Strategy of delayed repair of total anomalous pulmonary venous connection in right atrial isomerism and functional single ventricle

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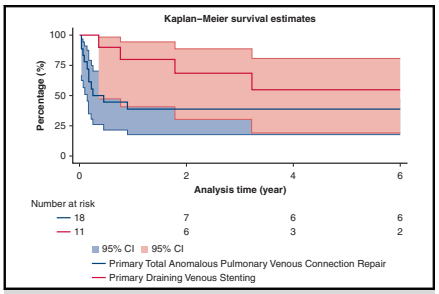
ABSTRACT

Objective: Repair of total anomalous pulmonary venous connection (TAPVC) in neonates with right atrial isomerism and functional single ventricle is challenging. In our novel strategy, primary draining vein stenting (DVS) was applied to patients with preoperative pulmonary vein obstruction to delay TAPVC repair. This study investigated our initial experience with a strategy of delayed TAPVC repair, incorporating DVS.

Methods: Twenty-nine patients with right atrial isomerism and functional single ventricle who had a severe obstruction in the course of draining veins, who required surgical or catheter intervention in their neonatal period were retrospectively reviewed (primary DVS: n = 11; primary TAPVC repair: n = 18).

Results: Patients in the primary DVS group had more mixed type TAPVC (primary DVS: n = 5, 45.5%; primary TAPVC repair: n = 2, 11.1%; $P = .03$) and required more systemic to pulmonary shunt surgeries during their lifetime (primary DVS: n = 9, 81.8%; primary TAPVC repair: n = 6, 33.3%; $P = .047$). Kaplan–Meier analysis showed that primary DVS repair was associated with improved survival compared with primary TAPVC repair (survival rates at 90 days, 1 year, 3 years and 5 years: primary DVS: 100%, 80%, 68.6%, and 54.9%; primary TAPVC repair: 55.6%, 38.9%, 38.9%, and 38.9%, respectively [$P = .04$]). Of the 4 patients who underwent stenting of the ductus venosus, 3 had elevated liver enzymes after surgical repair of TAPVC due to ductus venosus steal, which markedly improved after coil embolization of the stent.

Conclusions: For neonates with obstructive TAPVC and functional single ventricle, our delayed TAPVC repair using primary DVS appeared to improve survival compared with the conventional strategy. (JTCVS Open 2022;10:308-19)



Kaplan–Meier analysis showed improved survival of delayed strategy ($P = .04$).

CENTRAL MESSAGE

For neonates with obstructive total anomalous pulmonary venous connection, right atrial isomerism, and functional single ventricle, our strategy of delayed repair might improve survival.

PERSPECTIVE

Repair of total anomalous pulmonary venous connection in neonates with right isomerism and functional single ventricle is challenging. Further verification of our delayed total anomalous pulmonary venous connection repair strategy would augment clinical management and guide decision-making in this unique entity.

See Commentaries on pages 320 and 322.

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Although surgical outcomes in patients with total anomalous pulmonary venous connection (TAPVC) have improved over the past 2 decades, its management in patients with right atrial isomerism and functional single ventricle remains challenging.[1-3] The Society of Thoracic Surgeons Congenital Heart Surgery Database revealed

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Abbreviations and Acronyms
DVS = draining vein stenting
PVO = pulmonary vein obstruction
TAPVC = total anomalous pulmonary venous connection

that the repair of TAPVC in such patients has a high mortality rate (43%).[1] Younger age at TAPVC repair is also known to be associated with higher rates of mortality and postoperative pulmonary vein obstruction (PVO).[2,4-6] Some studies have suggested the possibility of stent implantation for obstructive drainage veins to delay the timing of surgical correction and improve survival.[2,7] In our new strategy, primary draining vein stenting (DVS) was applied to patients with preoperative PVO to delay TAPVC repair. This study investigated the efficacy and problems of a strategy of delayed TAPVC repair in patients with right atrial isomerism and functional single ventricle.

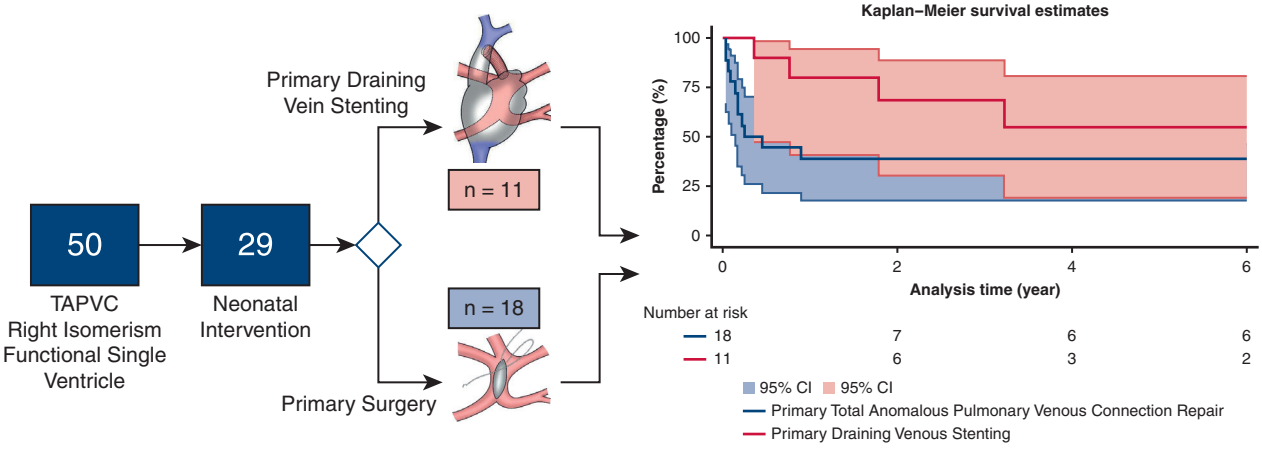
METHODS

We retrospectively reviewed all patients who underwent operative repair of TAPVC with right atrial isomerism and functional single ventricle at our institution between January 1990 and June 2020. Our hospital's institutional review board approved this study, and the requirement for written informed consent was waived because of the study's observational nature (IRB-2009-023; approval: October 23, 2020). Of the 50 patients, 29 consecutive patients had severe obstruction in the course of draining veins and needed surgical or catheter intervention in their neonatal periods. Preoperative obstruction was defined as a Doppler echocardiographic velocity of >1.2 m/s or a pressure gradient of 4 mm Hg or more or minimal diameter of draining vein of 1.5 mm or less or pulmonary congestion due to the narrowing of the draining veins requiring mechanical ventilation. These patients were divided into 2 groups: those who underwent primary DVS (n = 11) and those who underwent a primary TAPVC repair (n = 18; Figure 1). All imaging modalities were reviewed to confirm the anatomic diagnosis. Clinical information was extracted from the medical records, and operative notes were reviewed.

Delayed Strategy

In the 1990s, we performed primary TAPVC repair in all patients with right isomerism and functional single ventricle. Because younger age at TAPVC repair had begun to be known to be associated with higher mortality rates, since the 2000s, we have started to delay TAPVC repair if no PVO was present.

In 2009, we performed the first case of primary DVS to delay TAPVC repair. Although we did not have a clear indication for DVS, we tended to apply DVS especially to patients who had complex anatomical features such as patients who needed systemic to pulmonary shunt or mixed-type TAPVC because this was the most difficult patient group that often struggled with postoperative management to balance systemic and pulmonary circulation. Because we achieved successful outcomes of the primary cases, we extended the criteria to use primary DVS. We did not routinely conduct a computed tomography scan or magnetic resonance imaging before the catheter intervention. Anatomical features were examined using echocardiography. TAPVC repair was delayed until patients had a progressive cyanosis or required other surgical interventions. Among 11 patients who underwent primary DVS at a median age of 8 (interquartile range, 4-16) days, 1 patient needed emergency stent removal with TAPVC repair because of stent migration. The patient had type Ib TAPVC and the landing zone was short. The stent migrated to the pulmonary artery after going through the atrium and the right ventricle during the stenting procedure. After this case, we consider a short landing zone as a contraindication for DVS.



For neonates with obstructive TAPVC, right atrial isomerism, and functional single ventricle, our delayed repair strategy appeared to improve survival.

FIGURE 1. Of the 50 patients who underwent surgical repair of total anomalous pulmonary venous connection (*TAPVC*) with right atrial isomerism and functional single ventricle, 29 consecutive patients had a severe obstruction in the course of draining veins and needed surgical or catheter intervention in their neonatal periods. These cases were divided into those who underwent primary draining vein stenting (n = 11) or primary TAPVC repair (n = 18). Kaplan–Meier analysis showed a better survival in the primary draining vein stenting group compared with the primary TAPVC repair ($P = .045$).

In 7 patients, primary draining vein stents were implanted in the vertical vein. Three patients had infracardiac type and 1 had mixed-type TAPVC who underwent primary DVS in the ductus venosus. Types of stents and their diameters are shown in Table E1.

TAPVC Repair

TAPVC repair is usually performed with the patient under cardiac arrest and mild hypothermia without circulatory arrest. Conventional TAPVC anastomosis is performed in most patients. To minimize the thickness of the anastomosis, endocardial-to-endothelial bites were minimized.

Clinical Outcomes

The primary outcome was long-term survival, analyzed according to the Kaplan–Meier curve. We also investigated the clinical course of the patients after the procedures and patient characteristics including sex, birth weight, diagnosis after birth, and preoperative degree of atrioventricular valve regurgitation. Postoperative PVO was defined as a Doppler echocardiographic velocity of >1.2 m/s or a pressure gradient of 4 mm Hg or more. Catheter intervention was performed in patients with pulmonary congestion or high right ventricular pressure due to PVO. When the patients were refractory to catheter intervention, surgical PVO release was performed.

Statistical Analysis

All data were retrospectively analyzed. Data are presented as absolute numbers and percentages for categorical variables and as median values and interquartile ranges for continuous variables, unless stated otherwise. Dichotomous variables were compared using Fisher exact test, and χ^2 test whereas the continuous variables were compared using the Mann–Whitney *U* test. *P* values are reported without correction for multiple tests. Kaplan–Meier calculations were performed for survival analyses. All statistical analyses were performed using Stata/SE version 16 (StataCorp).

RESULTS

Patient Characteristics

Baseline characteristics of the study cohort are shown in Table 1. Patients in the primary DVS group had more mixed-type TAPVC (primary DVS: n = 5, 45.5%; primary TAPVC repair: n = 2, 11.1%; $P = .036$) and required more systemic to pulmonary shunt surgeries during their lifetime (primary DVS: n = 9, 81.8%; primary TAPVC repair: n = 6, 33.3%; $P = .047$).

Clinical Outcomes

The clinical courses are presented in Tables 2 and 3. The median follow-up was 19.5 months in the overall cohort, with 33.4 (interquartile range, 9.3-62.7) months in the primary DVS group and 4.3 (interquartile range, 1.7-103) months in the primary TAPVC repair group ($P = .28$). In the primary TAPVC repair group, postoperative echocardiography data of 5 patients were not available because of early mortality. Postoperative PVO was noted in 5 patients in the primary DVS group (45.5%) and 6 in the primary TAPVC repair group (46.2%; $P = .93$). PVO reintervention, including catheter and surgery was performed in 5

TABLE 1. Patient characteristics

Variable	Primary draining vein stenting (n = 11)	Primary TAPVC repair (n = 18)	*P* value
Female sex	5 (45.5)	10 (55.6)	.60
Birth weight (IQR), kg	2.6 (2.3-3.0)	2.7 (2.6-3.1)	.31
TAPVC			
Supracardiac type	3 (27.3)	10 (55.6)	.14
Infracardiac type	3 (27.3)	6 (33.3)	.73
Mixed type	5 (45.5)	2 (11.1)	.03
Sutureless technique	2 (18.2)	0 (0)	.06
Functional single ventricle with common atrioventricular valve			.08
Unbalanced atrioventricular septal defect	10 (90.9)	11 (61.1)	
Common inlet right ventricle	1 (9.1)	7 (38.9)	
Common inlet left ventricle	0	0	
Pulmonary valve			.10
Stenosis	9 (81.8)	8 (44.5)	
Atresia	2 (18.2)	6 (33.3)	
Major aortopulmonary collateral artery	1 (9.1)	0	.19
Systemic venous drainage			.06
Bilateral superior vena cava	6 (54.6)	4 (22.2)	
Left-sided superior vena cava	2 (18.2)	1 (5.6)	
Moderate or severe common atrioventricular valve regurgitation	4 (36.4)	2 (16.7)	.28
Systemic to pulmonary shunt	9 (81.8)	6 (33.3)	.04
Emergent intervention (within 24 h of birth)	2 (18.1)	8 (44.4)	.14

Data are presented as n (%) except where otherwise noted. *TAPVC*, Total anomalous pulmonary venous connection; *IQR*, interquartile range.

TABLE 2. Clinical courses

	Primary draining vein stenting (n = 11)	Primary TAPVC repair (n = 18)	*P* value
Follow-up period, months	33.4 (9.3-62.7)	4.3 (1.7-103)	.28
Primary draining stenting age, days	8 (4-16)	–	
Stenting site			
Vertical vein	7	–	
Ductus venosus	4	–	
TAPVC repair age, days	88 (58-106)	8.5 (0-18)	<.01
Postoperative PVO	5 (45.5)	6 (46.2)	.97
Reintervention for PVO	5 (45.5)	3 (16.7)	.09
Patients who reached or waiting for Glenn operation	8 (72.7)	9 (50)	.28
Fontan completion or awaiting Fontan operation	5 (45.5)	6 (33.3)	.38

Data are presented as median (interquartile range) or n (%) except where otherwise noted. *TAPVC*, Total anomalous pulmonary venous connection; *PVO*, pulmonary vein obstruction.

patients (45.5%) in the primary DVS group and 3 in the primary TAPVC group (16.7%; $P = .09$; Figure 2; Table 2). Details of the postoperative PVO are described in Table E2. All patients who needed catheter intervention subsequently underwent PVO release surgery during follow-up.

Survival and Fontan Achievement

Kaplan–Meier analysis showed a better survival in the primary DVS group than in the primary TAPVC repair (survival rates at 90 days, 1 year, 3 years and 5 years: primary DVS: 100%, 80%, 68.6%, and 54.9% vs primary TAPVC repair: 55.6%, 38.9%, 38.9%, and 38.9%, respectively [$P = .045$]; Figure 3; Video 1). Four patients died in the primary DVS group because of respiratory failure due to hypoplastic trachea, low output syndrome, heart failure after surgery, and thromboembolism of the conduit after Fontan operation (Table 3). Of the 11 patients who died in the primary TAPVC repair group, 9 patients died within 100 days before Glenn procedure mainly because of heart failure and low output syndrome. All 11 patients with primary DVS underwent TAPVC repair later at a median age of 88 days, whereas primary TAPVC repair was performed at a median age of 8.5 days ($P < .01$). Five patients (45.5%) achieved Fontan completion or awaiting Fontan procedure in the primary DVS group, whereas 6 patients (33.3%) completed Fontan procedure in the primary TAPVC group (Figure 4).

Liver Damage

Of the 4 patients who underwent stenting of the ductus venosus, 3 had liver damage 2 to 3 days after TAPVC repair. Before TAPVC repair, none of the 3 patients had liver damage and they tolerated to the stents. Their aspartate transaminase and alanine transaminase levels were elevated to 1684 to 5945 U/L and 566 to 3059 U/L, respectively. Ultrasound showed blood flow from the liver through the portal vein to the ductus venosus where the stent was applied. The patients were immediately transferred to the catheterization lab to embolize the stent, which improved the aspartate transaminase and alanine transaminase levels. Figure 5 shows the contrast-enhanced computed tomography images of the 3 patients who underwent stenting of the ductus venosus.

DISCUSSION

TAPVC repair in patients with right atrial isomerism and functional single ventricle is known to have high mortality rates.[1-3] The risk for TAPVC repair is higher when performed in neonates because this subset of patients usually represents the most severe end of the TAPVC spectrum with features including hypoxia, hypercapnia, or acidosis.[2,4-6] Because there was no alternative to delay emergency TAPVC repair in patients with pulmonary obstruction, the outcome was disappointing because of high mortality rates soon after the first operation.[2,4,5] In our institute, a delayed strategy was applied to patients with right atrial isomerism and obstructed TAPVC using primary DVS. Since 2009, when we performed the first case of primary DVS to delay TAPVC repair, it was performed in 11 neonates. This study showed the initial experience with improved survival in primary DVS compared with the conventional primary TAPVC repair. It is important to note that in the primary TAPVC repair group, most patients died soon after surgery because of low output syndrome and heart failure as the result of unbalanced systemic-to-pulmonary blood flow. Patients who undergo TAPVC repair in the neonatal period often have poor lung conditions with high pulmonary resistance. In such patients, controlling pulmonary circulation is difficult, especially in patients with systemic to pulmonary shunts. This causes low cardiac output, ventricular dysfunction, and atrioventricular valve regurgitation, which subsequently results in a lethal

TABLE 3. Details of each patient

Patient	TAPVC type	Cardiac anatomy	Surgery before TAPVC repair	Concomitant procedures	Subsequent procedures	Age	Cause of death
Primary draining vein stenting							
1	Mixed	SV, CAVV, PA, LSVC		m-BTS			LOS
2	Supracardiac	DORV, Hypoplastic LV, CAVV, PS, MAPCA, Rt AoA		m-BTS MAPCA ligation	PVO release Unifocalization CAVV repair	8 Months	Respiratory failure
3	Infracardiac	SV, CAVV, PS, Bil. SVC, Rt AoA, PDA		m-BTS CAVV repair	CAVV repair	7 Months	Heart failure
					CAVV replacement	1 Year	
					PM implantation	1 Year	
4	Supracardiac	SV, CAVV, PS	m-BTS		BDG CAVV repair BTS division	10 Months	TCPC graft embolism
					TCPC Pulmonary valve closure	1 Year	
5	Mixed	SV, CAVV, PS		CAVV repair Main pulmonary artery banding	m-BTS Pulmonary artery valve closure	28 Days	
6	Infracardiac	SV, PA, PDA, Rt AoA, Bil. SVC	PDA banding m-BTS				
7	Supracardiac	SV, CAVV, PS, Bil. SVC, Rt AoA, PDA		Pulmonary artery banding PDA ligation	BDG Pulmonary artery banding CAVV repair PVO release	6 Months	
					CAVV repair CRT implantation	1 Year	
8	Mixed	SV, CAVV, PS, Bil. SVC, Rt AoA		Main pulmonary artery banding	BDG and PVO release (open stent)	6 Months	
9	Mixed	SV, CAVV, PS		CAVV repair Pulmonary artery plasty Stent removal	PVO release	6 Months	
					PVO release CAVV repair	1 Year	
					PVO release (open stent) CAVV repair	1 Year	
					BDG Pulmonary artery semiclosure	1 Year	
					CAVV replacement CRT implantation	3 Years	
					Glenn take down m-BTS	5 Years	
10	Infracardiac	SV, CAVV, PS, Bil. SVC	m-BTS	BDG and Pulmonary artery banding	PVO release	7 Months	
					PVO release	10 Months	
					PVO release	1 Year	
					PVO release (open stent) CAVV repair	1 Year	

(Continued)

TABLE 3. Continued

Patient	TAPVC type	Cardiac anatomy	Surgery before TAPVC repair	Concomitant procedures	Subsequent procedures	Age	Cause of death
11	Mixed	SV, CAVV, PA, LSVC	m-BTS, Draining vein repair	ASD enlargement	BDG Pulmonary artery plasty CAVV repair TCPC CAVV repair	1 Year 3 Years	
Primary TAPVC repair							
1	Infracardiac	SV, CAVV, PS					LOS
2	Supracardiac	SV, CAVV, PA		m-BTS			LOS
3	Mixed	SRV, PA		m-BTS			LOS
4	Infracardiac	SRV, CAVV, PA		RV-pulmonary artery shunt CAVV repair			Heart failure
5	Infracardiac	SRV, CAVV, PS					Sepsis
6	Supracardiac	SRV, CAVV					Respiratory failure
7	Supracardiac	SV, CAVV, PS		pulmonary artery banding			Respiratory failure
8	Supracardiac	SV, CAVV, PS, Bil. SVC					Respiratory failure
9	Infracardiac	DORV, CAVV, PA		RV-pulmonary artery shunt	PVO release	2 Months	PVO
10	Infracardiac	SV, CAVV, PA, Bil. SVC		m-BTS	BDG BTS division	4 Months	Arrhythmia
11	Supracardiac	SV, CAVV, PS			BDG CAVV repair Glenn take down	7 Months 8 Months	Respiratory failure
12	Mixed	SV, CAVV, PS, LSVC			BDG pulmonary artery banding PM implantation Glenn take down CAVV repair PA debanding CRT upgrade	9 Months 9 Months 1 Year	
13	Supracardiac	SRV, CAVV, PA		RV-pulmonary artery shunt PDA ligation	BDG TCPC Maze PVO release Fontan fenestration recreation	7 Months 2 Years 6 Years	
14	Supracardiac	SV, CAVV, PS, Bil. SVC			BDG CAVV repair TCPC CAVV repair PM implantation	4 Months 2 Years 2 Years	
15	Supracardiac	SV, CAVV, Bil. SVC, Rt AoA		pulmonary artery banding	Bilateral BDG pulmonary artery banding TCPC	1 Year 2 Years	
16	Supracardiac	SRV, CAVV, DORV, PS, Bil. SVC		pulmonary artery banding	PVO release BDG TCPC	3 Months 6 Months 3 Years	

(Continued)

TABLE 3. Continued

Patient	TAPVC type	Cardiac anatomy	Surgery before TAPVC repair	Concomitant procedures	Subsequent procedures	Age	Cause of death
17	Infracardiac	SV, CAVV		pulmonary artery banding	BDG	1 Year	
					CAVV repair		
					TCPC	2 Years	
18	Supracardiac	DORV, CAVV		Pulmonary artery banding	BDG	7 Months	
					TCPC	2 Years	

TAPVC, Total anomalous pulmonary venous connection; *SV*, functional single ventricle; *CAVV*, common atrioventricular valve; *PA*, pulmonary atresia; *LSVC*, left superior vena cava; *m-BTS*, modified Blalock–Taussig shunt; *LOS*, low output syndrome; *DORV*, double outlet right ventricle; *LV*, left ventricle; *PS*, pulmonary stenosis; *MAPCA*, major aortopulmonary collateral artery; *Rt AoA*, right aortic arch; *PVO*, pulmonary venous obstruction; *Bil. SVC*, bilateral superior vena cava; *PDA*, patent ductus foramen; *PM*, pacemaker; *BDG*, bidirectional Glenn procedure; *BTS*, Blalock–Taussig shunt; *TCPC*, total cavopulmonary connection; *CRT*, cardiac resynchronization therapy; *ASD*, atrial septal defect; *SRV*, single right ventricle; *RV*, right ventricle.

condition.[2,4-6] TAPVC repair during cardiopulmonary bypass, in addition to systemic to pulmonary shunt, is far more invasive compared with drainage vein stenting. As such, a delayed TAPVC repair strategy has the advantage that TAPVC repair can be postponed beyond the neonatal period by avoiding TAPVC repair and systemic to pulmonary shunt.

Postoperative PVO is a well known complication associated with pulmonary venous hypertension, pulmonary vascular disease, and increased morbidity and mortality.[8,9] Younger age at TAPVC repair might be associated with postoperative PVO because of the small anastomotic site.[4] Therefore, a strategy of delayed TAPVC repair was expected to reduce postoperative PVO. However, postoperative PVO was noted in 5 patients in the primary DVS group (45.5%) and 6 in the primary TAPVC repair group (46.2%; $P = .93$); the primary DVS group still had a high postoperative PVO rate. There are several possible reasons for this finding. First, the primary TAPVC repair group had a high early mortality rate, and some patients were not

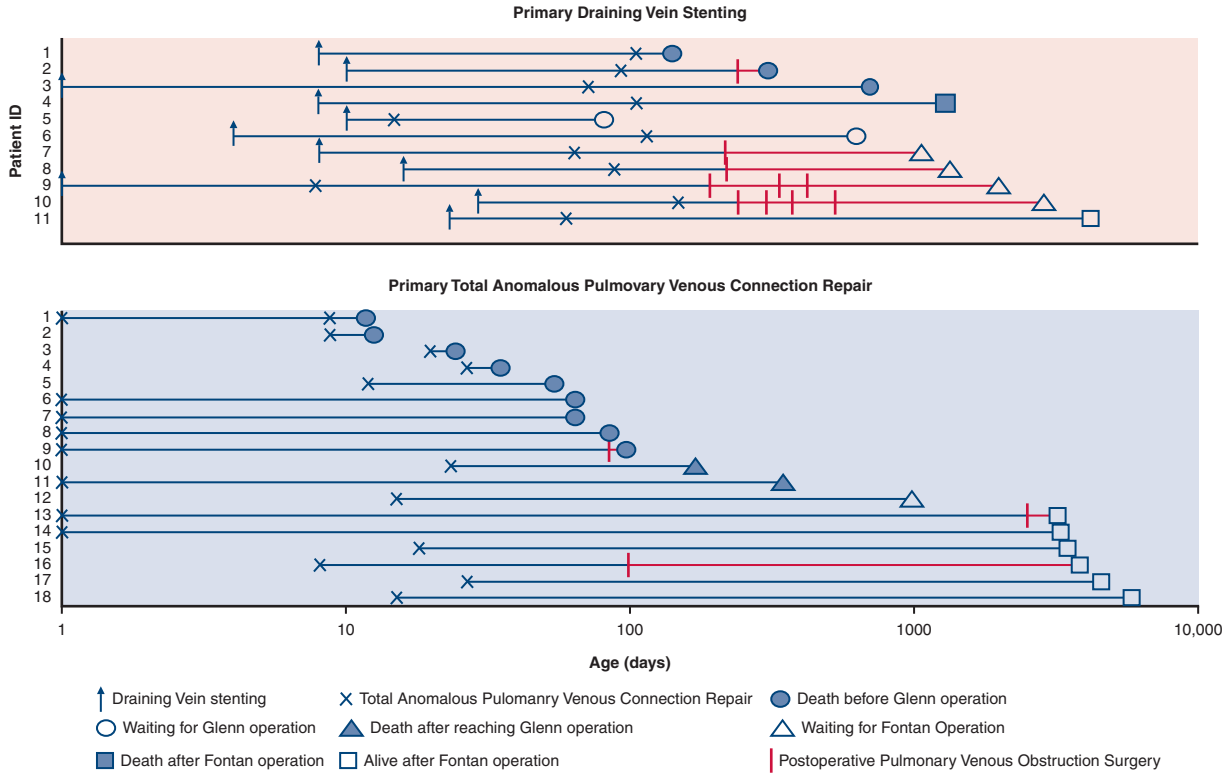


FIGURE 2. Timing of surgeries and interventions focused on pulmonary venous obstruction. Primary total anomalous pulmonary venous connection repair was performed immediately after birth, whereas primary draining venous stenting delayed total anomalous pulmonary venous connection repair were done beyond the neonatal period. The overall mortality was 36.4% in the primary draining venous stenting group versus 61.1% in the primary total anomalous pulmonary venous connection repair group. Nine of 11 deaths in the primary total anomalous pulmonary venous connection group were observed before Glenn procedure.

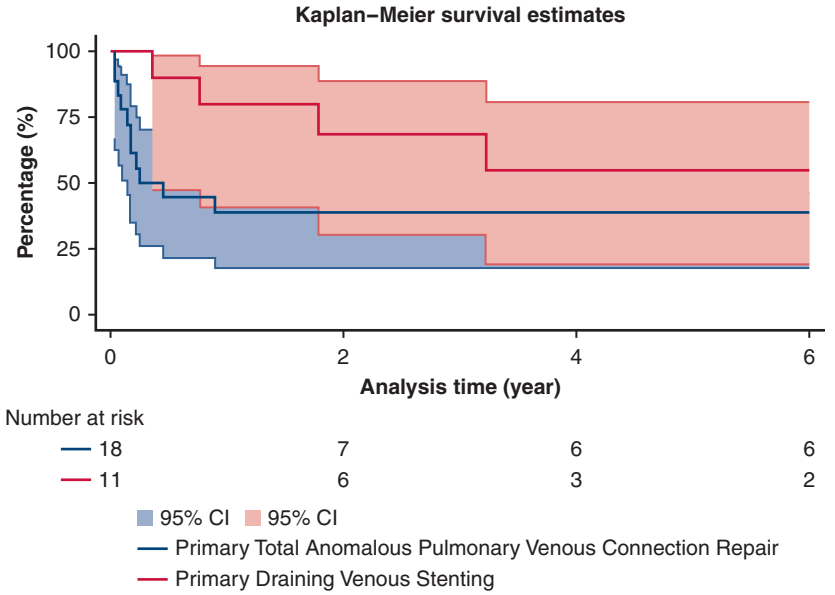
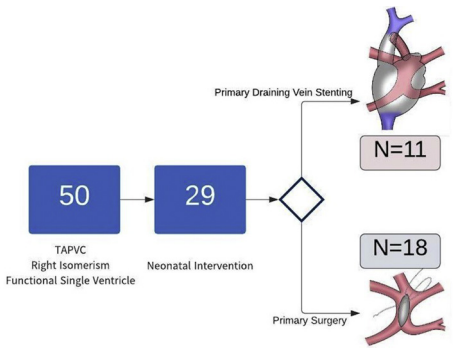


FIGURE 3. Kaplan–Meier analysis of overall survival for each group. Kaplan–Meier analysis showed that primary draining venous stenting repair was associated with improved survival compared with primary total anomalous pulmonary venous connection repair (survival rates at 90 days, 1 year, 3 years, and 5 years): primary draining venous stenting: 100%, 80%, 68.6%, and 54.9%, respectively; and primary total anomalous pulmonary venous connection repair: 55.6%, 38.9%, 38.9%, and 38.9%, respectively (95% CI, 0.26-0.63; $P = .045$). *CI*, Confidence interval.

assessed for PVO before they died. Second, more mixed-type TAPVC was observed in the primary DVS group, which could be a high risk for postoperative PVO. Finally, only 2 patients had a sutureless technique and the result might have been different if the technique was used more frequently for those with infracardiac and mixed-type TAPVC. Although this study was not able to prove the benefit of delayed TAPVC repair in the occurrence of postoperative PVO because of the small number of patients studied, further investigation is necessary to determine the effect of this strategy.

Stenting of the ductus venosus in patients with TAPVC and right isomerism has been previously reported.[10] However, problems of liver damage after TAPVC repair have not been studied. In this study, 3 of the 4 patients who underwent stenting of the ductus venosus had elevated aspartate transaminase and alanine transaminase levels after TAPVC repair. The cause of liver damage after TAPVC repair is a result of increased blood flow from the portal vein to the ductus venosus because of decreased blood flow from the pulmonary vein to the ductus venosus. Increased shunt across the ductus venosus decreased blood flow to the liver, resulting in liver damage. The elevated aspartate transaminase and alanine transaminase levels became normal soon after coil embolization of the stent. Therefore, careful monitoring of liver enzymes is recommended for 1 to 2 days after TAPVC repair or stenting of the ductus venosus, and early intervention, including catheter coil embolization of the stent should be considered. In our recent case, we planned percutaneous occlusion of the ductus venosus in anticipation of rapid liver function abnormalities after TAPVC repair (Y. Imai, unpublished data).



VIDEO 1. Summary of the study finding. Video available at: https://www.jtcvs.org/article/S2666-2736(22)00041-9/fulltext.

Our study has some limitations. This study was conducted retrospectively in a single center and consequently included a small number of patients. There were baseline differences among the 2 groups, which might have affected outcomes. A difference in survival rates might also have affected the secondary outcomes.

CONCLUSIONS

For neonates with obstructive TAPVC, right atrial isomerism, and functional single ventricle, our strategy

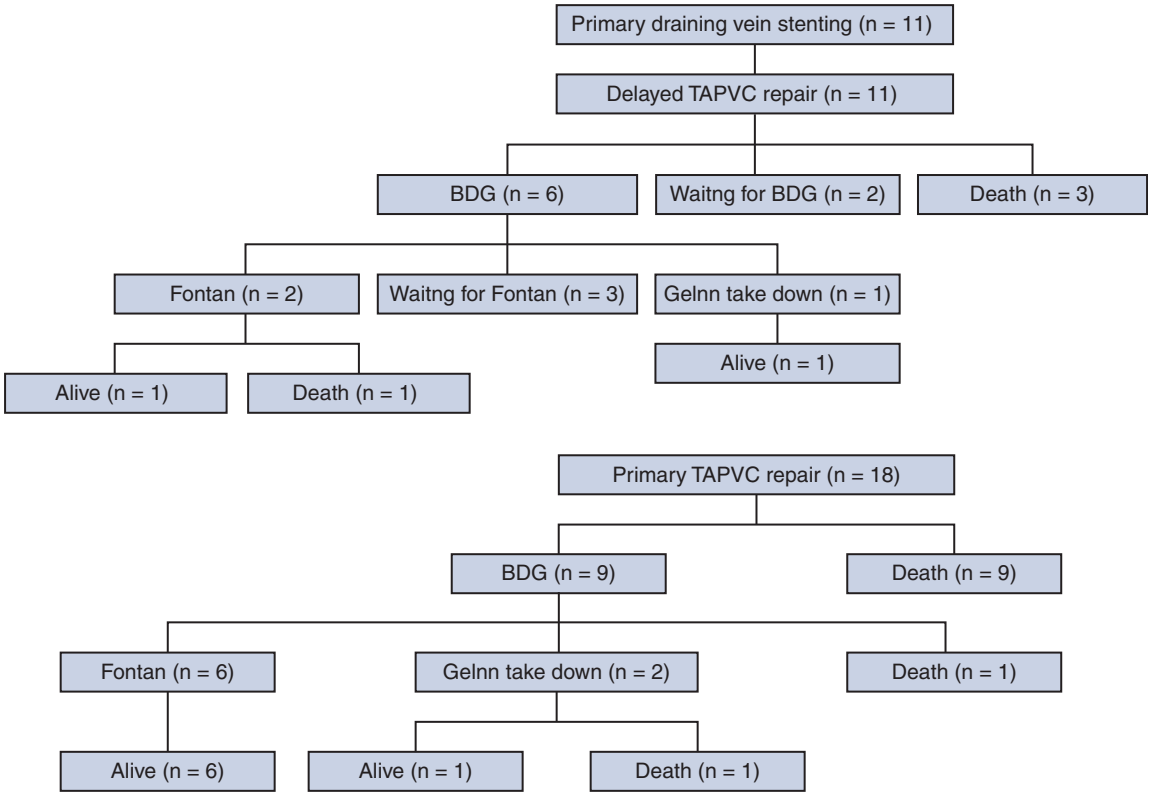


FIGURE 4. Diagram of postsurgical outcome. All 11 patients with primary draining venous stenting underwent total anomalous pulmonary venous connection (*TAPVC*) repair later at a median age of 88 days. Five patients (45.5%) achieved Fontan completion or awaiting Fontan operation in the primary draining venous stenting group, whereas 6 patients (33.3%) achieved Fontan operation in the primary TAPVC group. *BDG*, Bidirectional Glenn procedure.

of delayed TAPVC repair using primary DVS might delay the timing and improve survival compared with the conventional strategy. When TAPVC repair is performed after ductus venosus stenting, we should be aware of potential liver damage and consider early catheter intervention.

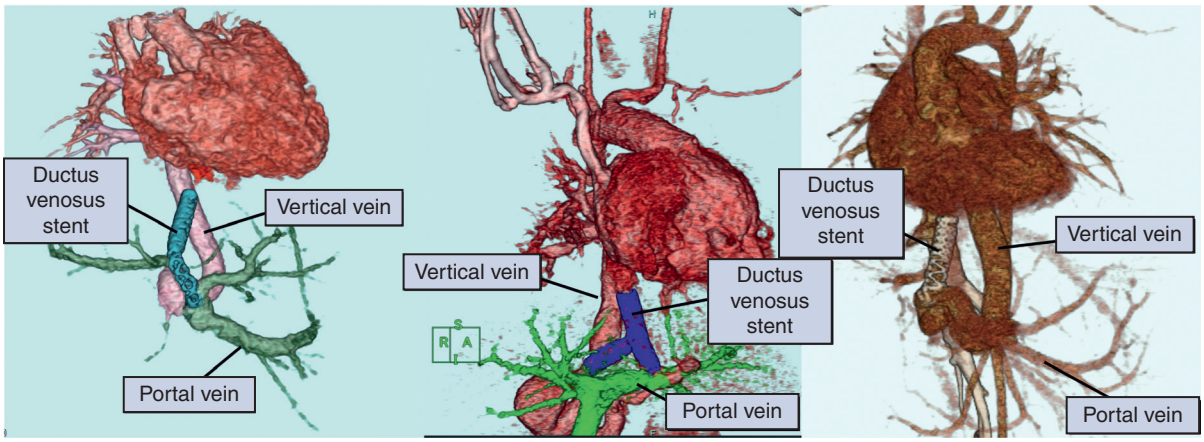


FIGURE 5. Contrast enhanced computed tomography images of patients with ductus venous stenting. Three of the 4 patients who underwent stenting of the ductus venosus had elevated aspartate transaminase and alanine transaminase levels after total anomalous pulmonary venous connection repair. The cause of liver damage after total anomalous pulmonary venous connection repair is a result of increased blood flow from the portal vein to the ductus venosus due to decreased blood flow from the pulmonary vein to the ductus venosus. Increased shunt across the ductus venosus decreased blood flow to liver, resulting in liver damage. The elevated aspartate transaminase and alanine transaminase levels became normal soon after stent embolization.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/21%20AM/AM21_CPlen/AM21_CPLEN_04.mp4.

Conflict of Interest Statement

The authors reported no conflicts of interest.

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Key Words: total anomalous pulmonary venous connection, right isomerism, neonate, congenital heart disease, surgical repair, stent implantation

Discussion

Presenter: Dr Eiri Kisamori

Dr Rachel D. Vanderlaan *(Toronto, Ontario, Canada)*. Congratulations. That was an excellent presentation and your research describes a novel approach for this very challenging group of patients. I just have a couple questions for you. For the selection of the patients that underwent the DVS (draining vein stenting), you state that this is based on anatomical and physiological feasibility and that the trigger for surgical repair was cyanosis, or the need for additional surgical procedures. Additionally, you describe the baseline characteristics of the patients as being similar.

What remains unclear is whether or not there were additional surgical or catheter-based procedures that were performed for each of these groups at the time of the index procedure and whether this might account for some differences in complexity between the 2 groups and therefore contribute to the survival difference. So my question is, in addition to the index TAPVC strategy, were there concomitant surgical or catheter-based procedures, and how might they differ between the 2 different patient cohorts? And is this a potential source of bias for your survival data?

Dr Eiri Kisamori *(Okayama, Japan)*. Thank you for the question. As I showed in the slides, there was not a statistically significant difference between 2 groups. However, as you indicated, there is the possibility that there is a difference between the 2 groups. The primary DVS group has a higher rate of mixed type compared with primary surgical type—45.5% versus 11.1%. The primary DVS group also had severe AV regurgitation—patients who have more than moderate AV regurgitation were 36% in primary the DVS group and 16% in the primary TAPVC repair group. So as you indicated, there can be some slight differences.

Dr Vanderlaan. In terms of the surgical interventions that were done at the time of the initial selection, were there more systemic shunts in one group? To clarify, did the DVS group have no other surgical or cath-based procedures? Did the surgical cohort have more palliative shunts?

Dr Kisamori. Thank you for the question. The percent of shunt was, I think, higher in the DVS group. I'm sorry, I don't have the exact number.

Dr Vanderlaan. Thank you. My second question relates more to the technique of the stenting of the draining vein. In

terms of determining the feasibility of who would get the stenting, did you use additional CT or MRI to triage these patients? What was the typical size of stent that was placed? And was there a preference for a bare-metal stents or drug-eluting stent? And then before getting their surgical repair for TAPVC, were there additional dilations that took place?

Dr Kisamori. Thank you. We did not usually perform any imaging tests routinely, including CT or MRI. We would usually use echocardiography. And we usually use 3- to 5-mm DES. And we usually did not perform additional dilation before surgery.

Dr Vanderlaan. Thank you. My last question relates to the pulmonary vein obstruction occurring in the postoperative period after TAPVR repair. In the manuscript you sent me, you suggest that the diagnosis for PVO in the postoperative period was similar, and the number of patients who underwent surgical procedures for that was also similar between the 2 cohorts. I was curious because there was more infracardiac TAPVD, which are at higher risk for PVO. I was wondering what surgical technique was mostly used for repair of TAPVC when they ultimately went on to their surgical repair.

Dr Kisamori. Thank you for the question. The number of catheter interventions was also not different among the 2 groups.

Dr Vanderlaan. Was the surgical approach typically a sutureless repair or a conventional repair for TAPVR?

Dr Kisamori. We rarely use a sutureless technique for first surgical intervention, but we sometimes use it for a second or third intervention. We usually use conventional technique.

Dr Vanderlaan. So you typically use conventional technique for the primary repair of TAPVR, and then a sutureless repair if you go on to developed pulmonary vein stenosis in the later course.

Dr Kisamori. Yes, that's correct.

Dr Vanderlaan. Thank you very much.

Dr Kisamori. Thank you very much.

TABLE E1. Type of stent used for primary draining vein stenting

Patient	Stent type	Stent diameter (mm)
1	Palmaz Genesis	5 × 15
2	Palmaz Genesis	6 × 15
3	BMX	3.5 × 24
4	Palmaz Genesis	6 × 10
5	Resolute Onyx	4 × 22
6	Resolute Integrity	3.5 × 30
7	Omnilink Elite	7 × 19
8	BMX	3.5 × 18
9	Nobori	3.5 × 18
10	Nobori	3.5 × 24
11	Genesis	5 × 18

Palmaz Genesis are from Cardinal Health, BMX from Biosensors, Resolute Onyx and Resolute Integrity are from Medtronic, Omnilink Elite from Abbott, and Nobori is from Terumo. *BMX*, BioMatrix.

TABLE E2. Pulmonary venous obstruction

Patient	TAPVC type	Postoperative PVO gradient (catheter), mm Hg	Postoperative peak velocity (echo) m/sec	Intervention	Stenotic site	Nonconfluent PV
Primary draining vein stenting						
2	Supracardiac		1.4	Stent Surgical PVO release	Multivessel	+
7	Supracardiac	3	1.5	Surgical PVO release	Single vessel	−
8	Mixed		1.2	Surgical PVO release Open stent BAP	Multivessel	+
9	Mixed	10	2.1	Surgical PVO release Open stent BAP	Multivessel	−
10	Infracardiac	5	2	Surgical PVO release Open stent BAP	Multivessel	+
Primary TAPVC repair						
8	Supracardiac		1.3		Anastomosis site	−
9	Infracardiac		1.3	Surgical PVO release	Multivessel	+
12	Mixed		1.2		Anastomosis site	−
13	Supracardiac		1.4	Surgical PVO release	Multivessel	−
16	Supracardiac		2.5	Surgical PVO release	Multivessel	−
18	Supracardiac		1.4		Anastomosis site	−

TAPVC, Total anomalous pulmonary venous connection; *PVO*, pulmonary venous connection; *PV*, pulmonary vein; *BAP*, balloon angioplasty; +, nonconfluent pulmonary vein; −, confluent pulmonary vein.