Original Article

Right ventricle to pulmonary artery conduit: a comparison of long-term graft-related events between bovine jugular vein conduit, aortic homograft, and porcine-valved conduits

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Background: The optimal conduit for right ventricle to pulmonary artery (RV-PA) reconstruction does not exist. Reinterventions are common due to conduit stenosis and endocarditis. Tailoring conduit choice according to patients' characteristics could improve the outcomes. The study aimed to compare graft-related events (infective endocarditis, transcatheter pulmonary valve replacement (PVR), transcatheter conduit dilatation, surgical conduit replacement, and transcatheter pulmonary branch intervention for RV-PA reconstruction using bovine jugular vein, aortic homograft, and porcine-valved conduits.

Methods: In a retrospective cohort study, 155 patients with 193 procedures that were done in King Faisal Specialist Hospital and Research Center-Jeddah (KFSHRC JED) for implanting RV-PA conduits from 1999 to 2021 were included. The patients were grouped according to the type of conduit into 3 groups; Group 1 (n=153) received bovine jugular vein (BJVs) grafts, Group 2 (n=29) received aortic homografts, Group 3 (n=11) received porcine-valved conduits. Factors associated with graft-related events were evaluated using stepwise Cox regression analysis.

Results: Patients with BJVs were significantly younger than those with porcine-valved conduits 3 (P=0.009). The weight of BJVs patients was significantly lower than homografts (P=0.002) and porcine-valved conduits patients 3 (P<0.001). The conduit size was as expected significantly lower in BJVs patients than patients who received porcine-valved conduits (P<0.001) and patients who received aortic homografts (P<0.001). There was no difference between Group 2 and 3 (P=0.084). Operative mortality occurred in 13 patients: 12 (7.84%) with BJV conduit and 1 (9.09%) with porcine valved conduit (P=0.351). Male gender [odds ratio (OR): 10.04; 95% confidence interval (CI): 1.28–78.86; P=0.028] and smaller conduit size (OR: 0.78; 95% CI: 0.61–0.99; P=0.048) were associated with increased operative mortality. Freedom from graft-related events at 5 and 10 years was 67% and 52% in BJVs patients, 74% and 36% in patients who received aortic homografts, and 53% in patients who received porcine-valved conduits. Factors associated with increased graft-related events were male gender (HR: 1.58; 95% CI: 1.004–2.50, P=0.048) and younger age (HR: 0.995; 95% CI: 0.991–0.999, P=0.041).

Conclusions: RV-PA reconstruction was associated with low mortality, unrelated to the conduit type.

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Reinterventions for graft-related events were common. The durability and graft-related events might be comparable among BJV grafts, aortic homografts, and porcine-valved conduits. Factors associated with increased graft-related events in this study were male gender and younger age.

Keywords: Bovine jugular vein conduit (BJV conduit); aortic homograft; porcine-valved conduits; right-ventricle to pulmonary artery reconstruction (RV-PA reconstruction)

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Introduction

Right ventricle to pulmonary artery (RV-PA) construction is an integral surgical procedure in the biventricular repair of several congenital heart diseases, including tetralogy of Fallot, pulmonary atresia, and truncus arteriosus (1-3). Reinterventions, either surgical or transcatheter, after RV-PA construction is common, and the optimal RV-PA conduit still does not exist (4,5). Several grafts are available for RV-PA reconstruction, including aortic and pulmonary homografts (6). However, the number of organ donors limited the use of homografts on a wide scale. Consequently, new alternatives have been introduced, including bovine jugular vein (BJV) conduits (Contegra, Medtronic, Minneapolis) and the composite porcine valve in the Dacron tube (Hancock, Medtronic, Minneapolis) (7-10).

BJV conduits are available in small sizes, making them suitable for neonates; additionally, they have a lower cost than homografts (11). Furthermore, BJV could have comparable durability to homografts. Herrmann and colleagues reported that BJV conduits had better freedom from reoperation compared to aortic homografts, with no difference between BJV conduits and pulmonary homografts (12). However, the risk of infective endocarditis is of concern with BJV conduits. Beckerman and associates reported an incidence of 10% of endocarditis rate at a median follow-up of 7.5 years with BJV conduits (13).

Several factors affect the longevity and the event-free survival of the RV-PA conduits that may be patients or conduit-related. The optimal conduit is still a matter of continuous debate, and tailoring conduit choice according to the patient's specific risk factors could improve the outcomes of RV-PA reconstruction.

This study compared RV-PA reconstruction using BJVs, aortic homografts, and porcine-valved conduits. Additionally, we reported different types of graft-related events after RV-PA reconstruction and their potential risk factors. We present this article in accordance with the STROBE reporting checklist (available at https://cdt.amegroups.com/article/view/10.21037/cdt-23-364/rc).

Highlight box

Key findings

- Bovine jugular vein should be avoided for patients at high risk of infective endocarditis or underdeveloped pulmonary artery branches and in these cases; homograft could be the conduit of choice.

What is known, and what is new?

- The smaller right ventricle to pulmonary artery conduits, the more risk for reintervention risk factor.
- In our study cohort, we reported that smaller conduit sizes were associated with an increased risk of operative mortality

What is the implication, and what should change now?

- The association between age and the increased risk of reoperation could suggest using other palliative procedures to postpone conduit implantation until the patients get older to decrease the risk of reoperation and operative mortality.

Methods

Patients

This retrospective cohort study included 155 patients who had 193 procedures for implanting RV-PA conduits from 1999 to 2021 at King Faisal Specialist Hospital and Research Center, Jeddah, Saudi Arabia. Three types of conduits were used: BJVs Medtronic® (Group 1, n=153), aortic homografts CenoValve® (Group 2, n=29), and porcine-valved conduits Carpentier Edwards® (Group 3, n=11). All patients had both orthotopic and heterotopic conduit implantation and biventricular repair. Patients with RV-PA reconstruction using synthetic conduits and those with the univentricular repair were excluded. The graft choice was dependent on surgeons' preference and experience and the available graft sizes. Patients who had RV-PA conduit with single ventricle pathway were excluded.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the local ethical committee of King Faisal Specialist Hospital and Research Center-Jeddah (IRB 2022-36). The ethical committee waived the need for informed consent for the retrospective nature of the study.

Data and outcomes

Preoperative data included age in months, gender, weight, diagnosis, and pulmonary blood flow. Baseline data were collected at the time of the indexed procedure. The type and size of the conduits were reported. The study outcomes were hospital mortality and follow-up graft-related events. Graft-related events included infective endocarditis, transcatheter pulmonary valve replacement (PVR), transcatheter conduit dilatation, surgical conduit replacement, and transcatheter pulmonary branch intervention.

Balloon dilation for severe conduit stenosis was indicated if right ventricular (RV) pressure was more than 60% of systemic pressure. Balloon dilation or stenting of peripheral pulmonary branch stenosis was required when lung perfusion showed one lung with less than 25% perfusion compared to the other lung or RV pressure of more than 60% of systemic pressure (14). Transcatheter PVR was indicated if symptomatic pulmonary regurgitation or asymptomatic with magnetic resonance imaging parameters of RV end-diastolic indexed volume >150 mL/m^2, Z-score >4, RV end-systolic indexed volume >80 mL/m^2, RV ejection fraction (EF) <47%, left ventricular EF <55% or large RV outflow tract aneurysm or ECG criteria of QRS duration >160 ms or sustained tachyarrhythmia. Conduit replacement was performed if the medical treatment of infective endocarditis failed, or cardiac catheter-based interventions were not possible.

Follow-up

The patients were followed in the outpatient clinics and the follow-up data were retrieved from the medical charts. Additionally, follow-up data were collected from admission and procedure records for patients who required readmission of interventions. Patients followed by phone calls to confirm the vital status, as a part of the clinical follow-up.

Statistical analysis

The continuous data were compared between the three groups using the one-way analysis of variance (ANOVA) for variables with equal variance and the Kruskal-Wallis test in case of unequal variance. Bartlett's test was used to assess the homogeneity of variance. The Bonferroni test was used for posthoc analysis after ANOVA and Dunn's test after the Kruskal-Wallis test. The adjusted P value cutoff for multiple comparison was 0.0167. Categorical data were compared with the Chi-squared or Fisher exact test. Univariable logistic regression analysis was used to evaluate factors associated with operative mortality, and odds ratios were reported. Time to events data were plotted using the Kaplan-Meier curve and compared with the log-rank test. Factors associated with graft-related events were evaluated using univariable and multivariable stepwise Cox regression analysis. All variables were included in the multivariable regression with a forward selection method, variables with a P value of less than 0.1 were retained in the final model, and hazard ratios were reported. Data were presented as median and (25th and 75th percentiles) or absolute frequency and percentages. Missing data were considered missing completely at random. Stata 17 (Stata Corp, College Station, TX, USA) was used to perform all analyses, and factors of a two-sided P value of less than 0.05 was considered statistically significant.

Results

Baseline and conduit characteristics

Gender was equally distributed among groups, and most patients were males. Patients in Group 1 were significantly younger than Group 3 (P=0.009), with no difference between other groups. The weight of patients in Group 1 was significantly lower than Group 2 (P=0.002) and Group 3 (P<0.001), with no difference in weight between Groups 2 and 3 (P=0.081).

The most frequent diagnosis in Group 1 and Group 2 was pulmonary valve atresia [72 (47.06%) and 17 (58.62%), respectively], and in Group 3 was tetralogy of Fallot (7, 63.64%). There was no difference in the diagnosis of additional lesions among groups. The additional lesions

Table 1 Comparison of baseline patients and conduit characteristics among patients who received bovine jugular vein conduit, aortic homograft, or porcine-valved conduit

Characteristics	Group 1 (n=153)	Group 2 (n=29)	Group 3 (n=11)	P value
Male	88 (57.52)	16 (55.17)	6 (54.55)	0.96
Age (months)	21 [8–45]; $P_{(vs.\ group\ 2)}$: 0.364	40 [12–130]; $P_{(vs.\ group\ 3)}$: 0.232	90 [18–220]; $P_{(vs.\ group\ 1)}$: 0.009	0.006
Weight (kg)	9 [6–15]; $P_{(vs.\ group\ 2)}$: 0.002	15 [9–25]; $P_{(vs.\ group\ 3)}$: 0.081	25 [12–60]; $P_{(vs.\ group\ 1)}$: <0.001	<0.001
Diagnosis				0.06
TOF	31 (20.26)	3 (10.34)	7 (63.64)	
Pulmonary atresia	72 (47.06)	17 (58.62)	2 (18.18)	
TGA, VSD and PS	17 (11.11)	2 (6.90)	1 (9.09)	
Truncus arteriosus	26 (16.99)	4 (13.79)	1 (9.09)	
Left-side lesion	7 (4.58)	3 (10.34)	0	
Additional lesion	14 (9.15)	0	2 (18.18)	0.09
Pulmonary flow				0.29
Normal	0	1 (3.45)	0	
Overflow	28 (18.42)	5 (17.24)	1 (9.09)	
Low flow	124 (81.58)	23 (79.31)	10 (90.91)	
Conduit size (mm)	14 [14–16] (n=150); $P_{(vs.\ group\ 2)}$: <0.001	19 [15–21] (n=27); $P_{(vs.\ group\ 3)}$: 0.084	20 [18–23]; $P_{(vs.\ group\ 1)}$: <0.001	<0.001

Data were presented as median [25^{th}–75^{th} percentile] or numbers and percentages. Group 1, bovine jugular vein; Group 2, homograft; Group 3, porcine valved conduit. PS, pulmonary stenosis; TOF, tetralogy of Fallot; TGA, transposition of great arteries; VSD, ventricular septal defect.

Table 2 Univariable logistic regression for factors affecting operative mortality

Risk factors	Odds ratio (95% confidence interval)	P value
Male	10.04 (1.28–78.86)	0.03
Age	0.98 (0.95–1.004)	0.10
Weight	0.91 (0.82–1.01)	0.08
Diagnosis	1.51 (0.96–2.38)	0.08
Additional lesion	0.92 (0.11–7.54)	0.936
Conduit type	0.61 (0.17–2.26)	0.47
Conduit size	0.78 (0.61–0.99)	0.048
Pulmonary blood flow	0.52 (0.16–1.68)	0.27

were absent pulmonary valve (n=6), atrioventricular septal defect (n=2), dextrocardia (n=1), Down syndrome (n=1), Fanconi syndrome (n=1), Marfan syndrome (n=2), mesocardia (n=1) and situs inversus totalis (n=2). There was no difference in the pulmonary blood flow among the groups.

The conduit size was significantly smaller in Group 1 than Group 3 (P<0.001) and Group 2 (P<0.001), with no difference between Groups 2 and 3 (P=0.084) (*Table 1*).

Operative mortality

Operative mortality occurred in 13 patients: 12 (7.84%) with BJV conduit and 1 (9.09%) with porcine-valved conduit (P=0.351). No mortality was reported in patients with aortic homograft. Univariable analysis revealed that male gender [odds ratio (OR): 10.04; 95% confidence interval (CI): 1.28–78.86; P=0.028] and smaller conduit size (OR: 0.78; 95% CI: 0.61–0.99; P=0.048) were associated with increased operative mortality (*Table 2*).

Follow-up

The median follow-up was 84 months (IQR: 33–127 months).

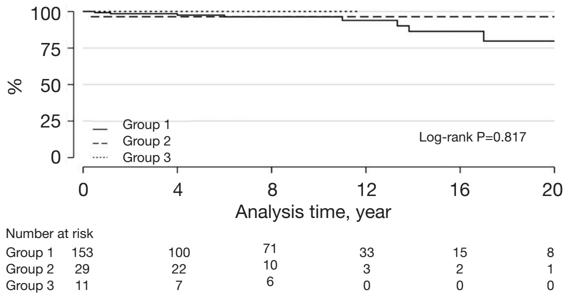

Figure 1 Kaplan-Meier freedom from infective endocarditis in bovine jugular vein conduit (Group 1), aortic homograft (Group 2), and porcine valved conduit (Group 3).

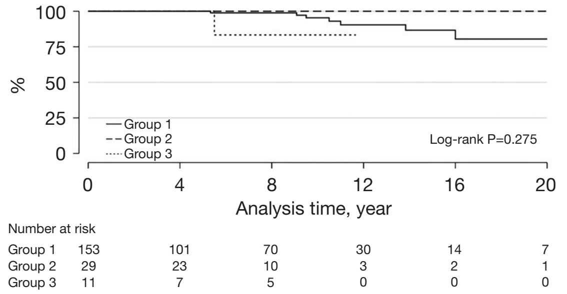

Figure 2 Kaplan-Meier freedom from transcatheter PVR in bovine jugular vein conduit (Group 1), aortic homograft (Group 2), and porcine valved conduit (Group 3). PVR, pulmonary valve replacement.

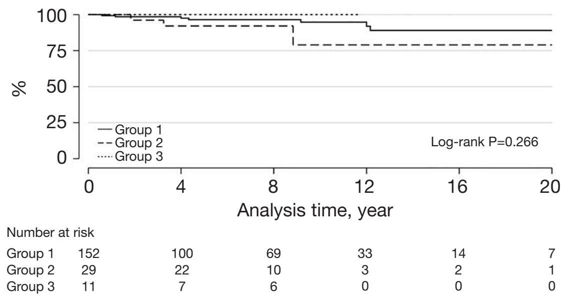

Figure 3 Kaplan-Meier freedom from transcatheter conduit dilatation in bovine jugular vein conduit (Group 1), aortic homograft (Group 2), and porcine valved conduit (Group 3).

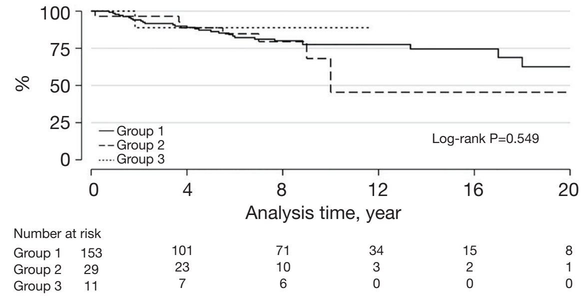

Figure 4 Kaplan-Meier freedom from conduit replacement in bovine jugular vein conduit (Group 1), aortic homograft (Group 2), and porcine valved conduit (Group 3).

Infective endocarditis of the graft occurred in 9 patients: 8 with BJVs and 1 with an aortic homograft (log-rank P=0.817) (*Figure 1*).

Transcatheter PVR was required in 8 patients: 7 with BJVs conduits and 1 with porcine-valved conduit (P=0.275) (*Figure 2*). Transcatheter conduit dilatation was performed in 10 patients: 7 with BJVs and 3 with homografts (P=0.266) (*Figure 3*). Thirty-eight patients had conduit replacement: 29 with BJVs, 8 with homografts, and 1 with porcine-valved conduits (P=0.549). Freedom from conduit replacement at 2, 5, and 10 years was 94%, 86%, and 78% in Group 1, 97%, 85%, and 45% in Group 2, and 89%, 89%, and 89% in Group 3 (*Figure 4*). Peripheral pulmonary branch interventions were required in 46 patients: 40 with BJVs, 4 with homografts and 2 with porcine-valved conduit (P=0.345). Balloon dilatation of pulmonary branches was performed in 7 patients (17.50%) with BJVs, 2 with homografts (50%), and 2 with porcine-valved conduit (100%). Stenting of the peripheral pulmonary artery branches was performed in 33 patients (82.50%) with BJVs, 2 with aortic homografts (50%) (P=0.012). Freedom from peripheral pulmonary branch interventions at 2, 5, and 10 years was 80%, 67%, and 68% in Group 1, 96%, 92%, and 73% in Group 2, and 100%, 75%, and 75% in Group 3 (*Figure 5*).

At least one graft-related event was reported in 85 conduits, 69 with BJVs, 12 with homografts, and 4 with porcine-valved conduits (P=0.919). Freedom from graft-related events at 2, 5, and 10 years was 76%, 67%, and 52% in Group 1, 86%, 74%, and 36% in Group 2, and 89%, 53%, and 53% in Group 3 (*Figure 6*). Factors associated with increased graft-related events were male gender (HR: 1.58; 95% CI: 1.004–2.50; P=0.048) and younger age (OR =0.995; 95% CI: 0.991–0.999; P=0.041) (*Table 3*).

Discussion

The different RV-PA conduits available for RV outflow tract reconstruction fall into one of five categories: (I) homograft conduit (pulmonary and aortic); (II) stented xenograft conduit; (III) stentless xenograft conduit; (IV) autologous tissue conduit; and (V) expanded polytetrafluoroethylene valved conduit. Although different RV-PA conduits are available, the ideal graft has yet to be developed. This study compared the most commonly used conduits for RV-PA reconstruction; BJVs, aortic homografts, and porcine-valved conduits. Individualizing conduit selection based on patient factors may result in improved outcomes.

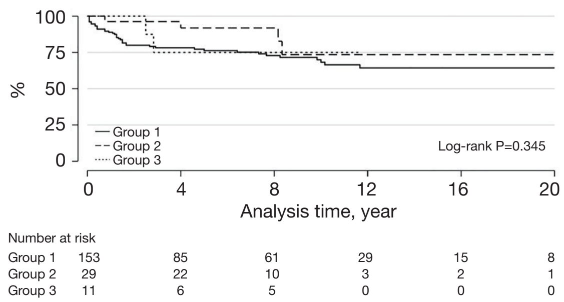

Figure 5 Kaplan-Meier freedom from peripheral pulmonary artery intervention in bovine jugular vein conduit (Group 1), aortic homograft (Group 2), and porcine valved conduit (Group 3).

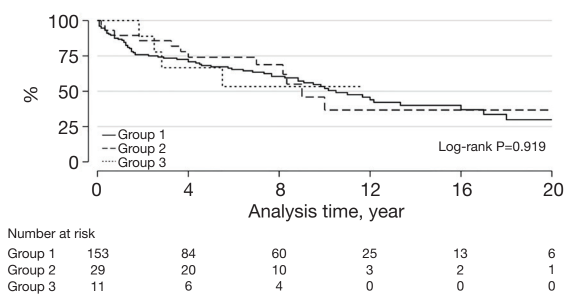

Figure 6 Kaplan-Meier freedom from graft-related events in bovine jugular vein conduit (Group 1), aortic homograft (Group 2), and porcine valved conduit (Group 3).

BJVs were the most common conduits used for young age, which could be attributed to the availability of small sizes compared to other graft types (11). Conduit choice at a young age is affected by several factors, including graft durability and availability of small sizes. Vitanova *et al.* compared the durability of RV-PA conduits for RV-PA reconstruction in patients below 1 year of age (15). They included 145 patients under one year with BJVs, homografts, or porcine-valved conduits. The freedom from conduit exchange did not differ significantly among groups. BJV conduits developed moderate conduit stenosis or regurgitation faster than other conduit types. They also reported that younger age (<1 month) was a risk factor for conduit replacement (13). Lewis and colleagues reported that smaller conduits size and smaller patients' age and weight at the time of surgery were risk factors for conduit replacement (16).

Additionally, we reported that smaller conduit sizes were associated with an increased risk of operative mortality. Bonilla-Ramirez reported that smaller RV-PA conduits were a reintervention risk factor (17). The findings about the association between age and the increased risk of reoperation could suggest using other palliative procedures to postpone conduit implantation until the patients get older to decrease the risk of reoperation.

Despite being non-significant, the risk of infective

Table 3 Factors affecting graft-related events

Risk factor	Univariable analysis		Multivariable analysis	
	Hazard ratio (95% confidence interval)	P value	Hazard ratio (95% confidence interval)	P value
Male	1.48 (0.95–2.29)	0.080	1.58 (1.004–2.50)	0.048
Age	0.99 (0.992–0.999)	0.036	0.995 (0.991–0.999)	0.04
Weight	0.98 (0.97–1.002)	0.094	–	–
Diagnosis	1.06 (0.88–1.28)	0.540	–	–
Additional lesion	0.87 (0.38–1.99)	0.739	–	–
Conduit type	0.93 (0.61–1.39)	0.715	–	–
Conduit size	0.97 (0.90–1.04)	0.419	–	–
Restricted pulmonary flow	1.45 (0.77–2.73)	0.246	1.87 (0.97–3.62)	0.06

endocarditis was higher after 10 years with BJV conduits specially in patients with bad dental hygiene. Mery *et al.* studied 586 patients who had 792 conduits, including pulmonary homograft, aortic homograft, BJVs, and porcine-valved conduits (18). They reported a higher infective endocarditis rate in patients with BJVs compared to other conduits. Another study also confirmed this finding; the risk of infective endocarditis was higher with BJVs, Melody valves, and patients with previous RV-PA reconstruction (19). Lewis and colleagues reported that the risk of endocarditis was lower with pulmonary homograft compared to BJV conduits (16). These results suggest that BJVs should be avoided in patients with a high risk of infections, such as those with previously infective endocarditis or DiGeorge syndrome.

Pulmonary valve stenosis or regurgitation is a potential clinical problem after RV-PA reconstruction. The condition can be safely managed with transcatheter PVR (20,21). In our series, we did not report a significant difference among the three conduits in transcatheter PVR; however, the rate seems to increase after 10 years with BJV conduits, and aortic homograft was the least conduit type associated with PVR. Skoglund *et al.*, in a study from the Swedish registry, reported that conduits replacement became the most common intervention performed on RV-PA conduits after the introduction of transcatheter PVR (22).

Interventions on peripheral pulmonary branches were the most common graft-related event in our series. We did not report a difference in peripheral pulmonary branch interventions among groups; however, the Kaplan-Meier curve showed that early interventions were required more frequently in BJV conduits, and aortic homografts had late reinterventions. The endovascular approach became the main management of peripheral pulmonary branch stenosis (23). In our series, stenting was the most common method used, especially in patients with BJV conduits.

Reinterventions are common after RV-PA reconstruction, and intervention-free survival is low (24). The freedom from graft-related events after 10 years in our series was 52% for BJVs, 36% for aortic homografts, and 53% for porcine-valved conduits. A tailored approach for each patient could help to decrease the reintervention rate. Younger age could be a risk factor for reintervention; therefore, delaying conduit insertion by using palliative procedures or patching of the pulmonary artery or RV outflow tract could be considered (25). Endovascular interventions may be used to delay the need for conduit replacement, such as stenting of the pulmonary artery branches and transcatheter conduit dilatation (26-28). BJVs should not be considered for patients at high risk of infective endocarditis, and homograft could be the conduit of choice. From our experience, the risk of endocarditis could be down syndrome or DiGeorge syndrome, history of infective endocarditis, dental caries or abscess and failure to thrive below 3rd percentile for weight.

In summary, the best conduit is what fits well. From our data we found that if there are risk factors for infective endocarditis, it might be better to use homograft. Homograft is also valid if the pulmonary branches are undeveloped or smaller in size. If the patient is young or the plan to do less surgical reoperation, it might be better to use BJV conduit.

Future perspectives

This study found that reintervention is common after RV-PA reconstruction. Endovascular interventions may be used to delay the need for conduit replacement, such as stenting of the pulmonary artery branches and transcatheter conduit dilatation. We reported relatively more infection with BJVs; therefore, they should not be considered for patients at high risk of infective endocarditis, and homografts could be the conduit of choice. This study provided insight into tailored conduit selection, and further studies are required to optimize conduit selection further and assess pulmonary homografts, which was not evaluated in our study because they are not available in our institution.

Study limitations

Several limitations should be considered when interpreting the results of this study. First, the study is retrospective with its inherent biases. However, this is a suitable design to evaluate the long-term outcomes of different RV-PA conduits because of the procedure's relative rarity. Second, the imbalance of the number of conduits in each group. This imbalance could be attributed to several factors, including the preference for BJVs in young patients due to the availability of small sizes and other conduits in older patients and patients requiring conduit replacement. Third, the study is a single-center experience, and the results could be affected by surgeons' experience. Lastly, all homografts used in our study were aortic, and we did not use pulmonary homografts, which could be superior to other conduits in this position.

The surgical techniques and equipment advanced with time, as well as the surgical skills. This could be a factor that may affect outcomes. On the other hand, complexity of the cases and the number of patients who required reinterventions also increased with time.

Conclusions

RV-PA reconstruction was associated with low mortality, unrelated to the conduit type. Reinterventions for graft-related events were common. The durability of BJV grafts was an advantage for this type of conduit but on expenses to have more frequent other cardiac catheterization interventions and risk of infective endocarditis. Factors associated with increased graft-related events in this study were male gender and younger age.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://cdt.amegroups.com/article/view/10.21037/cdt-23-364/rc

Data Sharing Statement: Available at https://cdt.amegroups.com/article/view/10.21037/cdt-23-364/dss

Peer Review File: Available at https://cdt.amegroups.com/article/view/10.21037/cdt-23-364/prf

Conflicts of interest: All authors have completed the ICMJE uniform disclosure form (available at https://cdt.amegroups.com/article/view/10.21037/cdt-23-364/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the local ethical committee of King Faisal Specialist Hospital and Research Center-Jeddah (IRB 2022-36). The ethical committee waived the need for informed consent for the retrospective nature of the study.

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