Predictors of Early Postoperative Supraventricular Tachyarrhythmias in Children After the Fontan Procedure

Jun Yasuhara,1,2 MD, Toshiki Kuno,3 MD, Moe Taki,1 MD, Koichi Toda,1 MD, Takashi Kumamoto,4,1 MD, Takuro Kojima,1 MD, Hiroyuki Shimizu,1,5 MD, Shigeki Yoshiba,1 MD, Toshi Kobayashi,1 MD and Naokata Sumitomo,1 MD

Summary
Postoperative arrhythmias are a frequent and fatal complication after the Fontan operation. However, clinical evidence demonstrating early postoperative arrhythmias in children undergoing the Fontan operation is limited. This study aimed to evaluate the prevalence of arrhythmias and identify the predictors of early postoperative supraventricular tachyarrhythmias (SVTs) after the Fontan procedure.

Data were analyzed from 80 pediatric patients who underwent Fontan procedures between April 2000 and December 2017 in a single-center retrospective study. Early postoperative SVTs were defined as arrhythmias within 30 days after the Fontan procedure. We divided the patients into two groups, with or without early postoperative arrhythmias, and the predictors of early postoperative arrhythmias were analyzed. A multivariate logistic regression analysis was performed to determine independent predictors of early postoperative SVTs after the Fontan procedure.

Early postoperative SVTs were observed in 21 patients (26.3%). The most common arrhythmia was junctional ectopic tachycardia. After an adjustment, an atrioventricular valve regurgitation (AVVR) grade of ≥2 (odds ratio 10.54, 95% confidence interval 2.52 to 44.17, P = 0.001) and preoperative arrhythmias (odds ratio 26.49, 95% confidence interval 1.64 to 428.62, P = 0.021) were significant predictors of early postoperative SVTs after the Fontan operation.

An AVVR grade ≥2 and preoperative arrhythmia were significant predictors associated with early postoperative SVTs. Intervention for AVVR may provide clinical benefit for preventing early postoperative arrhythmias after the Fontan operation.

Key words: Predictive factors, Arrhythmias following cardiac surgery, Fontan operation, Atrioventricular valve regurgitation, Junctional ectopic tachycardia

The Fontan procedure has improved the prognoses of patients with a single ventricle physiology since it was first introduced in 1971.1 However, postoperative arrhythmias are common and can cause life-threatening complications after congenital heart surgeries, including the Fontan operation.2-4 Several studies have reported arrhythmias in the late postoperative period after the Fontan operation;5-9 however, only a few data have been reported regarding the overall incidence and risk factors of early postoperative arrhythmias in children undergoing the Fontan operation.10,11

We aimed to determine the incidence of early postoperative supraventricular tachyarrhythmias (SVTs) in children after the Fontan procedure and to reveal the clinical predictors of developing early postoperative SVTs.

Methods
Study patients and study design: This is an observational, retrospective cohort study of early postoperative SVTs in children after the Fontan operation. We reviewed all patients who underwent an intra-atrial lateral tunnel (ILT) or extracardiac conduit (ECC) Fontan procedure at Saitama Medical University International Medical Center between April 2000 and December 2017 (Figure). Patients who underwent atriopulmonary connection (APC) Fontan surgery were not included. A total of 82 patients underwent the Fontan procedure during the study period. One patient over 18 years old and one patient who developed ventricular tachycardia (VT) were excluded.

Early postoperative arrhythmias were defined as arrhythmias occurring within 30 days of the Fontan opera-
Patients divided those patients into two groups: the arrhythmia group, or the non-arrhythmia group, according to the incidence of early postoperative arrhythmias. The patient baseline characteristics, onset, arrhythmia types, and long-term outcomes were retrospectively collected for both groups.

This study was approved by the Institutional Review Board of Saitama Medical University (authorization no. 15-279, Saitama Medical University International Medical Center).

**Definition of arrhythmias:** Early postoperative arrhythmias were diagnosed based on the 12-lead electrocardiogram (ECG). Both sustained and non-sustained arrhythmias were included. The type of arrhythmias was limited to SVT. SVT was defined as a narrow-QRS tachycardia, the mechanism of which involves tissue from the His bundle or above. These SVTs included atrial tachycardia (AT), atrial flutter (AFL), junctional ectopic tachycardia (JET), atrioventricular reciprocating tachycardia (AVRT) and SVT with unknown etiology. Ventricular arrhythmias, including VT and ventricular fibrillation (VF), were excluded.5) The following definitions were used in this study. AT: SVT arising from a localized atrial site, characterized by regular, organized atrial activity with discrete P waves and an isoelectric baseline on the ECG. AFL: Typical AFL was the type of macro-reentrant tachycardia propagating around the tricuspid annulus, characterized by a regular continuous undulation between QRS complexes at a cycle length of ≤ 250 ms on the ECG. Atypical AFL was defined as a focal or macro-reentrant tachycardia with the different reentrant circuits from typical AFL, which included the mitral valve annulus and scar tissue within the left or right atrium. JET: focal SVT, caused by abnormal automaticity, arising from the compact atrioventricular (AV) node or the bundle of His, characterized by a narrow QRS complex tachycardia with inverted P waves and AV dissociation on the ECG. Administration of adenosine triphosphate (ATP) and an atrial ECG was useful to confirm JET diagnosis. AVRT: A reentrant tachycardia with a circuit that consisted of two distinct pathways, a normal AV conduction system and an AV accessory pathway, characterized by regular, narrow QRS complexes, retrograde P waves with a short RP interval or wide QRS complexes with a short RP interval on the ECG. Most of these SVTs could be diagnosed by administration of ATP, an atrial ECG, and pacing maneuvers.12,13) However, when the hemodynamic status was unstable, SVT termination had a higher priority than an SVT diagnosis. Moreover, it was sometimes difficult to differentiate JET from AT or AVRT when the ECG showed 1:1 AV conduction. Therefore, there were some SVTs with an unknown etiology.

**Data collection:** Data were collected, including the patients’ ages and weights at the time of the Fontan operation, primary diagnosis, ventricular morphology (single right ventricle (RV), single left ventricle (LV), mixed), AV valve morphology, atrial situs, timing of the Fontan operation, type of Fontan, details of the Fontan operation (atrial incision, AV valvuloplasty), cardiopulmonary bypass (CPB) time, aortic cross clamp (ACC) time, pacemaker implantation (PMI), previous surgery (the number of surgery and AV valvuloplasty), preoperative and postoperative echocardiographic data (systemic atrioventricular valve regurgitation [AVVR] and the atrial short axis diameter measured in the apical 4-chamber view), preoperative and postoperative catheterization data (atrial pressure, ventricular end-diastolic pressure [EDP], pulmonary artery [PA] mean pressure, and AVVR grade evaluated by ventriculography), and preoperative arrhythmias. Single ventricle lesions were divided into three classifications: Single RV (right dominant and hypoplastic left ventricle), Single LV (left dominant and hypoplastic right ventricle) and Mixed (biventricular or indeterminate dominance). Due to the long follow-up, the Fontan operation timing was classified into two eras: the early era (2000-2010) and the recent era (2010-2017). AVVR was graded according to the American Society of Echocardiography recommendations on a 3-point scale, similar to tricuspid regurgitation or mitral regurgitation: grade 0, no AVVR; grade 1, mild AVVR; grade 2, moderate AVVR; and grade 3, severe AVVR.15) The postoperative laboratory data before an arrhythmia onset were collected, including the levels of the serum hemoglobin, electrolytes, white blood cells.
Early postoperative SVTs were observed in 26.3% (n = 21). The baseline clinical characteristics of the patients in both groups are summarized in Table I. The proportion with heterotaxy and preoperative arrhythmias was significantly higher in the arrhythmia group than in the non-arrhythmia group (heterotaxy: 42.9% versus 20.3%, P = 0.044; preoperative arrhythmias: 23.8% versus 1.7%, P = 0.006). Catheterization data showed that the atrial pressure was significantly higher in the arrhythmia group than in the non-arrhythmia group (8 [6, 9] versus 6 [5, 7], P = 0.003) and the AVVR grade was significantly higher in the arrhythmia group than the non-arrhythmia group (2 [1, 2] versus 1 [1, 2], P = 0.004). Echocardiographic data showed that an AVVR grade was significantly higher in the arrhythmia group than the non-arrhythmia group (2 [1, 2] versus 1 [1, 1], P < 0.001), and the proportion of an AVVR grade of ≥ 2 was significantly higher in the arrhythmia group than in the non-arrhythmia group (71.4% versus 20.3%, P < 0.001). The AVVR grade, evaluated by echocardiography, is sometimes underestimated, and the AVVR grade evaluated by ventriculography is accurate; however, the same trend was found in this study. There were no major differences in age and weight at the time of the Fontan operation, cardiac anatomic diagnosis, ventricular morphology, AV valve morphology, atrial situs, type of Fontan, details of the Fontan operation (atrial incision, AV valvuloplasty, CPB time, ACC time and PMI), the number of surgeries and prior AV valvuloplasty between the two groups. In addition, there was no significant difference in the Fontan operation timing (early era and recent era), preoperative atrial short axis diameter, and postoperative laboratory data. The most common primary diagnosis was common inlet right ventricle (CIRV) (arrhythmia group, 33.3% versus non-arrhythmia group, 22.0%, P = 0.304), followed by double inlet right ventricle (DIRV) (arrhythmia group, 19.0% versus non-arrhythmia group, 23.7%, P = 0.659). Non-sustained arrhythmias were observed in three patients. The statistical analysis of the baseline characteristics that excluded three patients with non-sustained arrhythmias revealed the same potential clinical factors associated with early postoperative arrhythmias after the Fontan operation, as shown in Table I. The proportion with an improved AVVR grade and atrial pressure after the Fontan operation were significantly higher in the non-arrhythmia group than the arrhythmia group (improvement in the AVVR grade: 9.5% versus 44.1%, P = 0.042; improvement in the atrial pressure: 28.6% versus 54.2%, P = 0.043).

### Results

#### Patient characteristics: Preoperative arrhythmias occurred in five patients in the arrhythmia group (JET; 3 patients, AT; 1 patient, AFL; 1 patient) and in one patient in the non-arrhythmia group (PSVT). AT occurred in a patient of CIRV with asplenia syndrome at the age of one month, and it was controlled by atenolol. A patient of hypoplastic left heart syndrome (HLHS) with polysplenia syndrome had AFL after the first surgery of bilateral pulmonary artery banding, and he received sotalol for preoperative management until the Fontan operation. JET in the other three patients occurred during postoperative periods of previous surgeries and was non-sustained. Hence, they did not need medications. Radiofrequency catheter ablation (RFCA) was not performed in any of the patients.

The early postoperative arrhythmia characteristics are shown in Table II. The most common arrhythmia was JET (71.4%) followed by AT (19.0%), AFL (4.8%), and AVRT (4.8%). 3 of 21 postoperative arrhythmias (14.3%) were the recurrence of preoperative arrhythmias (JET; 2 patients, AT; 1 patient) and 18 of 21 postoperative arrhythmias (85.7%) were new onset arrhythmias. The median length of time from surgery to the onset of the arrhythmia was one day (0-2). 10 of 15 patients with JET occurred within the first 24 hours after the Fontan operation. The median days from the surgery to the onset of AT was significantly later than that for JET (2 [0.75, 4.25] versus 0.5 [0, 1.75], P = 0.002). JET was treated by amiodarone, nifekalant and pacing shown in Table II. Also, AT was treated by landiolol and procainamide, AFL by Electrical cardioversion and AVRT by ATP.

### Predictive factors of early postoperative arrhythmias:

The potential clinical factors associated with early postoperative arrhythmias after the Fontan operation were analyzed (Table III). Heterotaxy, a history of preoperative arrhythmias, and an AVVR grade of ≥ 2 were identifiable predictors in the univariate analysis; however, an AVVR grade of ≥ 2 (odds ratio 10.54, 95% confidence interval 2.52 to 44.17, P = 0.001) and preoperative arrhythmias (odds ratio 26.49, 95% confidence interval 1.64 to 428.62, P = 0.021) remained significant predictors of early postoperative arrhythmias after the Fontan operation in the multivariate logistic regression analysis.
## Table 1. Baseline Patient Characteristics

|                                | Arrhythmia group (n = 21) | Non-arrhythmia group (n = 59) | P value |
|--------------------------------|---------------------------|-------------------------------|---------|
| Age (months)                   | 29 [24, 35]               | 24 [22, 29]                   | 0.170   |
| Female, n (%)                  | 8 (38.1)                  | 24 (40.7)                     | 0.836   |
| Weight (kg)                    | 10.0 [9.6, 11.5]          | 10.3 [9.5, 11.5]              | 0.772   |
| **Primary diagnosis**          |                           |                               |         |
| DIRV, n (%)                    | 4 (19.0)                  | 13 (22.0)                     | 0.659   |
| DILV, n (%)                    | 1 (4.8)                   | 6 (10.2)                      | 0.451   |
| CIRV, n (%)                    | 7 (33.3)                  | 13 (22.0)                     | 0.304   |
| CILV, n (%)                    | 1 (4.8)                   | 5 (8.5)                       | 0.579   |
| TA, n (%)                      | 1 (4.8)                   | 6 (10.2)                      | 0.451   |
| MA, n (%)                      | 1 (4.8)                   | 1 (1.7)                       | 0.439   |
| HLHS, n (%)                    | 3 (14.3)                  | 8 (13.6)                      | 0.934   |
| DIRV, n (%)                    | 1 (4.8)                   | 5 (8.5)                       | 0.579   |
| DILV, n (%)                    | 1 (4.8)                   | 1 (1.7)                       | 0.439   |
| **Ventricular morphology**    |                           |                               |         |
| Single RV, n (%)               | 15 (71.4)                 | 36 (61.0)                     | 0.262   |
| Single LV, n (%)               | 5 (23.8)                  | 22 (37.3)                     | 0.262   |
| Mixed, n (%)                   | 1 (4.8)                   | 1 (1.7)                       | 0.439   |
| **AV valve morphology**        |                           |                               |         |
| Two AV valve, n (%)            | 10 (47.6)                 | 33 (55.9)                     | 0.512   |
| CAVV, n (%)                    | 8 (38.1)                  | 17 (28.8)                     | 0.431   |
| TA, n (%)                      | 1 (4.8)                   | 6 (10.2)                      | 0.451   |
| MA, n (%)                      | 2 (9.5)                   | 3 (5.1)                       | 0.954   |
| **Atrial Situs**               |                           |                               |         |
| Situs solitus, n (%)           | 12 (57.1)                 | 46 (79.3)                     | 0.066   |
| Situs inversus, n (%)          | 1 (4.8)                   | 0 (0)                         | 0.092   |
| Situs ambiguous, n (%)         | 8 (38.1)                  | 13 (22.4)                     | 0.151   |
| **Heterotaxy, n (%)**          |                           |                               |         |
| Right atrial isomerism, n (%)  | 9 (42.9)                  | 12 (20.3)                     | 0.044   |
| Left atrial isomerism, n (%)   | 7 (33.3)                  | 9 (15.2)                      | 0.115   |
| **Timing of the Fontan operation** |                       |                               |         |
| Early era (2000-2010), n (%)   | 8 (38.1)                  | 32 (54.2)                     | 0.204   |
| Recent era (2010-2017), n (%)  | 13 (61.9)                 | 27 (45.8)                     | 0.204   |
| **Type of Fontan**             |                           |                               |         |
| ILT, n (%)                     | 1 (4.8)                   | 9 (15.2)                      | 0.212   |
| ECC, n (%)                     | 20 (95.2)                 | 50 (84.7)                     | 0.212   |
| **Detail of the Fontan operation** |                       |                               |         |
| Atrial incision, n (%)         | 2 (9.5)                   | 16 (27.1)                     | 0.097   |
| AV valvuloplasty, n (%)        | 1 (4.8)                   | 8 (13.6)                      | 0.273   |
| CPB time (minutes)             | 123 [111, 155]            | 137 [114, 161]                | 0.681   |
| ACC time (minutes)             | 70 [61, 82]               | 63 [36, 86]                   | 0.560   |
| PMI, n (%)                     | 2 (9.5)                   | 2 (3.4)                       | 0.268   |
| **Previous surgery**           |                           |                               |         |
| The number of surgery          | 2 [2, 2]                  | 2 [2, 2]                      | 0.521   |
| AV valvuloplasty, n (%)        | 1 (4.8)                   | 4 (6.8)                       | 0.743   |
| Preoperative arrhythmia, n (%) | 5 (23.8)                  | 1 (1.7)                       | 0.006   |
| JET, n (%)                     | 3 (14.3)                  | 0 (0)                         | 0.003   |
| AFL, n (%)                     | 1 (4.8)                   | 0 (0)                         | 0.092   |
| PSVT, n (%)                    | 0 (0)                     | 1 (1.7)                       | 0.548   |
| **Preoperative management of arrhythmia** |                   |                               |         |
| Antiarrhythmic drug, n (%)     | 2 (9.5)                   | 0 (0)                         | 0.016   |
| RFCA, n (%)                    | 0 (0)                     | 0 (0)                         | 1       |
| **Catheterization data**       |                           |                               |         |
| Atrial pressure (mmHg)         | 8 [6, 9]                  | 6 [5, 7]                      | 0.039   |
| Ventricular EDP (mmHg)         | 8 [7, 11]                 | 7 [6, 9]                      | 0.094   |
| PA mean pressure (mmHg)        | 13 [11, 14]               | 12 [10, 14]                   | 0.381   |
| AVVR grade                     | 2 [1, 2]                  | 1 [1, 2]                      | 0.004   |
Early postoperative arrhythmias in children after the Fontan operation are a life-threatening complication resulting in acute hemodynamic deterioration and death.\(^{[50]}\) We evaluated the characteristics and predictors of early postoperative SVTs in children after Fontan procedures. In this study, we found that 26.3% of the patients had early postoperative SVTs after the Fontan procedure. The most common arrhythmia encountered in this study was JET, with an incidence of 71.4%. We also detected that the significant predictors of early postoperative SVTs in children were an AVVR grade of ≥2 and preoperative arrhythmias.

To date, previous studies have reported mainly about late postoperative arrhythmias after the Fontan procedure;\(^{[5,10]}\) however, there have been scarce data regarding early postoperative arrhythmias after the Fontan operation. The first large retrospective cohort study about predictors of early onset arrhythmias, after the classical and contemporary Fontan operation, showed that the frequency of early onset SVT was 15% and a significant risk factor associated with an early onset SVT was an abnormal AV valve anatomy, AVVR, age at the time of the Fontan operation, and preoperative arrhythmias. There was no difference in the frequency of early and late onset SVT among Fontan operation types.\(^{[11]}\) The previous retrospective cohort study reported that the incidence of early postoperative atrial tachyarrhythmias was 12.8% after the classical Fontan procedure and 7.2% after the Fontan procedure. Early postoperative atrial tachyarrhythmias, follow-up length, and APC Fontan were demonstrated to be significant predictors of late ATs; however, predictors of early postoperative arrhythmias were not investigated.\(^{[10]}\) Another retrospective cohort study showed that the prevalence of early postoperative arrhythmias was 4.7% after the Fontan operation.\(^{[5]}\) The most common tachycardia in the early postoperative period was JET (67%). A multicenter, cross-sectional study in children showed that the

### Table I. Baseline Patient Characteristics (continued)

| Echocardiographic data | Arhythmia group (n = 21) | Non-arrhythmia group (n = 59) | P value |
|------------------------|-------------------------|-------------------------------|---------|
| AVVR grade             | 2 [1, 2]                | 1 [1, 1]                      | <0.001  |
| AVVR grade ≥ 2, n (%)  | 15 (71.4)               | 12 (20.3)                     | <0.001  |
| Mild AVVR, n (%)       | 6 (28.6)                | 35 (59.3)                     | 0.015   |
| Moderate AVVR, n (%)   | 13 (61.9)               | 7 (11.9)                      | <0.001  |
| Severe AVVR, n (%)     | 2 (9.5)                 | 5 (8.5)                       | 0.884   |
| Atrial short axis diameter (mm) | 26.7 [22.1, 34.4] | 22.9 [22.3, 26.2] | 0.071   |

Postoperative laboratory data

|                     | Arhythmia group (n = 21) | Non-arrhythmia group (n = 59) | P value |
|---------------------|-------------------------|-------------------------------|---------|
| Hb (g/dL)           | 16.7 [15.8, 17.5]       | 16.3 [15.5, 16.8]             | 0.282   |
| WBC (10^3/mL)       | 11.6 [9.2, 15.3]        | 10.7 [9.7, 13.0]              | 0.228   |
| CRP (mg/dL)         | 0.78 [0.57, 1.03]       | 0.85 [0.52, 0.98]             | 0.242   |
| pH                  | 7.45 [7.42, 7.47]       | 7.44 [7.42, 7.47]             | 0.166   |
| Sodium (mEq/L)      | 146 [144, 147]         | 145 [143, 147]               | 0.625   |
| Potassium (mEq/L)   | 3.9 [3.8, 4.2]         | 3.9 [3.7, 4.0]               | 0.192   |
| Calcium (mg/dL)     | 10.6 [10.2, 11.1]      | 10.1 [10.0, 10.8]             | 0.270   |
| Magnesium (mg/dL)   | 2.6 [2.5, 2.9]         | 2.6 [2.4, 2.8]               | 0.567   |
| AST (IU/L)          | 80 [61, 96]            | 76 [57, 96]                   | 0.161   |
| ALT (IU/L)          | 20 [16, 22]            | 17 [16, 22]                   | 0.176   |
| LDH (IU/L)          | 468 [383, 585]         | 487 [407, 572]                | 0.181   |
| γGT (IU/L)          | 37 [23, 61]            | 29 [21, 35]                   | 0.388   |
| BUN (mg/dL)         | 14.6 [13.0, 16.0]      | 15.0 [12.8, 18.0]             | 0.083   |
| Creatinine (mg/dL)  | 0.38 [0.34, 0.45]      | 0.34 [0.29, 0.42]             | 0.234   |
| BNP (pg/mL)         | 25.6 [5.9, 38.8]       | 20.4 [11.4, 32.0]             | 0.270   |

Postoperative data

|                     | Arhythmia group (n = 21) | Non-arrhythmia group (n = 59) | P value |
|---------------------|-------------------------|-------------------------------|---------|
| AVVR grade          | 2 [1, 2]                | 1 [0, 2]                      | <0.001  |
| Atrial short axis diameter (mm) | 25.3 [22.5, 34.4] | 22.9 [22.3, 26.4] | 0.130   |
| Atrial pressure (mmHg) | 7 [6, 10]            | 5 [5, 7]                      | 0.039   |

Improvement after the Fontan operation

|                     | Arhythmia group (n = 21) | Non-arrhythmia group (n = 59) | P value |
|---------------------|-------------------------|-------------------------------|---------|
| AVVR grade, n (%)   | 2 (9.5)                 | 26 (44.1)                     | 0.042   |
| Atrial short axis diameter, n (%) | 10 (47.6)      | 32 (54.2)                     | 0.602   |
| Atrial pressure, n (%) | 6 (28.6)            | 32 (54.2)                     | 0.043   |

Data are shown as the n (%) or median [interquartile range]. DIRV indicates double inlet right ventricle; DILV, double inlet left ventricle; CIRV, common inlet right ventricle; CILV, common inlet left ventricle; TA, tricuspid atresia; MA, mitral atresia; HLHS, hypoplastic left heart syndrome; PAIVS, pulmonary atresia with intact ventricular septum; cTGA, corrected transposition of the great arteries; RV, right ventricle; LV, left ventricle; AV, atriocentral; CAVV, common atriocentral valve; ILT, intra-atrial lateral tunnel; ECC, extracardiac conduit + CPB cardiopulmonary bypass; ACC, aortic cross clamp; PMI, pacemaker implantation; JET, junctional ectopic tachycardia; AT, atrial tachycardia; AFL, atrial flutter; PSVT, paroxysmal supraventricular tachycardia; RFCA, radiofrequency catheter ablation; EDP, end-diastolic pressure; PA, pulmonary artery; AVVR, atriocentral valve regurgitation; Hb, hemoglobin; WBC, white blood cell; CRP, C-reactive protein; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase; γGTP, γ-glutamyl transferase; BUN, blood urea nitrogen; and BNP, brain natriuretic peptide.

**Discussion**

Early postoperative arrhythmias in children after the Fontan operation are a life-threatening complication resulting in acute hemodynamic deterioration and death.\(^{[50]}\) We evaluated the characteristics and predictors of early postoperative SVTs in children after Fontan procedures. In this study, we found that 26.3% of the patients had early postoperative SVTs after the Fontan procedure. The most common arrhythmia encountered in this study was JET, with an incidence of 71.4%. We also detected that the significant predictors of early postoperative SVTs in children were an AVVR grade of ≥2 and preoperative arrhythmias.

To date, previous studies have reported mainly about late postoperative arrhythmias after the Fontan procedure;\(^{[5,10]}\) however, there have been scarce data regarding early postoperative arrhythmias after the Fontan operation. The first large retrospective cohort study about predictors of early onset arrhythmias, after the classical and contemporary Fontan operation, showed that the frequency of early onset SVT was 15% and a significant risk factor associated with an early onset SVT was an abnormal AV valve anatomy, AVVR, age at the time of the Fontan operation, and preoperative arrhythmias. There was no difference in the frequency of early and late onset SVT among Fontan operation types.\(^{[11]}\) The previous retrospective cohort study reported that the incidence of early postoperative atrial tachyarrhythmias was 12.8% after the classical Fontan procedure and 7.2% after the Fontan procedure. Early postoperative atrial tachyarrhythmias, follow-up length, and APC Fontan were demonstrated to be significant predictors of late ATs; however, predictors of early postoperative arrhythmias were not investigated.\(^{[10]}\) Another retrospective cohort study showed that the prevalence of early postoperative arrhythmias was 4.7% after the Fontan operation.\(^{[5]}\) The most common tachycardia in the early postoperative period was JET (67%). A multicenter, cross-sectional study in children showed that the
Table II. Characteristics of Early Postoperative SVTs in the Arrhythmia Group

| Arrhythmia (n = 21) | Early postoperative SVT | JET, n (%) | 15 (71.4) |
|---------------------|-------------------------|------------|-----------|
|                     | AT, n (%)               | 4 (19.0)   |
|                     | AFL, n (%)              | 1 (4.8)    |
|                     | AVRT, n (%)             | 1 (4.8)    |
| Recurrence of preoperative arrhythmia, n (%) | 3 (14.3) |
|                     | JET, n (%)              | 2 (9.6)    |
|                     | AT, n (%)               | 1 (4.8)    |
| New onset arrhythmia, n (%) | 18 (85.7) |
| Median time from the Fontan to the arrhythmia onset (days) | 1 (0-2) |
|                     | JET                     | 0.5 (0.1-1.75) |
|                     | AT                      | 2 (0.75-4.25) |
|                     | AFL                     | 6          |
|                     | AVRT                    | 1          |
| Treatment of early postoperative SVT | | |
|                     | JET                     | Amiodarone, n (%) | 5 (23.8) |
|                     |                          | 10 (47.6)  |
|                     |                          | 4 (4.8)    |
|                     | AT                      | Landiolol, n (%) | 2 (9.5) |
|                     |                          | 1 (4.8)    |
|                     | AFL                     | Electrical cardioversion, n (%) | 1 (4.8) |
|                     |                          | 1 (4.8)    |
|                     | AVRT                    | Adenosine triphosphate, n (%) | 1 (4.8) |

Data are shown as the n (%) or median [interquartile range]. SVT indicates supraventricular tachyarrhythmia; JET, junctional ectopic tachycardia; AT, atrial tachycardia; AFL, atrial flutter; and AVRT, atrioventricular reciprocating tachycardia.

Table III. Univariate and Multivariate Logistic Regression Analysis of Early Postoperative Arrhythmias

| Univariate | Multivariate |
|------------|-------------|-------------|-------------|
| Age (months) | OR (95% CI) | 0.90 (0.32-2.50) | 1.05 (0.97-1.14) |
| Female | P value | 0.836 | 0.247 |
| Weight (kg) | OR (95% CI) | 3.60 (0.43-30.30) | 0.81 (0.50-1.31) |
| ECC | P value | 0.212 | 0.390 |
| Single RV | OR (95% CI) | 2.37 (0.84-6.72) | 4.42 (0.97-20.18) |
| Heterotaxy | P value | 0.100 | 0.055 |
| Prior AV valvuloplasty | OR (95% CI) | 2.94 (1.01-8.58) | 10.54 (2.52-44.17) |
| Preoperative arrhythmia | P value | 0.000 | 0.001 |
| AVVR grade ≥ 2 | OR (95% CI) | 18.13 (1.97-166.42) | 26.49 (1.64-428.62) |

A multivariate logistic regression analysis was performed to calculate the OR and 95% CI. OR indicates odds ratio; CI, confidence interval; ECC, extracardiac conduit; RV, right ventricle; AV, atrioventricular; and AVVR, atrioventricular valve regurgitation.

The overall prevalence of SVT was 9.6% after the Fontan operation. A recent international multicenter study reported that early postoperative tachyarrhythmia occurred in 5.0% of patients undergoing the ILT Fontan operation and 8.0% of patients undergoing the ECC Fontan operation. There was no difference in the incidence of early and late postoperative tachyarrhythmia between the ILT and the ECC Fontan operation. Our prevalence of data on early postoperative arrhythmias after the Fontan operation was higher than previously published reports. One reason for high incidence of early postoperative arrhythmias in this study may be that we included both sustained and non-sustained arrhythmias. Another reason might be that the number of AV valvuloplasties during Fontan procedures was higher in the non-arrhythmia group than in the arrhythmia group without any significant statistical difference; however, an AVVR grade ≥ 2 was shown to be a significant predictor of early postoperative arrhythmias.
anemia, electrolyte imbalance, circulatory failure and postoperative use of inotropic medications were reportedly associated with JET in the previous studies.\(^2\) In this study, there was no significant difference between these risk factors and JET. One of the reasons for this difference can be that previous reports mentioned JET risk factors after various types of surgery, but our study analyzed only SVT after the Fontan operation. Another reason may be that a postoperative electrolyte imbalance and anemia were aggressively maintained within normal levels in the intensive care unit (ICU). Moreover, the recurrence incidence of preoperative arrhythmias after the Fontan operation was low, and most postoperative arrhythmias were new onset JET. Therefore, our study illustrated that an AVVR grade and preoperative arrhythmia may be associated with early postoperative JET.

Atrial arrhythmias are known to significantly contribute to patient mortality and morbidity after the Fontan operation.\(^2\) Therefore, identifying patients at high risk for early postoperative arrhythmias is essential to prevent early postoperative arrhythmias. In our study, patients with an AVVR grade of ≥ 2 are more likely to develop early postoperative SVTs after the Fontan procedure. Atrial enlargement and distension were reported as one cause of developing atrial arrhythmias in animal models and patients with congenital heart disease, including after APC Fontan procedure.\(^2\) Tissue injury of the atrial muscle and extension of the atrial wall, because of atrial enlargement by AVVR, may result in development of early postoperative SVTs. In our study, there were no significant differences in the atrial size, but there was a potential trend toward a larger atrial size in the arrhythmia group. Moreover, the improvement in the AVVR grade and atrial pressure after the Fontan operation was significantly associated with the prevention of early postoperative arrhythmias. Hence, intervention, such as AV valveoplasty during the Fontan procedure in patients with an AVVR grade of ≥ 2, may prevent early postoperative SVTs after the Fontan operation.

Several limitations of our study should be acknowledged. The relatively small sample size limited statistical analyses. Furthermore, we could not completely eliminate the influence of survivor bias due to the short duration of the follow-up after the Fontan. Finally, selection bias and residual confounding variables were inevitable in this type of retrospective cohort study regardless of the multivariate logistic regression analysis.

**Conclusion**

We demonstrated that significant predictors associated with early postoperative SVTs in children after the Fontan operation were an AVVR grade of ≥ 2 and preoperative arrhythmias. Intervention for AVVR during the Fontan procedure may result in clinical benefit of preventing early postoperative SVTs following the Fontan operation.

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**Disclosure**

**Conflicts of interest:** The authors declare that there is no conflict of interest.

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