The Cardiothoracic Surgeon

RESEARCH

Open Access

Post-right ventricle to pulmonary artery conduit: short- and intermediate-term outcomes: a single-center study

Yasmin Abdelrazek Ali[1*], Alaa Roushdy[1], Mohammed Abdullah Hegab[1,2] and Amr Mansour Mohammed[1]

Abstract

Background Surgery for congenital heart disease has progressed by leaps and bounds in the last few decades, but the right ventricular outflow tract continues to pose a challenge to the congenital heart surgeon.

Objectives We aim to describe the outcomes of patients with CHD who had surgical placement of right ventricle to pulmonary artery conduits with a focus on the risk factors for redo-surgery.

Methods We performed a retrospective single-center clinical data review of patients who had RVOT surgery using RV-to-PA conduits

Results Thirty-three patients (54.5% males) were included. The mean age at first conduit placement was 3.57 ± 3.18 years, mean conduit size conduit was 14.45 ± 3.85 mm. 51.5% of patients received Contegra tubes. On a mean follow-up of 2.07 ± 2.36 years, 45.5% of patients underwent RV-to-PA conduits redo replacement after 5.67 ± 3.25 years from the first surgery, 2 patients underwent re-intervention for the second time, 7 patients had transcatheter interventions on RVOT or branch PAs. The main mode of conduit failure was stenosis. The median survival without the need for surgical reintervention was 2.5 years for the non-contegra subgroup versus 3 years for the contegra subgroup ($P = 0.59$). we predicted that 100% of the study group would require redo surgery for conduit replacement within the first 11 years post-initial surgery. For every year of age increase at follow-up, the hazard ratio for redo surgery increases by a factor of 1.47. For every year of age increase at the time of first operation, the hazard ratio for redo surgery decreases by a factor of 0.7.

Conclusions The use of conduits to treat the RV to PA discontinuity is a cornerstone in treating congenital heart diseases. Nevertheless, conduit failure and replacement are inevitable. In our experience the higher the age at the first conduit, the longer the re-intervention-free survival period.

Keywords Single ventricle, Contegra, Hancock, Right ventricle to pulmonary artery conduit, Pulmonary atresia, Truncus arteriosus, Double outlet right ventricle

Background

Surgery for congenital heart disease (CHD) has progressed by leaps and bounds in the last few decades, but the right ventricular outflow tract continues to pose a challenge to the congenital heart surgeon [1].

A considerable proportion of CHD has a component of RVOT abnormality. This may be in the form of a simple stenosis or a more complicated atresia, discordant ventriculo-arterial connection, absent pulmonary valve, or

*Correspondence:
Yasmin Abdelrazek Ali
yasminabdelrazek@med.asu.edu.eg
[1] Department of Cardiology, Ain Shams University, Cairo, Egypt
[2] Agouza Police Hospital, Cairo, Egypt

rarely a common systemic and pulmonary outflow as in truncus arteriosus (TA) [1].

The absence of continuity between the RV and PA either because of atresia or a discordant arterial connection calls for a more complicated intervention. Valved conduits were first used by Ross and soon after by Rastelli in the early 1960s, and since then have remained the principal choice of treatment for RV to PA discontinuity [2, 3].

Valved conduits do a great job simulating the natural right ventricular outflow; however, they have one major drawback: they don't grow. This means that once a patient receives a conduit, re-operation for conduit replacement is inevitable. Growth may not be a relevant issue in the older patient who has reached full physical development, however, conduit stenosis necessitating replacement usually develops as a result of intimal peel formation, anastomotic stricture, or calcific degeneration of the conduit valve [4, 5].

The ideal RV-to-PA conduit has been extensively searched for, and it goes without saying that a perfect RV-to-PA conduit does not exist. Several factors that influence RV to PA conduit reintervention risk have been identified, these include the patient's age and weight, the underlying anatomy, the quality of the branch pulmonary arteries, and of course conduit type and size [6, 7].

We aim to describe the short and intermediate-term outcomes, in patients with CHD, undergoing surgical repair using right ventricle to pulmonary artery conduits at our institute.

Methods

We performed a retrospective study, that included patients who were operated upon by putting a conduit between the RV and the pulmonary artery in a single Egyptian center. Patients were followed up and data was gathered starting in 2021 till the end of 2022.

Inclusion criteria

All patients who had RV to PA conduit were included. Verbal and written consent were taken from our patients' guardians.

All patients were subjected to the following:

History taking and data collection from medical reports

With special emphasis on age at first operation, diagnosis, weight, height, redo surgery if present and its cause (mode of conduit failure: stenosis, regurgitation, both), duration till redo surgery, percutaneous intervention if present (pulmonary conduit/artery stenting or balloon angioplasty), diagnostic catheterization with special emphasis on pressure recordings and duration till percutaneous intervention.

Two-dimensional trans thoracic echocardiogram

Philip's IE33 echocardiography machine with phase array probes tailored according to the size of the patient was used, with special emphasis on the baseline diagnosis, flow across the conduit (peak pressure gradient (PPG), mean pressure gradient (MPG) and regurgitation degree), main pulmonary artery, left and right pulmonary arteries diameter if feasible, RV end-diastolic dimensions in apical 4 chamber view just above the level of the tricuspid valve, systolic function was evaluated using (transannular systolic peak excursion (TAPSE), fractional area change (FAC), tricuspid regurgitation (TR) degree, and right ventricle systolic pressure (RVSP).

Retrospective evaluation of the operative details

Including type and size of conduit, occurrence of postoperative complications, medications (antiplatelets, anticoagulants), redo operation (if present), type of redo, or the details of total repair if done.

The study group was subdivided according to whether or not the patient required conduit replacement

Statistical analysis

All data were gathered, tabulated, and statistically analyzed on a personal computer (PC) using a commercially available statistical software package MedCalc version 11.6.1.0 (MedCalc Software, Mariakerke, Belgium). Categorical variables were expressed as frequency and percentage while numerical variables were expressed as mean ± SD. Univariate analysis was applied to all variables measured using an independent sample *t* test. Multivariate analysis was done to define independent risk factors of the need for re-intervention using logistic regression analysis with a stepwise approach. Only significant variables in the univariate analysis were entered into the multivariate analysis model. A *P*-value was considered significant if < .05 and $P < .01$ was considered highly significant. The study group was analyzed using the Kaplan-Meier curve to estimate the percentage of patients who did not require redo surgery over time for the entire study group

Results

A total of 33 patients were included in this study, with a mean age of 8.29 ± 4.7 years at the last follow-up. The youngest patient had 1.5 years and the oldest was 17 years old. Among the study group, 54.5% ($n = 18$) were males and 45.5% ($n = 15$) were females.

The mean age at placement of the first conduit was 3.57 ± 3.18 years. The youngest patient at the time of first conduit placement was 2.4 months old and the oldest was

12.5 years. Fifteen patients (45.5%) underwent re-intervention with conduit replacement, at a mean age of 8.32 ± 4.3 years.

Only 2 patients underwent re-intervention for the second time, with conduit replacement at the age of 12 and 14 years

The re-operation-free interval after the first conduit placement for the 15 patients that underwent conduit placement had an average value of 5.67 ± 3.25 years. Whereas the re-operation-free interval before the second re-intervention had a mean value of 5 years. The 33 patients were followed up after the last conduit for each, for a period of 2.07 ± 2.36 years (Table 1).

The most common underlying CHD necessitating heart surgery with conduit placement in the RVOT region was pulmonary atresia with VSD and normally related great vessels. Table 2 demonstrates the underlying diagnoses among the study group.

Based on retrieved operative data of the studied patients, 17 of the first conduits were Contegra (bovine jugular vein valved tube), 5 were Goretex (polytetrafluoroethylene conduit), 4 were Neocore (porcine aortic valve mounted in a bovine pericardial tube), 3 were Carpentier Edwards (porcine valved conduit), 2 were Hancock (porcine valved conduit) and 1 was Biointegral (bovine pericardial conduit, valved), and data regarding the first

Table 1 Demographic and echocardiographic data

	N	Mean	SD	Minimum	Maximum
Age (years)	33	8.28	4.70	1.50	17.00
Age at first conduit (years)	33	3.57	3.18	0.20	12.50
Age at second conduit (years)	15	8.32	4.31	2.50	15.80
Age at third conduit (years)	2	13.00	1.41	12.00	14.00
Re-operation free interval after first conduit (years)	15	5.67	3.25	1.00	10.30
Re-operation free interval after second conduit (years)	2	5.00	5.65	1.00	9.00
Follow-up interval (years)	33	2.07	2.36	0.20	11.50
Height at last follow-up (cm)	33	122.15	27.13	82.00	170.00
Weight at last follow-up (kg)	33	28.98	17.969	10.00	70.00
BSA at last follow-up (m^2)	33	0.97	0.40	0.48	1.82
First conduit size mm	33	14.45	3.8543	8.00	23.00
Second conduit size mm	33	18.40	2.7968	14.00	23.00
Third conduit size mm	33	19.00	4.2426	16.00	22.00
First conduit MPG mmHg	33	34.05	14.0607	8.00	60.00
Second conduit MPG mmHg	33	14.54	4.5025	8.00	22.00
Third conduit MPG mmHg	33	28.00	31.1127	6.00	50.00
First conduit PPG mmHg	33	52.61	22.5585	10.00	90.00
Second conduit PPG mmHg	33	34.53	17.6428	17.00	80.00
Third conduit PPG mmHg	33	44.00	43.84	13.00	75.00
First conduit, RVSP mmHg	33	53.80	18.72	35.00	90.00
Second conduit, RVSP mmHg	33	45.00	0.000	45.00	45.00
First conduit TAPSE mm	33	13.43	2.22	10.00	18.00
Second conduit TAPSE mm	33	13.45	3.48	9.00	20.00
Third conduit TAPSE mm	33	11.00		11.00	11.00
First conduit RVEDD mm	33	26.16	6.75	14.00	38.50
First conduit RVEDD indexed to BSA mm/m^2	33	34.507	8.95	20.26	50
Second conduit RVEDD mm	33	22.80	6.18	15.00	31.00
Second conduit RVEDD indexed to BSA mm/m^2	33	28.66	6.76	17.56	34.84
Third conduit RVEDD mm	33	27.00		27.00	27.00
Third conduit RVEDD indexed to BSA mm/m^2	33	18.12		18.12	18.12
RPA mm (in the last follow-up)	33	10.94	3.99	3.50	20.00
LPA mm (in the last follow-up)	33	9.30	4.49	2.00	18.00
FAC % (in the last follow-up)	33	44	6.4	30	51

BSA body surface area, *FAC* fractional area change, *MPG* mean pressure gradient, *LPA* left pulmonary artery, *RPA* right pulmonary artery, *PPG* peak pressure gradient, *RVEDD* right ventricle end-diastolic diameter, *RVSP* right ventricle systolic pressure, *TAPSE* transannular peak systolic excursion

Table 2 Underlying congenital heart disease

	Number	Percentage
VSD + pulmonary atresia	23	69.7%
DORV + pulmonary atresia	3	9.1%
TA	4	12.1%
D-TGA + VSD + pulmonary atresia	3	9.1%
Total	33	100.0%

D-TGA dextro-transposition of great arteries, *DORV* double outlet RV, *TA* truncus arteriosus, *VSD* ventricular septal defect

conduit type of 2 patients was missing. Whereas 4 out of 10 second conduits were Biointegral, 3 were Contegra, 2 were Hancock and only 1 was Goretex, and data regarding the second conduit type of 5 patients out of 15 was missing. Concerning the third conduit, 1 was Contegra, and 1 was Hancock. The mean size of the first, second, and third conduits were 14.45 ± 3.85 mm, 18.4 ± 2.79 mm, and 19 ± 4.24 mm respectively.

The mean value of peak pressure gradient across the first conduit among all the included patients in the last follow-up (including PPG across the first conduit just before replacement among the redo group) in the study was 52.61 ± 22.55 mmHg. The mean value of the peak pressure gradient across the second conduit in 13 patients was 34.53 ± 17.64 mmHg. The mean value of the peak pressure gradient across the third conduit in 2 patients was 44.00 ± 43.84 mmHg (Table 1).

Percutaneous intervention

Percutaneous intervention by stenting or balloon inflation in the conduit and/or one/two central pulmonary arteries was encountered in 7 patients: 2 patients had the first conduit stented, with no great impact on conduit longevity (they underwent surgical redo after conduit stenting), 3 patients had balloon angioplasty done to the left pulmonary artery and one to the right pulmonary artery. One patient underwent left pulmonary artery stenting, and one had right pulmonary artery stenting.

Regurgitation across the first conduit

The majority of patients during the last follow-up visit had either no or mild regurgitation across the first conduit (Table 3). The majority of patients had either no or mild tricuspid regurgitation (Table 3).

The study group was subdivided according to whether or not the patient required conduit replacement. We want to identify causes of early redo in some patients and factors that shorten the conduit longevity. To offer future patients longer periods free of reintervention. The patients who required redo surgery were significantly older than those who did not require conduit replacement (11.3 ± 4.04 vs 5.76 ± 3.64 years). Body surface area, weight, and height were significantly larger in the redo group (Table 4).

Table 3 Regurgitation degree across the first conduit and tricuspid valve as evaluated by echocardiography

Conduit regurgitation	Number (33)	Percentage of the total
No conduit regurgitation	19	57.57%
Mild conduit regurgitation	11	33.3%
Moderate conduit regurgitation	2	6.06%
Severe conduit regurgitation	1	3.03%
Tricuspid regurgitation	Number (31)	Percentage of the total
No-mild tricuspid regurgitation	26	83.9%
Moderate tricuspid regurgitation	5	16.1%

There was no significant difference between the two subgroups regarding the size of the first conduit, despite the significant difference in age and body surface area. The mean pressure gradient, was significantly higher in group 1 (redo) versus group 2 (no redo), with a mean value of 47.83 ± 7.22 mmHg in group 1 (in the last visit before redo) versus 27.167 ± 11.24 mmHg in group 2. Peak pressure gradient across the first conduit in the redo group was significantly higher, with a mean value of 69.5 ± 20.01 mmHg in group 1 versus 42.06 ± 17.29 mmHg in group 2 (Table 5).

Redo free interval

At 2 years of follow-up 66.1% of the study group did not require redo surgery, this percentage dropped to 42% after 3 years of follow-up. Based on this curve it is predicted that 100% of the study group will require redo surgery for conduit replacement within the first 11 years post-initial surgery (Fig. 1).

The study group was then subdivided according to the conduit type used at the time of first intervention into Contegra ($n = 17$) and non-contegra ($n = 14$) subgroups. There was no significant difference between the 2 subgroups as regards the median survival without the need for redo surgery for conduit replacement. The median survival without the need for surgical reintervention was 2.5 years for the non-contegra subgroup versus 3 years for the contegra subgroup ($P = 0.59$). However, the survival without reintervention proportion of both groups at 3 years of follow-up was 21.8% for the non-contegra subgroup versus 49.9% for the contegra subgroup (Fig. 2).

The survival without reintervention at mean covariates of age, age at the time of first intervention, conduit size, and peak PG after first intervention using

Table 4 Comparison between the two subgroups as regards general characteristics

General	Redo conduit						Paired *t* test	
	Yes			No			*T*	*P*
	Mean		SD	Mean		SD		
Age (years)	11.317	±	4.0416	5.764	±	3.6456	− 4.148	**0.0002**
Age at first conduit	3.050	±	2.7970	4.011	±	3.4974	0.859	0.3969
BSA (m^2)	1.212	±	0.4049	0.774	±	0.2832	− 3.648	**0.0010**
Height (cm)	138.73	±	24.7342	108.333	±	20.9031	− 3.828	**0.0006**
Weight (kg)	39.233	±	19.1301	20.450	±	11.6875	− 3.467	**0.0016**
Follow-up interval (years)	2.447	±	3.3621	1.764	±	0.9907	− 0.822	0.4173

BSA body surface area

A *P*-value is considered significant if <0.05 and *P* <0.01 is considered highly significant

Table 5 Conduit parameters in the two subgroups

General	Redo conduit						Paired *t* test	
	Yes			No			*T*	*P*
	Mean		SD	Mean		SD		
First conduit size (mm)	13.200	±	3.9677	15.625	±	3.4617	1.816	0.0797
First conduit MPG mmHg	47.833	±	7.2226	27.167	±	11.2479	− 4.067	**0.0009**
First conduit PPG mmHg	69.500	±	20.0125	42.063	±	17.2915	− 3.707	**0.0011**
First conduit RVSP mmHg	70.000	±	28.2843	49.750	±	15.5816	− 1.449	0.1853
First conduit TAPSE mm	14.400	±	2.5100	13.147	±	2.1343	− 1.112	0.2793
FAC %	42.72	±	6.306	45.48	±	6.802	65	53.03

FAC fractional area change, *MPG* mean pressure gradient, *PPG* peak pressure gradient, *RVSP* right ventricle systolic pressure, *TAPSE* transannular peak systolic excursion

A *P*-value is considered significant if <0.05 and *P* <0.01 is considered highly significant

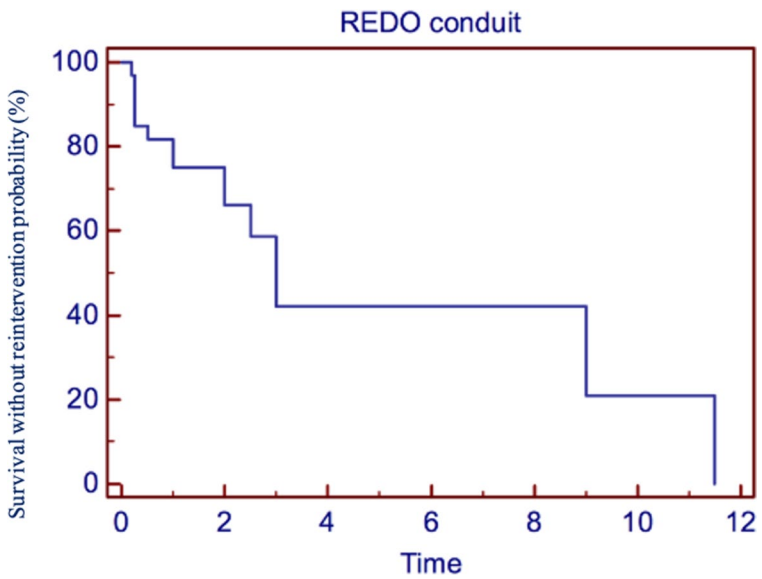

Fig. 1 Redo-free intervals

cox-proportional hazards regression with stepwise regression was done. The entire model was highly significant ($P = 0.0016$). The cumulative hazard at mean of all covariates included was 0.45 at 2.5 years of follow-up with survival proportion free of reintervention equals 0.63 (Fig. 3).

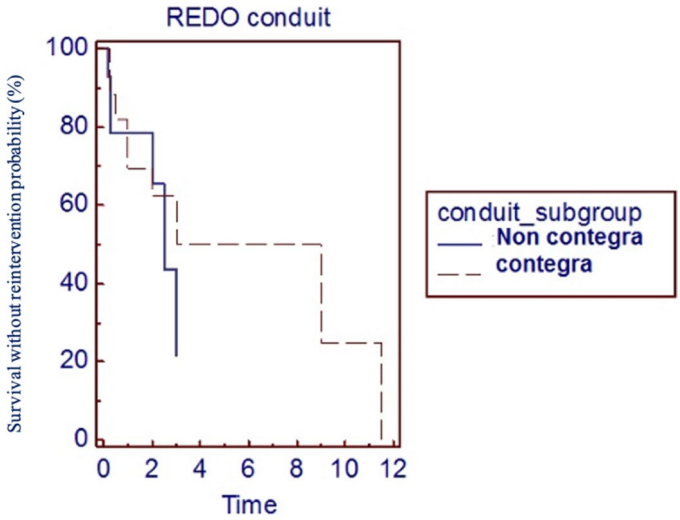

Fig. 2 Contegra versus non-contegra conduits

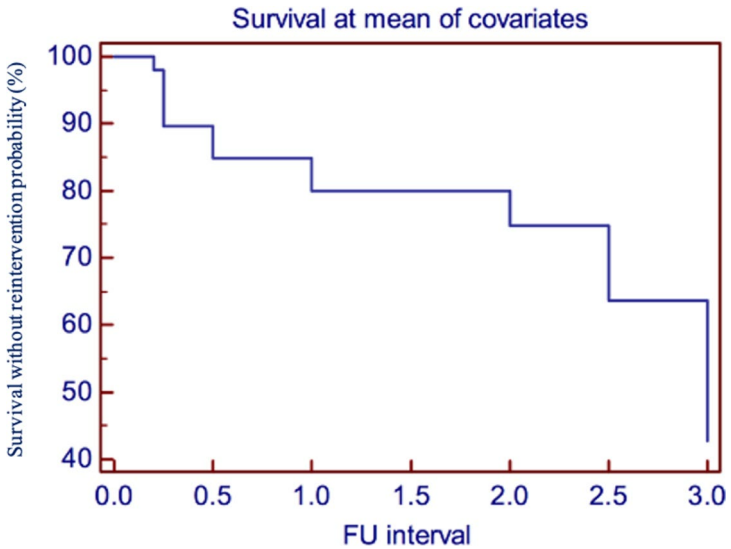

Fig. 3 Survival at a mean of covariates

Only age at the time of the last follow-up and age at the time of the first conduit implantation were retained in the final model ($P = 0.0005$, 0.03 respectively). These two covariates significantly predicted the redo surgery-free interval in the study group. The coefficient for age in years at follow-up was 0.38 (95% CI 1.18–1.83) meaning that for every year of age increase at follow-up, the hazard ratio for redo surgery increases by a factor of 1.47. On the other hand, the coefficient for age at the time of the first operation was − 0.35 (95% CI 0.5–0.97) meaning that for every year of age increase at the time of the first operation, the hazard ratio for redo surgery decreased by a factor of 0.7 (Table 6).

Table 6 Coefficients and standard errors

Covariate	*b*	SE	*P*	Exp(b)	95% CI of Exp(*b*)
Age (years)	0.3879	0.1122	0.0005	1.4739	1.1843 to 1.8342
Age at first conduit (years)	− 0.3522	0.1691	0.0372	0.7031	0.5057 to 0.9777

Discussion

Reconstruction of RV to PA continuity is a principal part of various surgical procedures commonly performed in neonates and young infants to repair CHD. In spite of

our initial success in treating those complex patients, this part of the repair seems to be the "gift that keeps on giving," and RV to PA reinterventions, both surgical and catheter-based, have rapidly become among the most common procedures performed in children, as well as adults, with CHD [8].

Over the years, different types of conduits were developed; among them valved conduits, which can be divided mainly into three categories: (i) homograft (pulmonary and aortic); (ii) stented xenograft; and (iii) stentless xenograft conduits. Cryo-preserved homografts are preferred to irradiate homografts, chemically sterilized, and fresh antibiotic-sterilized, the latter three showed alterations in biological characteristics observed shortly after implantation [6, 9, 10].

This study was done in order to follow-up with patients who underwent surgery for conduit placement between the RV and PA, to observe the re-intervention rates, and to determine the most important determinants of re-operation.

In our study the most prevalent mode of failure of the first conduit was stenosis (81.2%), both stenosis and regurgitation—as one mode of failure—came second (12.5%) and regurgitation only occurred in 6.2% of the cases requiring redo surgery for conduit failure. Concerning the second conduit, one was replaced due to stenosis, and the other one was replaced due to regurgitation. In our study, the patients who required redo surgery were significantly older than those who did not require conduit replacement (11.3 ± 4.04 vs 5.76 ± 3.64 years respectively).

In the study done by Göber, et al. a total of 38 Contegra valved conduits (12 to 22 mm) were implanted, in 36 children less than 5 years old and in 2 patients 8 and 21 years old. The underlying disease for which this type of repair was conducted was concordant with our study group [11].

During the follow-up which had a mean duration of 18 ± 5 months, Göber, et al. found that there was excessive intimal peel formation in all conduits, 6 needed reoperation with conduit replacement, and the other 6 showed significant stenoses across the conduits; that's a total of 12/38 patients (33%) had stenosis which is concordant with our results of the inevitable stenosis and the need for replacement at a certain point, however our follow up duration was slightly longer (2.07 ± 2.36 years); which accounts for the larger number of patients who underwent replacement [11].

Also, Meyns, et al. reported in 2004 a series of 58 patients (mean age 9 years old) who received a Contegra conduit. Freedom of severe stenosis was 91% at 3 months, 68% at 12 months, and 49% at 24 months, and that is concordant with our study where we found that the survival without reintervention proportion at 3 years of follow-up for Contegra conduits was 49.9%. In the study done by Meyns, et al., young age was significantly related to the occurrence of stenosis, and 51% needed reoperation at a 2-year follow-up duration, which is also concordant with our results [12].

According to Yuan, et al. conduit failure was defined as the need for reoperation for conduit stenosis or extrinsic compression, conduit regurgitation, or anastomotic dehiscence, and the same definition was applied in the current study. The conduit failure rates at 2 years were 9–55%, 35%, and 25% for homograft, stented xenograft, and stentless xenograft conduits, respectively. The 5-year actuarial freedoms from reoperation were 87–98.2% for homograft, 37% for Hancock, 81–92% for Carpentier–Edwards, 78% for Contegra, and 82.95% for LabCor, respectively [13].

Yuan, et al. study showed clearly that homografts are better than xenografts in terms of the need for reoperation, and that reoperation at the 5-year actuarial occurrence of re-intervention for conduit replacement for xenografts (mainly Contegra and Hancock) was 22% and 63% respectively. Due to the diverse nature of the conduits used in our study which were used depending purely on the availability of a conduit of suitable size at the time of operation, reaching a similar conclusion as that of Yuan et al. was impossible [13].

Skoglund, et al. found that 176 out of 574 patients (30%) required re-intervention; which was significantly less than the 45% of the patients requiring re-intervention in the current study. That can be attributed to the fact that, in the former study, more than 70% of the patients had pulmonary homograft as the first conduit; which is well known for its greater longevity than the xenografts which were the mainstay in our study [14].

Skoglund, et al. also stated that male sex was associated with more adverse outcomes; unlike the current study which showed comparable results among males and females. Skoglund, et al. stated that the higher the age at the first conduit, the bigger the event/re-intervention-free survival period which was concordant with our results [14].

In their retrospective study, Shinkawa T. et al. reviewed all RV to PA conduit operations for the repair of CHD between 1982 and 2013 in a single center, with 476 RV to PA conduit operations for 345 patients. 103 patients with Hancock conduits with a median age of 6.8 years were followed up for a median of 7 years, 53 patients (51%) required conduit replacement, 70% of which were due to stenosis, 19% due to stenosis and regurgitation, and 8% due to regurgitation only and 4% due to infection. Such results are concordant with our study results where 45% of patients required conduit replacement, 81.2% of which

were due to stenosis, 12.5% due to both stenosis and regurgitation, and 6.2% due to regurgitation. The absence of conduit infection as an adverse outcome in the current study could be attributed to the smaller number of patients in our study group [15].

Breymann and coworkers presented a series of 71 patients operated on between 1999 and 2001. The mean age was 1.2 years old. The main underlying CHD was similar to that of our study, and the size of the conduit ranged from 12 to 22 mm. The longest follow-up was 27 months. No conduit or valve degeneration was observed during this interval. Early post-operatively, maximal trans-valvular pressure gradient was between 25 and 42 mmHg, 6 patients developed pressure gradients greater than 70 mmHg but no conduit had to be ex-planted. In contrast to these findings, the group of patients who underwent reinterventions in the current study had a mean peak PG across the conduit of 69.5 ± 20 mmHg which reflects the difference in threshold for conduit replacement between the two studies [16].

Conclusions

The use of conduits to treat the RV to PA discontinuity is a cornerstone in the treatment of some CHD requiring construction of the RVOT. Nevertheless, conduit failure and replacement are inevitable, and depend on many factors: age at the first operation, type of conduit, and mean and peak pressure gradient across the conduit. The higher the age at the first conduit, the bigger the event/re-intervention-free survival period.

The main mode of conduit failure is stenosis, and it accounts for approximately 80% of the causes of failure, and transthoracic echocardiography remains the most convenient means to primarily assess the state of conduit and determine the need for further tests as MSCT or interventions.

The Survival without a reintervention period for Contegra conduits has a median value of approximately 3 years vs 2.5 years for non-contegra conduits, whereas survival without the need for reintervention at 3 years of follow-up for Contegra conduits is 49.9% vs 21% for non-contegra.

Limitations of the study

The operative data retrieved in this study was retrospective, and although we did our best to collect most of the required data, some data was missing in some patients. Also, The limited number of patients included in this study (33 patients) was due to the late introduction of conduit usage in Egypt and to the fact that this was a single-center study. In addition, not all types of conduits were included in this study (e.g., homografts); as conduit usage in Egypt still depends on the availability of the conduit rather than technical preference.

Abbreviations

BSA	Body surface area
CHD	Congenital heart diseases
d-TGA	Dextro-transposition of great arteries
DORV	Double outlet RV
ECG	Electrocardiogram
FAC	Fractional area change
LPA	Left pulmonary artery
MPG	Mean pressure gradient
MSCT	Multi-slice computed tomography
PA	Pulmonary artery
PS	Pulmonary stenosis
PV	Pulmonary valve
PPG	Peak pressure gradient
RPA	Right pulmonary artery
RV	Right ventricle
RVEDD	Right ventricle end-diastolic diameter
RVOT	Right ventricle outflow tract
RVSP	Right ventricle systolic pressure
TA	Truncus arteriosus
TAPSE	Transannular peak systolic excursion
TR	Tricuspid regurgitation
VSD	Venrtricular septal defect

Acknowledgements
Not applicable.

Adherence to national and international regulations
We followed all national and international regulations of medical research.

Authors' contributions
Yasmin Abdelrazek Ali (YAA) wrote the manuscript and revised the collected data. Alaa Roushdy (AR) revised the study design, did the statistical analysis, and revised the manuscript. Mohammed Abdullah Hegab (MAH) collected data, wrote the introduction, and gathered data for discussion. Amr Mansour Mohammed (AMM) helped in collecting data, revised and modified the manuscript. All authors read and approved the final manuscript.

Funding
None received.

Availability of data and materials
All data and materials of the study are available upon request.

Declarations

Ethics approval and consent to participate
Our department's Ethical committee approval was obtained. Written and oral consent was taken from all participants or their guardians.

Consent for publication
Consent for publication was taken from all authors.

Competing interests
The authors declare that they have no competing interests.

Received: 25 September 2023 Accepted: 9 November 2023
Published online: 16 November 2023

References

1. Iyer KS (2008) Alternatives to conduits. Ann Pediatr Cardiol 1:46–49
2. Ross DN, Somerville J (1966) Correction of pulmonary atresia with a homograft aortic valve. Lancet. 288(7479):1446–1447
3. Rastelli GC, McGoon DC, Wallace RB (1969) Anatomic correction of transposition of the great arteries with ventricular septal defect and subpulmonary stenosis. J Thorac Cardiovasc Surg 58(4):545–552

4. Danielson GK, Anderson BJ, Schleck CD, Ilstrup DM (1995) Late results of pulmonary ventricle to pulmonary artery conduits. Semin Thorac Cardiovasc Surg 7(3):162–167
5. Forbess JM (2004) Conduit selection for right ventricular outflow tract reconstruction: contemporary options and outcomes. Seminars in thoracic and cardiovascular surgery. Pediat Cardiac Surg Annual 7:115–124
6. Dearani JA, Danielson GK, Puga FJ, Schaff HV, Warnes CW, Driscoll DJ et al (2003) Late follow-up of 1095 patients undergoing operation for complex congenital heart disease utilizing pulmonary ventricle to pulmonary artery conduits. Ann Thorac Surg 75(2):399–411
7. Poynter JA, Eghtesady P, McCrindle BW, Walters HL, Kirshbom PM, Blackstone EH et al (2013) Association of pulmonary conduit type and size with durability in infants and young children. Ann Thorac Surg [Internet] 96(5):1695–1702
8. Alsoufi B (2016) Right ventricle-to-pulmonary artery conduits: do we really have an option? J Thorac Cardiovasc Surg [Internet] 151(2):442–443
9. Kay PH, Ross DN (1985) Fifteen years' experience with the aortic homograft: the conduit of choice for right ventricular outflow tract reconstruction. Ann Thorac Surg [Internet] 40(4):360–364
10. Saravalli OA, Somerville J, Jefferson KE (1980) Calcification of aortic homografts used for reconstruction of the right ventricular outflow tract. The J Thoracic Cardiovasc Surg 80(6):909–920
11. Göber V, Berdat P, Pavlovic M, Pfammatter JP, Carrel TP (2005) Adverse mid-term outcome following RVOT reconstruction using the Contegra valved bovine jugular vein. Ann Thorac Surg 79(2):625–631
12. Meyns B, Van Garsse L, Boshoff D, Eyskens B, Mertens L, Gewillig M et al (2004) The Contegra conduit in the right ventricular outflow tract induces supravalvular stenosis. J Thorac Cardiovasc Surg *128*(6):834–840
13. Yuan SM, Mishaly D, Shinfeld A, Raanani E (2008) Right ventricular outflow tract reconstruction: Valved conduit of choice and clinical outcomes. J Cardiovasc Med 9(4):327–337
14. Skoglund K, Svensson G, Thilén U, Dellborg M, Eriksson P (2017) Long-term outcome after right ventricle to pulmonary artery conduit surgery and reintervention. Scand Cardiovasc J 51(5):284–291
15. Shinkawa T, Chipman C, Bozzay T, Tang X, Gossett JM, Imamura M (2015) Outcome of right ventricle to pulmonary artery conduit for biventricular repair. Ann Thorac Surg [Internet] 99(4):1357–1366
16. Breymann T, Thies WR, Boethig D, Goerg R, Blanz U, Koerfer R (2002) Bovine valved venous xenografts for RVOT reconstruction: results after 71 implantations. Eur J Cardiothorac Surg 21(4):703–710

Publisher's Note