Sinus node dysfunction after repair of partial anomalous pulmonary venous connection

Hiroaki Takahashi, MD,^a Yoshihiro Oshima, MD,^b Masahiro Yoshida, MD,^b Masahiro Yamaguchi, MD, PhD,^c Kenji Okada, MD, PhD,^a and Yutaka Okita, MD, PhD^a

Objectives: Sinus node dysfunction is known as a major complication after repair of partial anomalous pulmonary venous connection. We retrospectively analyzed the results of the atrial wall flap technique compared with the results of patch repair or direct suturing in the intra-atrial tunnel technique.

Methods: Between 1991 and 2007, 23 patients (mean age, 6 years; range, 5 months–17 years) with partial anomalous pulmonary venous connection underwent surgical intervention. The right anomalous pulmonary veins drained to either the right atrium or superior vena cava in 8 and 15 patients, respectively. Patients were divided into 2 groups: group F (n = 14), who had repair with an atrial flap, and group N (n = 9), who had repair without an atrial flap. All patients had normal sinus rhythm preoperatively.

Results: No patients had signs of superior vena cava or pulmonary venous obstruction within a mean follow-up of 4.8 years. One patient in group F required pacemaker implantation. In the early postoperative period, sinus node dysfunction developed in 93% of group F and 44% of group N patients ($P < .01$) and was prolonged until discharge in 57% of group F and 0% of group N patients ($P < .01$). At the most recent clinical visit, sinus node dysfunction was identified in 50% of group F patients, whereas all patients in group N had normal sinus rhythm ($P < .02$).

Conclusions: The atrial flap technique, which requires incision or suture crossing the crista terminalis, could cause sinus node dysfunction, whereas the intra-atrial rerouting method with a patch or direct suture maintains normal sinus node function postoperatively.

From the Department of Surgery, Division of Cardiovascular Surgery,^a Kobe University Graduate School of Medicine, Kobe, Japan; the Department of Cardiovascular Surgery,^b Kobe Children's Hospital, Kobe, Japan; and the Department of Cardiovascular Surgery,^c Akashi Medical Center, Kobe, Japan.

Received for publication Sept 7, 2007; revisions received Nov 7, 2007; accepted for publication Dec 7, 2007.

Address for reprints: Hiroaki Takahashi, MD, Department of Surgery, Division of Cardiovascular Surgery, Kobe University Graduate School of Medicine, 7-5-2, Kusunoki-cho, Chuo-ku, Kobe, 650-0017, Japan (E-mail: takahashi-cvs@hotmail.co.jp).

J Thorac Cardiovasc Surg 2008;136:329-34
0022-5223/\$34.00

Copyright © 2008 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2007.12.039

Several methods for repairing partial anomalous pulmonary venous connection (PAPVC) to the superior vena cava (SVC) or the right atrium (RA) have been described since 1958.¹ Ideal surgical repair demands complete closure of the atrial septal defect (ASD) and redirection of the anomalous pulmonary veins into the left atrium without either pulmonary venous or SVC obstruction or injury to the sinus node or its blood supply. The atrial wall flap technique, which was originally established in 1985 for the repair of total anomalous pulmonary venous drainage to the SVC,² has been applied because the atrial wall flap was expected to grow, resist infection, and persist for the lifetime of the patient. However, undesirable complications, particularly sinus node dysfunction (SND), have been reported. We retrospectively analyzed the results of the atrial wall flap technique compared with the results of patch repair or direct suturing in the intra-atrial tunnel technique.

Materials and Methods

Patients

Between September 1991 and September 2007, 23 patients (11 male and 12 female patients; age at repair, 5 months–17 years; mean age, 5.6 ± 4.7 years; weight, 6.0–70 kg; mean weight, 19.6 ± 16.3 kg) underwent repair of PAPVC to the SVC or RA. This study was approved by the institutional review board, and patients or guardians of the patients provided informed preoperative consent. Additional cardiac anomalies included ventricular septal defect (n = 3),

Abbreviations and Acronyms

ASD	= atrial septal defect
PAPVC	= partial anomalous pulmonary venous connection
RA	= right atrium
SND	= sinus node dysfunction
SVC	= superior vena cava

tetralogy of Fallot ($n = 2$), pulmonary stenosis ($n = 2$), and coarctation of the aorta ($n = 1$). The right anomalous pulmonary veins drained to the RA in 8 patients and to the SVC in 15 patients. Sinus venosus ASDs were present in 9 patients, and fossa ovale was present in 12 patients. The atrial septum was intact in 2 patients. Preoperative electrocardiographic analysis revealed normal sinus rhythm in all patients. None of the patients had cardiac isomerism.

Patients were divided into 2 groups: group F ($n = 14$), who had repair with a right atrial flap, and group N ($n = 9$), who had no atrial flap. All patients had normal sinus rhythm preoperatively.

Routine postoperative follow-up included a physical examination, electrocardiographic analysis, and transthoracic echocardiographic analysis. The venous structures were assessed for obstruction by means of 2-dimensional echocardiographic visualization and Doppler echocardiography. Two of the more recent patients underwent thoracic computed tomography in addition to echocardiography to optimally visualize the repair site.

Surgical Technique

A median sternotomy was applied in 20 patients, and a right-sided thoracotomy was applied in 3 patients. The SVC and anomalous pulmonary veins were fully mobilized, and the azygous vein was divided. The aortic cannula was placed in position on the ascending aorta. Separate venous cannulas were placed, with the SVC cannulated directly and high near the innominate vein junction. After cardioplegic arrest, intra-atrial rerouting was performed to drain the anomalous pulmonary veins into the left atrium by using an atrial wall flap, a xenograft pericardium patch, or free autologous pericardium (Figure 1). As for the atrial wall flap procedures, a J-shaped

right atriotomy was applied to the anomalous pulmonary vein, which drained into the SVC, or a U-shaped right atriotomy was performed to the pulmonary veins, which were connected to the RA (Figure 2). Twelve patients in group F and 4 patients in group N required enlargement or creation of an ASD. In 1984, Warden and colleagues³ reported a technique in which the SVC was divided, the cephalic SVC was anastomosed to the right atrial appendage, and the caudal SVC served as a conduit for pulmonary venous drainage to the left atrium. The Warden procedure was applied to 13 of the 14 patients (8 patients in group F and 5 patients in group N) with PAPVC to the SVC, whereas for the remaining patient with the left SVC connecting to the right SVC, division of the right SVC was done.

Follow-up

The patients were followed up from 1.7 to 13 years (mean, 4.8 ± 3.3 years). The postoperative electrocardiograms were evaluated immediately after surgical intervention, at discharge (mean, 38.3 ± 18.8 days), or at the most recent clinical visit.

Sinus Node Dysfunction

SND was defined as the presence of any one of the following: (1) minimum or mean heart rate of greater than 2 standard deviations less than the age-adjusted mean, (2) predominant junctional rhythm, and/or (3) sinus pause of 3 seconds in duration.⁴⁻⁶ Patients with preoperative complete heart block, pacemakers, or both were excluded from the analysis of SND.

Statistical Analysis

The characteristics of the study population are expressed as frequencies, medians with range, or means with standard deviations, as appropriate. Univariate associations with postoperative late SND among clinical variables were obtained with χ^2 , Fisher exact, and unpaired t tests, and we decided to investigate the risk factor. Furthermore, multivariate logistic regression analysis was performed with variables that reached a P value of less than .20 on univariate testing to investigate which of the factors best predicted the postoperative late SND. Data analysis was performed with StatView 5.0 for Windows (SAS Institute, Inc, Cary, NC).

Figure 1. Intra-atrial rerouting with a xenograft pericardial patch or free autologous pericardium (A) or without materials (B).

Figure 2. J-shaped and U-shaped right atriotomy for patients with partial anomalous pulmonary venous connection (PAPVC) to the superior vena cava (SVC; A) and PAPVC to the right atrium (RA; B), respectively. IVC, Inferior vena cava.

Results

Intraoperative Data

Mean operative, bypass, and cardiac ischemic times were 375 ± 100 , 158 ± 57 , and 77 ± 31 minutes, respectively.

Mortality and Morbidity

No in-hospital or late mortality was observed over a mean follow-up of 4.8 ± 3.3 years, and no significant SVC or pulmonary venous obstruction developed. Patients were not significantly different according to their preoperative basic characteristics and demographics between group F and group N (Table 1). In the immediate postoperative period, the SND occurred in 93% of group F and 44% of group N patients ($P < .01$). The SND remained at discharge in 57% of patients in group F and 0% of patients in group N ($P < .01$). All patients remained well over the follow-up period, which ranged from 4 months to 12 years. At the latest clinical visit, SND was identified in 50% of patients in group F, whereas all patients in group N had normal sinus rhythm ($P < .02$) (Figure 3).

TABLE 1. Preoperative clinical characteristics

	Group F (n = 14)	Group N (n = 9)	P value
Male sex	6	5	.68
Age at operation (y)	5.9 ± 5.0	3.9 ± 3.2	.12
Weight at operation (kg)	22.3 ± 19.1	11.0 ± 1.6	.09
RPA to RV	4	4	.08
ASD (sinus venosus)	3	6	.08
Associated cardiac lesions	5	2	.99
Qp/Qs	2.1 ± 0.9	2.6 ± 0.6	.19
Pp/Ps	0.32 ± 0.12	0.34 ± 0.07	.76

RPA, Right pulmonary vein; RA, right atrium; ASD, atrial septal defect.

One patient in group F required repeated surgical intervention for a pacemaker implantation 3 years after PAPVC repair. He had bradycardia and sinus pause of 3 seconds or longer in duration, and at the latest examination after discharge, group F included 2 patients with sinus bradycardia that was inappropriate for age and 3 patients with predominant junctional rhythm (Table 2).

Patients were also divided into 2 groups, which were with or without postoperative late SND. Statistically, there was no difference between the 2 groups in age, body weight, location of the ASD, associated cardiac lesion, preoperative Qp/Qs, and Pp/Ps among preoperative factors. The atrial flap

Figure 3. Ratio (percentage) of patients with sinus node dysfunction after repair of partial anomalous pulmonary venous connection. Postoperative electrocardiograms were evaluated at 3 different time points. *Immediate postoperatively* means 1 week postoperatively. *Late postoperatively* means postoperatively after discharge from the hospital and at the most recent clinic visit.

TABLE 2. Summary of electrocardiographic findings

	Normal sinus rhythm	Sinus bradycardia	Junctional rhythm	Sinus pause
Preoperative (group F/N)	23 (14/9)	0 (0/0)	0 (0/0)	0 (0/0)
Postoperative				
Early (group F/N)	11 (6/5)	3 (2/1)	8 (5/3)	1 (1/0)
Late (group F/N)	17 (8/9)	2 (2/0)	3 (3/0)	1 (1/0)

Early, Postoperatively during hospitalization; Late, postoperatively after discharge from the hospital and at the most recent clinical visit.

technique was significantly higher in the group with postoperative SND. Furthermore, the difference between the incidence of supraventricular arrhythmias between J-shaped and U-shaped incisions in the right atrial wall was not statistically significant; however, the incidence of atrial arrhythmias was likely to be high (50% each), and the operative time in patients with postoperative SND was likely to be longer than that without postoperative SND (Table 3).

We used multiple logistic regression analysis to discover the explanatory variable that could best predict the postoper-

TABLE 3. Univariate analysis of potential risk factors associated with SND after repair of PAPVC

Risk factor	Normal sinus rhythm (n = 16)	SND (n = 7)	P value
Preoperative factors			
Male sex	7	4	.67
Age at operation (y)	5.8 ± 5.0	5.3 ± 4.3	.81
Weight at operation (kg)	20.8 ± 18.2	17.0 ± 11.9	.63
RPV to RA	6	2	.67
Location of ASD (sinus venosus)	8	1	.17
Associated cardiac lesions	5	2	.99
Qp/Qs	2.3 ± 0.9	2.3 ± 1.1	.92
Pp/Ps	0.30 ± 0.10	0.41 ± 0.25	.16
Operative factors			
ASD enlargement/creation	10	6	.37
Atrial flap technique	7	7	.02
J-shaped flap technique	5	5	.17
U-shaped flap technique	2	2	.56
Warden procedure	9	4	.99
Right thoracotomy	2	1	.83
Operative time (min)	349.6 ± 106.7	433.6 ± 51.4	.06
ECC time (min)	145.1 ± 58.8	164.0 ± 57.0	.48
ACC time (min)	77.2 ± 30.1	79.4 ± 37.2	.88

SND, Sinus node dysfunction; PAPVC, partial anomalous pulmonary venous connection; RPV, right pulmonary vein; RA, right atrium; ASD, atrial septal defect; ECC, extracorporeal circulation; ACC, aortic crossclamp.

TABLE 4. Multivariate logistic analysis of potential risk factors associated with SND after repair of PAPVC

Selected variables	Odds ratio	95% Confidence interval	P value
ASD (sinus venosus)	0.80	0.57–1.30	.37
Preoperative Pp/Ps	0.45	0.85–1.12	.49
Atrial flap technique	9.73	2.83–33.44	<.01
J-shaped flap technique	0.10	0.99–1.02	.89
Operative time	2.16	0.98–1.10	.14

SND, Sinus node dysfunction; PAPVC, partial anomalous pulmonary venous connection.

ative SND (Table 4). Our results revealed that the atrial wall flap technique best predicted the postoperative SND (odds ratio, 9.73; 95% confidence interval, 2.83–33.44; $P < .01$). However, the main limitation of our study is related to the small number of our patients, and we think that it is a just reference value about statistical discussion.

Discussion

Several methods of repairing PAPVC have been reported. Some of these methods have been associated with significant morbidity, including pulmonary venous or SVC obstruction or atrial arrhythmias, especially SND. Until 2002, we had applied the atrial wall flap technique, which was originally established in 1985 for the repair of total anomalous pulmonary venous drainage to the SVC,² because the atrial wall flap was expected to grow, resist infection, and persist for the lifetime of the patient. However, it was recognized that the incidence of postoperative supraventricular arrhythmia occurred frequently, although there was no obstruction of pulmonary vein orifices and SVC stenosis or obstruction. It was reported that the postoperative incidence of SND ranged from 0% to 33%.⁷⁻¹² Procedures applied near the sinus node and in the atrium might increase the risk of SND and atrial arrhythmias.⁴ Shahriari and associates⁷ described the lower incidence of atrial arrhythmias with the Warden procedure was likely related to less manipulation of the RA and the SVC and avoidance of the sinus node and its arterial supply compared with the internal patch repair. Injury to the sinus node and its arterial supply has been considered one explanation for SND after surgical intervention.^{10,13}

On the other hand, we experienced the SND after the atrial wall flap repair, even if the operation was designed so that the atriotomy did not extend across the atriocaval junction, sinus node, or its arterial supply. Based on our analysis, the intra-atrial rerouting method with a patch or direct suture maintains normal sinus node function postoperatively. Therefore we also believe that the postoperative SND was caused by making the atrial wall flap. Anatomically, the sinus node extends caudally along the crista terminalis, and sinus node depolarization results in excitation that spreads preferentially toward the crista terminalis,¹⁴ a region that must be crossed when

Figure 4. Schema shows site of sinus node and J-shaped right atriotomy for repair of partial anomalous pulmonary venous connection with right atrial wall flap (A). Intra-atrial rerouting can be performed below the crista terminalis by using patch or direct suturing (B). SVC, Superior vena cava; IVC, inferior vena cava.

applying a J-shaped or U-shaped incision in the right atrial wall (Figure 4, A). This prevents sinus node excitation from spreading to the crista terminalis and causes SND. Fishberger¹⁴ described that the sinus node was superficial, lying immediately beneath the epicardial surface in the sulcus terminalis, and that in neonates and infants the sinus node might extend more caudally toward the inferior vena cava. Dobrzynski and associates¹⁵ also showed the location and extent of the sinus node by means of histologic analyses. They stated that the node was lateral and inferior to the crest and extended down the terminal crest toward the orifice of the inferior caval vein.¹⁵ Therefore suturing the remaining edge of the atriotomy might also lead to SND. In contrast, intra-atrial rerouting could be performed below the crista terminalis by using patch or direct suture, and that contributes to avoidance of SND (Figure 4, B). In the current study the difference between the incidence of supraventricular arrhythmias between J-shaped and U-shaped incisions in the right atrial wall was not statistically significant; however, the incidence of atrial arrhythmias was high, and this result suggested that J-shaped or U-shaped incisions in the right atrial wall or suturing of the remaining edge of the atriotomy have the potential to cause SND.

We could not help making the sufficiently large atrial wall flap to prevent the postoperative obstruction of pulmonary vein orifices and SVC stenosis or obstruction, but it cannot be avoided to cross the crista terminalis in making the flap, and we think the incision or suture crossing the crista terminalis in the atrial wall flap repair for PAPVC has the potential to cause SND.

None of the patients had clinical symptoms of supraventricular arrhythmias, except for one patient who required pacemaker implantation. However, Sanders and coworkers¹⁶ mentioned that evidence existed to implicate atrial fibrillation in the development of SND, and we think that severe follow-up is necessary in the future for these patients.

There are some limitations to the present study. First, this is a retrospective study, and it was performed in a nonrandomized fashion. The second limitation of our study is related to the small number of our patients and bias, possibly resulting

from performance of the study at a single institution. We cannot but say that it is a reference value about statistical discussion.

In conclusion, an incision or suture that crosses the crista terminalis for atrial pedicle flap repair might cause SND. Intra-atrial rerouting with a patch or direct suture is considered to be superior for maintaining normal sinus node function.

We thank Dr Shinichirou Yanagisawa (Department of Sociomedical Informatics, Health Informatics and Sciences, Kobe University Graduate School of Medicine, Japan) for statistical collaboration in this article.

References

1. Ehrenhaft JL, Theilen EO, Lawrence MS. The surgical treatment of partial and total anomalous pulmonary venous connection. *Ann Surg.* 1958; 148:249-58.
2. Vargas FJ, Kreutzer GO. A surgical technique for correction of total anomalous pulmonary venous drainage. *J Thorac Cardiovasc Surg.* 1985;90:410-3.
3. Warden HE, Gustafson RA, Tamay TJ, et al. An alternative method for repair of partial anomalous pulmonary venous connection to the superior vena cava. *Ann Thorac Surg.* 1984;38:601-5.
4. Cohen MI, Wernovsky G, Vetter VL, et al. Sinus node function after a systemically staged Fontan procedure. *Circulation.* 1998;98(suppl): II352-9.
5. Cohen MI, Bridges ND, Gaynor JM, et al. Modifications to the cavopulmonary anastomosis do not eliminate early sinus node dysfunction. *J Thorac Cardiovasc Surg.* 2000;120:891-901.
6. Romano M, Clarizia M, Onofrio E, et al. Heart rate, PR, and QT intervals in normal children: a 24-hour Holter monitoring study. *Clin Cardiol.* 1988;11:839-42.
7. Shahriari A, Rodefeld MD, Turrentine MW, et al. Caval division technique for sinus venosus atrial septal defect with partial anomalous pulmonary venous connection. *Ann Thorac Surg.* 2006;81:224-30.
8. Gaynor JW, Burch M, Dollery C, et al. Repair of anomalous pulmonary venous connection to the superior vena cava. *Ann Thorac Surg.* 1995;59: 1471-5.
9. Walker RE, Mayer JE, Alexander ME, et al. Paucity of sinus node dysfunction following repair of sinus venosus defects in children. *Am J Cardiol.* 2001;87:1223-6.
10. Gustafson RA, Warden HE, Murray GF. Partial anomalous pulmonary venous connection to the superior vena cava. *Ann Thorac Surg.* 1995; 60(suppl):S614-7.
11. DeLeon SY, Freeman JE, Ilbawi MN, et al. Surgical techniques in partial anomalous pulmonary veins to the superior vena cava. *Ann Thorac Surg.* 1993;55:1222-6.
12. Williams WH, Zorn-Chelton S, Raviele AA, et al. Extracardiac atrial pedicle conduit repair of partial anomalous pulmonary venous connection to the superior vena cava in children. *Ann Thorac Surg.* 1989;98:861-8.

13. Nicholson IA, Chard RB, Nunn GR, et al. Transcaval repair of the sinus venosus syndrome. *J Thorac Cardiovasc Surg.* 2000;119:741-4.
14. Fishberger SB. Sinus node dysfunction. In: Walsh EP, Saul JP, Friedman JK, eds. Cardiac arrhythmias in children and young adults with congenital heart disease. Vol. 12. Philadelphia: Lippincott Williams & Wilkins; 2001:271-83.
15. Dobrzynski H, Boyett MR, Anderson RH, et al. New insights into pacemaker activity. *Circulation.* 2007;115:1921-32.
16. Sanders P, Kistler PM, Morton JB, et al. Remodeling of sinus node function in patients with congestive heart failure. *Circulation.* 2004;110:897-903.

Interactive eLearning Activities

<http://learning.ctsnet.org>

The Joint Council on Thoracic Surgery Education was pleased to introduce a series of unique eLearning activities to CTSNet users at the AATS annual meeting in Philadelphia. Sponsored by several cardiothoracic surgical groups, this exciting new educational tool contains narrated videos of actual surgical procedures followed by a series of questions and an evaluation to earn Continuing Medical Education credit.

- * **Diagnosis and Management of Complications of Mitral Valve Repair**
- * **Off Pump Coronary Artery Bypass**
- * **OPCAB Debriefing**
- * **Pediatric Cardiopulmonary Bypass Emergency Situations**

Experience these new educational tools today and provide us with your feedback. Go to: <http://learning.ctsnet.org>

William E. Baumgartner, Chair
Joint Council on Thoracic Surgery Education

Sponsored By:
American Association for Thoracic Surgery
The Society of Thoracic Surgeons
European Association for Cardio-Thoracic Surgery
Children's Memorial Hospital