, IQR 3.6-9.4)
months vs. 9.6 months, IQR 5.0-60.4 months, p=0.0084). The median weight of the MSA group was also significantly lower than that of the RVIAT group (6.0 kg, IQR 5.2-8.7 vs. kg 7.5 kg, IQR 5.6-14, p=0.034). The VSD diameter was not significantly different between the two groups. The median VSD diameter before the operation in the MSA group was 8.0 mm (IQR, 7.0-11 mm), comparable to that in the RVIAT group (8.0 mm, IQR, 7.0-10 mm). No case in the RVIAT group was converted to the MSA approach.

Perioperative data

Early mortality or late mortality was not observed in either group. The pre-bypass surgical time (calculated as the time from skin incision to the start of partial cardiopulmonary bypass) in the RVIAT group was significantly higher than that in the MSA group (31.8 ± 5.6 minutes vs. 36.1 ± 8.2 minutes, p=0.03). The median length of incision in the RVIAT group was 6 cm (IQR, 5-6 cm). As shown in Table 2, there were no significant differences between groups in the mean aortic cross-clamp time, the mean bypass time, and the mean operation time. However, the mean time of mechanical ventilation in the RVIAT group was significantly shorter than that in the MSA group (11.9 ± 8.2 hours vs. 15.4 ± 6.3 hours, p=0.006). Five patients suffered from postoperative arrhythmia in the RVIAT group, including 3 with junctional ectopic tachycardia, 1 with sinus bradycardia and 1 with atrial tachycardia, while no patients experienced arrhythmia after surgery in the MSA group (p=0.05). All patients with tachycardiac arrhythmia fully recovered after cooling and medications. Before discharge, 2 patients in the MSA group had residual VSD, but no residual VSD was found in the RVIAT group. All residual VSD was spontaneously closed 6 months after surgery. At a median follow-up time of 35.9 months (IQR, 15.9-40.6 months), all patients survived with NYHA I.
DISCUSSION

The RVIAT approach has been applied to repair simple congenital heart defects and is demonstrated to be a safe approach with satisfactory cosmetic results compared to conventional MSA.\textsuperscript{7,8,10,11} DCVSD closure has a limited number of reports from Fuwai Hospital\textsuperscript{14,15} and Qingdao University Hospital.\textsuperscript{16} Interestingly, DCVSD closure through the tricuspid valve using the RVIAT approach by Fuwai’s team was performed with a very short aortic cross-clamp time. Additionally, they suggested sutures at the superior edge of the patch could be placed through the aortic sinus, which requires an additional incision in the ascending aorta. The team from Qingdao University Hospital has chosen to close the DCVSD with a right subaxillary thoracotomy via the incision at the pulmonary artery trunk or right ventricular outflow tract. They are more comfortable closing the DCVSD by the RVIAT approach and recommend using this approach for surgeons who are not experienced with the thoracotomy approach. Due to the difficulty approaching through right-side thoracotomy, Zhu and colleagues used left anterolateral thoracotomy and peripheral cardiopulmonary bypass to close the DCVSD through the pulmonary trunk with a technique similar to the conventional MSA approach.\textsuperscript{5} According to our cumulative experiences of DCVSD closure via the RVIAT approach, the left anterolateral thoracotomy approach might be unnecessary to close the DCVSD. Cherup and colleagues also reported that anterolateral thoracotomy in the third or fourth space of a child may result in significant breast or pectoral asymmetry in at least 60% of children operated on.\textsuperscript{17}

Technically, the most critical part of closure of a DCVSD is the superior border, which has a risk of aortic valve injury. We doubt that closure of a DCVSD through the tricuspid valve will be a safe approach for preventing aortic valve injury, especially in cases of moderate or
severe aortic valve prolapse, which is not a rare complication of DCVSD in infants or young
adolescents. For that reason, approaching through the pulmonary artery trunk is our first choice.
In the beginning, we started the thoracotomy by the fifth intercostal space, which required more
time and did not enable good visualization of the DCVSD. Recently, we have approached the
fourth intercostal space, which provides better visualization and better exposure. We removed
the cardioplegia needle immediately after completing the cardioplegia infusion to minimize the
instrumentation in an already crowded operative field. No patient in our study had intraoperative
aortic valve injury or the degree of aortic valve insufficiency progressing after surgery and
during follow-up.

In our study, the lower limits of patient age (2 months) and weight (4 kg) were the only
criteria used to select patients, and more older patients were accidentally included in the RVIAT
group, which explains why the mean pre-bypass surgical time was longer in the RVIAT group
than the MSA group (p=0.03) and indicates the possibility of a more difficult preparing
cannulation via the thoracotomy approach. However, our operation results showed that there
were no significant differences between groups in bypass time (p=0.21), aortic cross-clamp time
(p=0.08), and operation time (p=0.59). In our study, the oldest patient was 15 years old (46 kg),
and some patients were over 10 years old. Approaching the DCVSD through the main
pulmonary trunk via RVIAT was much more challenging in these patients than in infants
because of the larger thoracic depth and deeper surgical field created by the pulmonary artery's
location on the left side of the thorax, which did not reflect the learning curve. We recommend
starting the RVIAT approach of DCVSD closure for a patient with a body weight of
approximately 7-8 kg to obtain better visualization and easier cannulation.
In our study, the mechanical ventilation time in the RVIAT group was significantly shorter than that in the MSA group (p=0.006), and that there was a trend toward a shorter duration of hospital stay (p=0.09). More patients who underwent the RVIAT approach were extubated in the operating room, resulting in a shorter ICU stay and early discharge from the hospital, which is helpful for decreasing associated medical costs (Figure 2). Our strategy of using local anesthesia for intercostal nerve block with levobupivacaine before starting the intracardiac procedure helped promote early extubation in the RVIAT group. This strategy was also proven effective in reducing pain and opioid usage for maintaining sedation during surgery.\textsuperscript{18,19} Most of the patients in our study did not require any additional dose of fentanyl or muscle relaxant after levobupivacaine was administered. Although some patients developed arrhythmia after undergoing the RVIAT approach in the early stages of the study period, possibly due to the manifestation of adverse outcomes related to levobupivacaine use for anesthesia, the length of ICU stay was comparable between the groups (p=0.89). However, since we reduced the dose of levobupivacaine to 0.5 mg/kg, no significant arrhythmia was detected in the ICU.

The current study included three patients diagnosed with total conal defects resulting in a very large VSD from the juxta-arterially deviated to the membranous septum, which required closing the VSD through the pulmonary artery trunk combined with the tricuspid valve approach. Despite this no patients in the RVIAT group were transferred to the MSA group, and neither required extension of the incision for clearer visualization. RVIAT for DCVSD closure should be performed by an experienced surgeon with the ability to introduce a safe cardiopulmonary bypass, overcome the challenge of difficult VSD exposure with a long-distance approach to the pulmonary artery trunk, and potentially limit complications during the operation. Overall, our
results demonstrated that RVIAT is indeed feasible, reproducible, and safe despite the defect being present in the left side of the chest and far-removed from the right side of the chest.

LIMITATIONS

Our study contains many limitations including a small number of patients, a retrospective study design, and enrollment in a single institution. The follow-up time may need further extension in order to more precisely evaluate the effectiveness of DCVSD closure via the RVIAT approach. Future studies involving multiple institutions are essential to further evaluate patient outcomes associated with the RVIAT approach.

CONCLUSIONS

Closure of the DCVSD through the RVIAT is feasible and safe, and does not increase bypass-related complications.

ACKNOWLEDGEMENTS
REFERENCES


### Table 1. Patient demographics

<table>
<thead>
<tr>
<th>Variables</th>
<th>RVIAT (n=37)</th>
<th>MSA (n=37)</th>
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<tbody>
<tr>
<td>Age (months)</td>
<td>9.6 (IQR 5.03–60.4)</td>
<td>4.9 (IQR 3.6–9.4)</td>
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<tr>
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<td>21 (57%)</td>
<td>16 (43%)</td>
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<td>Weight (kg)</td>
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<td>VSD diameter (mm)</td>
<td>8.4 ± 3.2</td>
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<tr>
<td>Total canal defect</td>
<td>3 (8%)</td>
<td>0 (0%)</td>
<td></td>
</tr>
<tr>
<td>Moderate MR</td>
<td>2 (5%)</td>
<td>1 (3%)</td>
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</tr>
<tr>
<td>Mild AR</td>
<td>7 (19%)</td>
<td>0 (0%)</td>
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AR: aortic valve regurgitation; IQR: interquartile range; MR: mitral valve regurgitation; MSA: median sternotomy approach; RVIAT: right vertical infra-axillary mini-thoracotomy; VSD: ventricular septal defect.
Table 2. Perioperative data

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<td>ICU stay time</td>
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ICU: intensive care unit; MSA: median sternotomy approach; RVIAT: right vertical infra-axillary mini-thoracotomy
FIGURES

Figure 1. Exposure of the doubly committed VSD via the RVIAT approach. RVIAT, right vertical infra-axillary mini-thoracotomy; VSD, ventricular septal defect.

Figure 2. Doubly committed VSD closure via the RVIAT approach is feasible and does not increase the rate of bypass-related complications. RVIAT, right vertical infra-axillary mini-thoracotomy; VSD, ventricular septal defect.

VIDEO. Video demonstration of the RVIAT approach for DCVSD closure. DCVSD, doubly committed ventricular septal defect; RVIAT, right vertical infra-axillary mini-thoracotomy.
# TABLES

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<td>151.7 ± 17.3</td>
<td>0.59</td>
</tr>
<tr>
<td>Aortic cross-clamp time</td>
<td>54.1 ± 19.0</td>
<td>46.9 ± 11.7</td>
<td>0.08</td>
</tr>
<tr>
<td>Bypass time</td>
<td>71.8 ± 21.5</td>
<td>64.9 ± 11.6</td>
<td>0.21</td>
</tr>
<tr>
<td>Pre-bypass surgical time</td>
<td>36.1 ± 8.2</td>
<td>31.8 ± 5.6</td>
<td>0.03</td>
</tr>
<tr>
<td>Mechanical ventilation time</td>
<td>11.9 ± 8.2</td>
<td>15.4 ± 6.3</td>
<td>0.006</td>
</tr>
<tr>
<td>ICU stay time</td>
<td>1.9 ± 0.7</td>
<td>1.9 ± 0.7</td>
<td>0.89</td>
</tr>
<tr>
<td>Hospital time (after surgery)</td>
<td>8.6 ± 3.1</td>
<td>9.9 ± 3.4</td>
<td>0.09</td>
</tr>
<tr>
<td>Blood transfusion</td>
<td>48.6%</td>
<td>59.5%</td>
<td>0.48</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>5</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>Residual shunt</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Atelectasis</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Wound infection</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

ICU: intensive care unit; MSA: median sternotomy approach; RVIAT: right vertical infra-axillary mini-thoracotomy
Is it safe to perform trans-pulmonary closure for doubly committed ventricular septal defect via right vertical axillary mini-thoracotomy?

74 patients having DCVSD

RVIAT approach (N=37)

No conversion from RVIAT group to MSA group

Bypass time (P=0.21), aortic cross clamp time (P=0.09), operation time (P=0.59)

Temporary postoperative arrhythmia fully recovered in RVIAT group

DCVSD closure via RVIAT approach is safe and does not increase bypass-related complications

DCVSD: doubly committed ventricular septal defect
MSA: Median sternotomy approach
RVIAT: Right vertical infra-axillary mini-thoracotomy