Rapid Two-stage Versus One-stage Surgical Repair of Interrupted Aortic Arch with Ventricular Septal Defect in Neonates

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Background/Purpose: The optimal management of interrupted aortic arch (IAA) with ventricular septal defect is controversial. The aim of this study was to evaluate our 12 years of experience of surgical outcomes of one-stage and rapid two-stage total corrections of IAA with ventricular septal defect and to delineate the management of postoperative complications.

Methods: We reviewed the medical charts of all patients from 1996 to 2007. Neonates with inherent complex anatomy were excluded. There were 26 patients in our series, with 11 type A and 15 type B IAA. Nineteen patients received one-stage repair and seven patients received rapid two-stage total correction. Rapid two-stage total correction was defined as two operations performed within 1 week.

Results: The 1-month postoperative survival rate was 81% (21/26), with 79% (15/19) in the one-stage group, and 86% (6/7) in the rapid two-stage group. The rapid two-stage group had a shorter cardiopulmonary bypass time (160.1 ± 58.4 vs. 216.8 ± 73.7 minutes, p = 0.054) and aortic cross clamp (AXC) time (65.6 ± 24.4 vs. 91.8 ± 22.4 minutes, p = 0.022) than the one-stage group. Postoperative left ventricular outflow tract obstruction (LVOTO) and aortic arch restenosis were common in survivors, with frequencies of 48% (10/21) and 71% (15/21) respectively. Within the postoperative arch stenosis subgroup, nine out of 15 patients received balloon angioplasties, which proved effective after only one treatment. The overall late survival rate was 73% (19/26), with 68% (13/19) in the one-stage group, and 86% (6/7) in the rapid two-stage group.

Conclusion: The outcome of rapid two-stage repair is comparable to that of one-stage repair. Rapid two-stage repair has the advantages of significantly shorter cardiopulmonary bypass duration and AXC time, and avoids deep hypothermic circulatory arrest. LVOTO remains an unresolved issue, and postoperative aortic arch restenosis can be dilated effectively by percutaneous balloon angioplasty. [J Formos Med Assoc 2008;107(11):876–884]

Key Words: aortic arch syndromes, congenital heart defects, heart surgery, left ventricular outflow tract obstruction, ventricular septal defects

Interrupted aortic arch (IAA) with ventricular septal defect (VSD) is defined as the presence of VSD and loss of luminal continuity between the ascending and descending aorta.¹ In a review of the literature by Van Praagh and associates² in 1971, this rare disease entity accounted for about 1.5% of all congenital heart disease, and without treatment, carried a mortality rate approaching

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90% within the first year of life. The median age of death was between 4 and 10 days.\textsuperscript{2,3} Hence, IAA is a newborn cardiac emergency.\textsuperscript{2} Conventionally, it has been corrected with the two-stage method.\textsuperscript{4,5} Since Trusler and Izukawa performed the first one-stage repair in 1975,\textsuperscript{6} many investigators have supported it as the procedure of choice.\textsuperscript{3,7,8}

Either two-stage or one-stage repair carries a substantial risk of perioperative mortality and morbidity.\textsuperscript{5,7} In our institute, because neonatal myocardial protection and cardiopulmonary bypass (CPB) procedures have been critical issues in congenital heart operations, we have developed a “rapid” two-stage repair without pulmonary artery banding as a novel approach for neonates with this complex anomaly. Rapid two-stage total correction is defined as two operations within 1 week, which provides the surgeon with the opportunity to closely monitor the patient’s hemodynamics before the second-stage operation. The separation into two operations not only reduces the duration of deep hypothermic circulatory arrest (DHCA) but also reduces the time of CPB and aortic cross clamp (AXC). We believe that, by this rapid method, patients are managed more securely with better myocardial protection, avoiding DHCA and pulmonary artery banding, leading to better outcomes. Nevertheless, postoperative left ventricular outflow tract obstruction (LVOTO) and residual or recurrent aortic arch stenosis are common in clinical scenarios.

Herein, we present the surgical outcomes as well as postoperative management of LVOTO and residual or recurrent aortic arch stenosis in our experience.

**Methods**

**Patients**

Between 1996 and 2007, 26 patients, 14 males and 12 females, were diagnosed with IAA plus VSD. IAA was defined as either a complete discontinuity or a nonpatent fibrous strand in the transverse arch or aortic isthmus. Neonates with complex anomalies, including transposition of the great arteries, aortopulmonary window, double outlet right ventricle and truncus arteriosus, were excluded from this study. The medical records for all patients were reviewed. The data collected included demographics, anatomic features, clinical presentation at admission, operative procedures, postoperative complications, hospitalization time, morbidities such as LVOTO and residual aortic arch stenosis, and mortality.

Eleven of these 26 neonatal patients were classified as IAA type A, and the other 15 were classified as type B. There were no type C patients in our series (Table 1).

In terms of cardiac anomalies, all patients had patent ductus arteriosus (PDA). Eighteen patients had posterior-malaligned VSD. Seven patients were documented with LVOTO preoperatively. Other cardiac anomalies included atrial septal defect in 25 patients, aberrant right subclavian artery in five, persistent left superior vena cava in two, pulmonary stenosis in one, and right aortic arch in one. Noncardiac anomalies included DiGeorge syndrome in five patients, and one VACTERL anomaly. The acronym VACTERL stands for vertebral defects, anal atresia, cardiac anomaly, tracheoesophageal fistula with esophageal atresia, renal defects and radial limb dysplasia.

Clinical conditions at presentation included congestive heart failure in four patients, cyanosis in seven, heart murmur in 14, and circulatory collapse in one patient. The rare incidence of circulatory collapse may be due to prostaglandin E1 infusion given to every patient on admission to our hospital.

Postoperatively, LVOTO and residual or recurrent aortic arch stenosis were diagnosed when there was a pressure gradient detected by pediatric cardiologists during echocardiography follow-up.

**Operative techniques**

One-stage repair was performed by median sternotomy. CPB was commenced with ascending aorta or innominate artery cannulation and bicaval
venous cannulation. Aortoplasty and PDA division with ductal tissue resection were performed under DHCA at 18°C. Then the VSD was repaired under CPB.

When aortoplasty and VSD repair were performed separately within a 1-week interval, we referred to it as the rapid two-stage operation. The first-stage operation included aortoplasty with extended end-to-end anastomosis and PDA division with ductal tissue resection by left posterolateral thoracotomy. The second-stage operation was then performed with VSD repair under CPB. The purpose of the rapid two-stage total correction was to complete all the procedures within one single admission period.

**Statistical analysis**

Statistical analysis was performed with STATA version 8.0 (STATA Corp., College Station, TX, USA). Data were described as frequencies, median with ranges and means with standard deviations as appropriate. Pearson’s χ² or Fisher’s exact test was used for categorical variables and Student’s t test was used for continuous variables. Logistic regression was used for prognostic factor analysis and Cox regression was used for survival analysis.

**Results**

**Hospital outcome and postoperative follow-up**

The median age for IAA repair was 14 days old (range, 4–88 days). Nineteen out of 26 patients underwent one-stage total correction with 1-month survival rates of 79% (15/19). Four newborns succumbed to heart failure related to the operation itself. However, there were two late deaths from arrhythmia and circulatory collapse 1 year after the primary repair. Both patients had complications of LVOTO after the initial total corrections. Seven patients underwent rapid two-stage correction with 1-month survival rates of 86% (6/7). The one death was also due to heart failure related to the operation. There was no late death in this group. Therefore, the overall late survival rate was 73% (19/26), with 68% (13/19) in the one-stage group and 86% (6/7) in the rapid two-stage group.

At the time of surgical repair, the mean duration of CPB was 216.8±73.7 minutes in the one-stage group (n=19) and 160.1±58.4 minutes in the rapid two-stage group (n=7). The mean duration of AXC was 91.8±22.4 minutes in the one-stage group (n=19) and 65.6±24.4 minutes in the rapid two-stage group (n=7). The mean duration of circulatory arrest (n=19) was

<table>
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*Data shown as n (%), n or mean ± standard deviation; †comparison between one-stage and rapid two-stage group. IAA = interrupted aortic arch; AXC = aortic cross clamp; DHCA = deep hypothermic circulatory arrest; ICU = intensive care unit; LVOTO = left ventricular outflow tract obstruction.
62.7 ± 23.9 minutes in the one-stage group. There was no need for circulatory arrest in the rapid two-stage group. The repair of the aortic arch was extended end-to-end anastomosis in five patients (19%), end-to-side anastomosis in nine (35%), with autologous pericardial patch augmentation in 10 (38%) and with prosthetic graft patch in two patients (8%).

The mean ICU stay was 26.2 ± 27.9 days, with 28.9 ± 31.7 days in the one-stage group and 18.9 ± 11.9 days in the rapid two-stage group. Mean length of hospitalization was 60 ± 80.6 days, with 71.8 ± 91.6 days in the one-stage group and 27.9 ± 16.0 days in the rapid two-stage group. Postoperative complications consisted of residual or recurrent aortic arch stenosis in 15 patients (71% of survivors), LVOTO in 10 patients (48% of survivors), pneumonia in six, acute renal failure in three, low cardiac output syndrome necessitating extracorporeal membrane oxygenation support in three, chylothorax in two, residual VSD in two, arrhythmia in two, wound infection in two, pneumothorax in one, tamponade in one, sepsis in one, and hemothorax in one.

**LVOTO**

In this study, there were seven patients who were diagnosed with LVOTO preoperatively. Among them, two patients received procedures to manage LVOTO. One was LVOT plasty with Luciani’s VSD patch deflection technique,9 and the other was the Damus-Kaye-Stansel procedure during initial repair. The other five patients received conservative treatment. Unfortunately, three of them died within 30 days of initial repair; another still had LVOTO postoperatively, and in the last one LVOTO resolved spontaneously.

Ten patients were found to have LVOTO postoperatively by echocardiography. Four had subsequent procedures. One patient received percutaneous balloon angioplasty for stenosed aortic valve dilatation and the other three received subaortic ridge resection. Of note, one of the three patients who received subaortic ridge resection was one of the late deaths in our series. The remaining six patients were under surveillance only, and there was either regression or no progression of LVOTO during the follow-up period (Table 2).

### Residual or recurrent aortic arch stenosis

The prevalence of residual or recurrent aortic arch stenosis was 71% (15/21). Separating these 15 patients by the method of arch repair, six patients underwent anastomosis with pericardium patch augmentation, seven underwent extended end-to-end or end-to-side direct anastomosis,
and two with prosthetic graft patch augmentation. Ten patients had subsequent procedures for residual or recurrent aortic arch stenosis. Nine of them had percutaneous balloon angioplasty, and the other one had surgical aortoplasty. The details for each patient are shown in Table 3. Of note, every percutaneous balloon procedure was effective in reducing the pressure gradient along the aortic arch to a level below 20 mmHg after one treatment.

### Discussion

IAA is a rare and highly lethal congenital heart disease, which frequently coexists with other intracardiac and extracardiac defects. VSD is the most common one, which can be seen in about 90% of cases. LVOTO resulting from posterior deviation of the infundibular septum may be present as well.

In the largest multi-institutional study of 472 patients with IAA by the Congenital Heart Surgeons Society (CHSS) reported by McCrindle et al, type A was noted in 28% of patients, type B in 70%, and type C in 1% of patients. The composition of IAA types was similar in our study, with type B being the most frequent (15 out of 26 patients).

**Overall survival: one-stage vs. rapid two-stage**

In our study, the early 1-month survival was 81% and the overall late survival was 73% compared with an overall 59% survival rate in McCrindle et al's series. From a literature review, two methods of operative repair are most widely used and consist of either one-stage repair or two-stage repair.

Advantages of the two-stage repair consist of the ability to get the infants through the first operation no matter what their preoperative condition (especially in IAA type A patients), reduced adverse effects of CPB and the attendant anticoagulation, particularly in infants who have sustained a critical cerebral insult and those who may have already had intracranial bleeding. In addition, for infants whose condition is extremely critical or for whom other complex congenital heart anomalies make a primary repair tremendously difficult, the two-stage repair would be the better choice. However, there are disadvantages of the two-stage repair. In Serraf et al’s study, patients with a two-stage repair had a higher attrition rate during the period...
waiting for complete repair. Also, pulmonary artery banding in conventional two-stage repair might increase the risk of right ventricular hypertrophy, substantial pulmonary artery scarring, pulmonary artery distortion caused by band migration, and marked dilatation of the pulmonary artery after removal of the band, which may cause severe tracheobronchial malacia. Therefore, we developed a rapid two-stage repair to avoid pulmonary artery banding and subsequent complications.

Table 4 summarizes contemporary surgical results with either one-stage or two-stage repair by several groups and compares these results with the present series. In Schreiber et al’s group, the early and late mortalities for two-stage procedures (37% and 26%, respectively) were significantly higher than those for one-stage repair (12% and 20%, respectively) \((p = 0.013)\). However, in our study, early 1-month mortality and late mortality were both higher in the one-stage group (21% vs. 14% and 32% vs. 14%, respectively). Although these may not be statistically significant \((p = 0.422)\), by plotting the Kaplan-Meier survival curve, the trend that rapid two-stage repair shows a higher survival rate and implies safer clinical progression is delineated. Also, we observed that survival rates in both one-stage and rapid two-stage groups stabilized 2 years after surgical repair (by multivariate Cox regression, hazard ratio = 3.4, \(p = 0.422\)) (Figure 1).

Table 4. Published surgical results of interrupted aortic arch plus ventricular septal defect by either one-stage or two-stage repair

<table>
<thead>
<tr>
<th>Reference</th>
<th>Authors</th>
<th>Patients (n)</th>
<th>Overall survival (%)</th>
<th>Repair method</th>
<th>Follow-up* (yr)</th>
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<tr>
<td>4</td>
<td>Irwin et al</td>
<td>20</td>
<td>75</td>
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<td>1–11</td>
</tr>
<tr>
<td>5</td>
<td>Mainwaring &amp; Lamberti</td>
<td>27</td>
<td>81</td>
<td>Two-stage</td>
<td>6–10</td>
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<tr>
<td>7</td>
<td>Menahem et al</td>
<td>20</td>
<td>60</td>
<td>Two-stage</td>
<td>0.5–8</td>
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<tr>
<td>11</td>
<td>Serraf et al</td>
<td>15</td>
<td>75</td>
<td>Two-stage</td>
<td>0.1–7</td>
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<td>12</td>
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<td>19</td>
<td>74</td>
<td>Two-stage</td>
<td>0.1–21</td>
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<tr>
<td>This series</td>
<td>Lee et al</td>
<td>7</td>
<td>86</td>
<td>Rapid two-stage</td>
<td>0.1–12</td>
</tr>
<tr>
<td>7</td>
<td>Menahem et al</td>
<td>26</td>
<td>75</td>
<td>One-stage</td>
<td>0.5–8</td>
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<td>8</td>
<td>Kostelka et al</td>
<td>24</td>
<td>100</td>
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<td>70.3</td>
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<tr>
<td>12</td>
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<td>80</td>
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<tr>
<td>This series</td>
<td>Lee et al</td>
<td>19</td>
<td>68</td>
<td>One-stage</td>
<td>0.1–12</td>
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*Years since total correction.

Figure 1. Kaplan-Meier survival curves for one-stage correction compared with rapid two-stage correction \((p = 0.4602, \text{log-rank test})\).
The definite higher survival rate can be explained by the different anatomy characteristics in each group. In the one-stage correction group, there were 14 IAA type B patients, while there was only one type B patient in the rapid two-stage group. According to McCrindle et al’s study, the type B lesion is one of the risk factors for overall mortality. Furthermore, type B IAA patients had aberrant right subclavian artery and LVOTO more frequently than patients of other types, which might further complicate the surgical outcomes.

In our study, most type B IAA patients underwent one-stage repair (Table 1, \( p = 0.021 \)). It is our belief that by median sternotomy, we can better approach the lesion and perform aortoplasty. In contrast, most of the rapid two-stage repairs were performed in type A IAA patients, because it was easier to dissect the descending aorta to the diaphragm level by the posterolateral thoracotomy approach.

There were 11 type A patients in our study. Of the six treated by rapid two-stage repair, there was one surgical death, while there was also one surgical death in the five patients treated by one-stage repair. The survival rates between the two repair methods were comparable in the type A subgroup (\( p = 0.887 \)). However, for a long time, myocardial ischemia, CPB duration, DHCA duration and postoperative care have been critical issues in congenital heart surgery. Our results demonstrated a definite shorter duration of CPB time and AXC time in the rapid two-stage group (CPB time, \( p = 0.054 \); AXC time, \( p = 0.022 \)), which implied better myocardial protection in this group of patients. Moreover, we avoided DHCA in the rapid two-stage group. DHCA has been documented to cause more neurologic sequelae in the literature. These factors may all account for the higher mortality rate in the one-stage group compared with the rapid two-stage group, though it did not reach statistical significance in our study (\( p = 1.000 \)). As a result, we observed a shorter duration of ICU stay and hospitalization in the rapid group in our experience (ICU stay, \( p = 0.428 \); hospitalization, \( p = 0.224 \)).

Additionally, family members may suffer from knowing about the high morbidity and mortality risks in the one-stage correction, and the long waiting periods for the second operation in the conventional two-stage repair. Hence, the rapid two-stage operation offers an alternative to reduce family members’ anxiety time to within 1 week; meanwhile, the patients are monitored securely with ventilator support in the ICU.

Therefore, based on the reasons above, because neonatal CPB is in itself difficult and sophisticated, the rapid two-stage method can be a safe and effective option for surgical repair of IAA patients, especially the type A variants.

LVOTO

LVOTO is a complex morphologic entity. Reviewing the literature, the presence of LVOTO is currently controversial in predicting postoperative mortality. Serraf et al found that the actuarial survival rate at 5 years was 60% in those with subaortic stenosis and 73.5% in those without. On the contrary, in Fulton et al’s retrospective study, patients with LVOTO had a comparable 10-year survival to those without obstruction (83% vs. 87%).

In our study, patients who were diagnosed with LVOTO preoperatively had a worse prognosis (by multivariate Cox regression, hazard ratio = 12.5, \( p = 0.005 \)) (Figure 2). Five out of seven patients, who were diagnosed with LVOTO preoperatively, died either within 30 days after the initial repair or within 2 years due to complications related to LVOTO. Recently, Suzuki and colleagues have demonstrated that IAA plus VSD with posterior malalignment of the infundibular septum could be repaired with acceptable mortality in the neonatal period. They also recommended that a subaortic diameter of less than 4 mm or a subaortic diameter index of less than 0.9 cm/(body surface area) might be considered selection criteria for concomitant resection of the infundibular septum at the time of primary repair.

Therefore, we believe that a certain number of patients need to undergo treatment for LVOTO,
either with valvotomy,\textsuperscript{12} muscle resection,\textsuperscript{19,20} Luciani’s VSD patch deflection technique,\textsuperscript{9} balloon dilatation or the LVOT bypass technique.\textsuperscript{21}

However, during this retrospective study, it was impressed upon us that there is a possible lack of accurate diagnostic criteria for LVOTO. LVOTO was diagnosed in seven patients preoperatively, while eight patients without preoperative diagnosis of LVOTO developed LVOTO postoperatively. This awkward finding may be explained by the increased blood flow through the LVOT after correction, which may reflect the increasing pressure gradient detected by postoperative echocardiography. In other words, a large number of patients with LVOTO morphology are diagnosed postoperatively.

Residual or recurrent aortic arch stenosis
Residual or recurrent aortic arch stenosis is another common postoperative complication. In McCrindle et al’s survey,\textsuperscript{10} 109 out of 453 patients underwent reintervention for IAA repair obstruction. In Oosterhof et al’s series, 31% of patients underwent re-operation for recurrent or persistent aortic arch obstruction.\textsuperscript{13} Our study showed comparable results. Ten out of 26 patients (38%) received reintervention including balloon angioplasty and surgical aortoplasty. However, our series demonstrated a 100% success rate of transcatheter balloon angioplasty in dealing with aortic arch restenosis.

It is also interesting to see if the methods of arch repair can influence aortic arch stenosis. Serraf and coworkers\textsuperscript{11} and Oosterhof and associates\textsuperscript{13} both found that direct end-to-end or end-to-side anastomosis was not associated with residual or recurrent arch stenosis. On the other hand, McCrindle et al’s data suggested that, wherever possible, the preferred method of arch repair is by direct anastomosis augmented with either homograft or pericardial material.\textsuperscript{10} Our data showed no significant difference between pericardium patch augmentation and direct anastomosis statistically (by logistic regression, odds ratio $=1.29$, $p=0.814$); among patients with available pressure gradient recordings, 66.7% of patients (6/9) with pericardial patch augmentation developed arch stenosis, while 70% of patients (7/10) with direct anastomosis developed arch stenosis. Interestingly, the two patients with prosthetic graft patch augmentation both developed arch stenosis during follow-up.

Study limitation
This study presented our 12-year experience in dealing with the different types of IAA plus VSD. However, it was limited by its retrospective nature, prolonged follow-up time, small sample size, and non-uniform definition of LVOTO.
Conclusion

This study demonstrated that rapid two-stage repair plays an important role in the treatment of IAA patients compared with the one-stage repair method, especially in patients with type A lesions. With the rapid two-stage correction, we can avoid DHCA, shorten myocardial ischemia and CPB duration, decrease hospitalization, and perform extended aortoplasty easily through thoracotomy. LVOTO and aortic arch restenosis are common in clinical scenarios. Patients with preoperatively diagnosed LVOTO have worse prognosis, while aortic arch restenosis can be managed effectively by percutaneous balloon angioplasty.

Acknowledgments

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References
