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ORIGINAL ARTICLE

Long-term results after physiologic repair for congenitally corrected transposition of the great arteries

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Abstract
Objective We aimed to evaluate the long-term results of physiologic repair for associated lesions of congenitally corrected transposition of great arteries (ccTGA) and to provide a basis for comparison with anatomic repair for this entity.
Subjects and methods Sixteen ccTGA patients who underwent physiologic repair from 1970 to 2000 comprise this retrospective study. Conventional Rastelli procedure was performed in 12 patients with pulmonary stenosis or atresia (PS/PA). Ventricular septal defect closure was carried out in 2 patients, atrial septal closure in 1, and tricuspid valvuloplasty in 1 without PS/PA. Mean follow-up period was 19.4 years. Long-term survival rates were assessed with respect to the presence or the absence of preoperative PS/PA and specifically in relation with the magnitude of pre- and postoperative tricuspid regurgitation (TR).
Results There has been no long-term mortality in the ccTGA patients without PS/PA. Twenty-year survival rate after conventional Rastelli was 71 %. Overall 20-year freedom from more than mild TR or tricuspid valve replacement was 44 %. The development of postoperative more than mild TR was significantly linked with pre-repair right ventricular enlargement ($p = 0.019$), but not with the magnitude of pre-repair TR ($p = 0.85$).
Conclusion Long-term outcomes of physiologic repair for ccTGA were equivalent to those of reported anatomic repair performed in several centers during the same era. Notably, significant TR was observed in more than half of physiologically repaired patients over the 20 years after repair. The degree of pre-repair TR cannot predict the long-term function of tricuspid valve after physiologic repair.

Keywords Congenitally corrected transposition of the great arteries · Atrioventricular discordance · Ventriculoarterial discordance · Physiologic repair · Functional repair

Introduction

Congenitally corrected transposition of the great arteries (ccTGA) is characterized by atrioventricular (AV) and ventriculoarterial (VA) discordance [1]. The classical surgical approach to ccTGA has been to repair the associated cardiac lesions without addressing the AV and VA discordance [2–4]. In this approach, the morphologic right ventricle serves as the systemic ventricle and the tricuspid valve serves as the systemic AV valve. Concerns about the long-term function of the morphologic right ventricle and the systemic tricuspid valve have led to the concept of anatomic repair that incorporates the morphological left ventricle and mitral valve in the systemic circulation [5]. Although some centers reported excellent short-term results of this approach [6–8], several complications long after anatomic repair have become apparent. Atrial switch, which is inevitable procedure to correct AV discordance, has a risk of obstruction of systemic or pulmonary venous return [7, 9]. It also can provoke supraventricular arrhythmia or sinus node dysfunction, which entails a late

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morbidity [10]. Especially, in ccTGA with pulmonary stenosis (PS) or pulmonary atresia (PA) conditions, the left ventricular outflow obstruction after atrial switch and Rastelli operation could impair the late left ventricular function [9, 11]. There has been no large-scale randomized control study comparing the long-term outcomes between physiologic and anatomic repairs. Naturally, it must be practically difficult to conduct such a randomized trial because of rarity of this malformation. The purpose of this study is to evaluate the long-term outcomes of physiologic repair for ccTGA and to provide a basis for comparison with anatomic repair for this entity.

Subjects and methods

Study population and data acquisition

Sixteen consecutive patients with ccTGA (10 males and 6 females) who underwent a physiologic repair at Tohoku University Hospital between January 1970 and June 2000 were identified from the database of the Division of Cardiovascular Surgery. The mean age at repair was 6.9 years (range 7 months to 23 years). Mean follow-up was 19.4 years after the surgery (range 0.1–44 years) (Tables 1, 2). Other than these patients, only one patient with ccTGA associated with PS, complete AV septal defect, and total anomalous of pulmonary venous drainage underwent a Fontan-type repair during this period. This patient was excluded from this cohort. No patient had anatomic repair during the same period.

Table 1 Summary of patient characteristics

	$n = 16$	(%)
Gender		
Male	10	(63)
Age at repair, years		
6.9 (range 0.6–23)		
Diagnosis		
VSD, PS	9	(56)
VSD, PA	3	(19)
VSD	2	(13)
ASD	1	(6)
Ebstein	1	(6)
Pre-repair palliation		
SP shunt	5	(31)
PAB, CoA repair	1	(6)
Repair procedure		
VSD closure + LV-PA conduit	12	(75)
VSD closure	2	(13)
ASD closure	1	(6)
TV repair	1	(6)
Follow-up duration, years		
19.4 (range 0.1–44)		

VSD ventricular septal defect, *ASD* Atrial septal defect, *PA* pulmonary atresia, *PS* pulmonary stenosis, *SP* systemic to pulmonary, *PAB* pulmonary artery banding, *CoA* coarctation of Aorta, *TV* tricuspid valve

Medical records, including echocardiographic data, cardiac catheterization data, and operative notes, were reviewed. The degree of pre-repair tricuspid regurgitation (TR) was evaluated by the right ventriculogram, and the degree of post-repair TR was evaluated by echocardiography. Because there was no documentation on TR grade by the right ventriculogram in two patients who underwent the repair in the 1970s, their pre-repair TR was not assessed. The long-term follow-up was accomplished by review of medical charts and outpatient clinic notes. Institutional Review Board approval was waved prior to the initiation of these retrospective analyses.

Diagnosis

The segmental anatomical classification was S, L, L in 15 patients (94 %) and I, D, D in 1 patient (6 %).

Associated anomalies included ventricular septal defects (VSD) in 14 patients (88 %), pulmonary stenosis in 9 patients (56 %), pulmonary atresia in 3 patients (19 %), atrial septal defect in 1 patient (6 %), and Ebsteinoid dysplasia of the left-sided tricuspid valve in 1 patient (6 %) (Tables 1, 2).

Surgical techniques

All intracardiac procedures were performed with cardiopulmonary bypass. Myocardial protection was achieved by the administration of cold cardioplegic solution in most of the cases except for the early two cases who underwent Rastelli procedure under deep hypothermia with cardiopulmonary bypass. VSD was closed with a patch material via a right atriotomy or a left ventriculotomy in 13 of 14 patients who required VSD closure; only one patient required right ventriculotomy to ascertain precise morphology of VSD. An Ebsteinoid tricuspid valve in the ccTGA patient who had isolated TR was repaired by Hardy's procedure. Rastelli procedure was performed for ccTGA with PS/PA with artificial graft with or without a prosthetic valve.

Statistics

All statistical analyses were performed using an SPSS software (SPSS, Inc., Chicago, IL, USA). Continuous variables were expressed as mean ± standard deviation and compared using Student *t* test. Categorical variables,

Table 2 Patient profiles

Case no.	Associated lesion	Pallitative surgery	Repair age	Pre-repair RVEDV (% of *N*)	Pre-repair RVEF	Pre-repair TR	Repair procedure	RV tomy	CAVB	Post-repair TR	Follow-up (years)	Status
1	VSD, PS		5	n.o.	n.o.	n.o.	VSD closure + LV-PA conduit			Moderate	44	III
2	VSD, PA	Bil. BTS	9	n.o.	n.o.	n.o.	VSD closure + LV-PA conduit		Y	Mild	35	I
3	VSD, PS		5	116	0.72	0	VSD closure + LV-PA conduit		Y	Mild	22	I
4	VSD, PS	Lt. BTS	5	79	0.63	0	VSD closure + LV-PA conduit		Y	Mild	19	II
5	VSD, PA	Rt. BTS	8	n.o.	n.o.	I	VSD closure + LV-PA conduit	Y		Moderate	18	Dead (26 yo)
6	VSD, PS		4	76	0.70	0	VSD closure + LV-PA conduit		Y	Trivial	18	I
7	VSD, PS	Bil. BTS	12	103	0.67	I	VSD closure + LV-PA conduit			Trivial	18	II
8	VSD, PA	Rt. BTS	3	94	0.62	0	VSD closure + LV-PA conduit			Trivial	16	I
9	VSD, PS, {IDD}		5	157	0.56	0	VSD closure + LV-PA conduit	Y		TVR	16	I
10	VSD, PS		6	98	0.54	I	VSD closure + LV-PA conduit		Y	Trivial	13	I
11	VSD, PS		5	134	0.68	I	VSD closure + LV-PA conduit		Y	TVR	11	Dead (16 yo)
12	VSD, PS		6	88	0.60	0	VSD closure + LV-PA conduit		Y	Moderate	0	Dead (6 yo)
13	VSD		0	n.o.	n.o.	0	VSD closure		Y	TVR	28	I
14	ASD		23	100	0.58	II	ASD closure		Y	Mild	21	I
15	Ebstein, TR		12	123	0.59	IV	TVP(Hardy)			Mild	17	I
16	VSD, CoA	CoA repair, PAB	3	92	0.67	0	VSD closure		Y	Trivial	14	I

VSD ventricular septal defect, *ASD* Atrial septal defect, *PA* pulmonary atresia, *PS* pulmonary stenosis, *TR* tricuspid valve regurgitation, *Bil* bilateral, *BTS* Blalock Taussig shunt, *CoA* coarctation of Aorta, *PAB* pulmonary artery banding, *n.o.* not obtained, *RVEDV* right ventricular end-diastolic volume, *RVEF* right ventricular ejection fraction, *LV-PA*, *TVP* tricuspid valve plasty, left ventricle to pulmonary artery, *Y* yes

expressed as percentages, were analyzed using either the Chi-squared or Fisher's exact tests. Survival rate, freedom from reoperation, and freedom from more than mild TR or TVR in the two groups were compared using a Kaplan–Meier method. A p value less than 0.05 was assumed to indicate statistical significance.

Results

Survival

There was one operative death due to mediastinitis complicating a conventional Rastelli procedure. Among 11 survivors after physiologic repair for ccTGA with PS/PA, two late deaths were identified. One patient died from low output syndrome after tricuspid valve replacement for tricuspid regurgitation 10 years after the previous conventional Rastelli procedure. The other patient died of congestive heart failure due to tricuspid regurgitation 16 years after the prior Rastelli procedure. There was no death after physiologic repair for patients of ccTGA without PS/PA. Eventually, 10- and 20-year survival rates after physiologic repair for ccTGA with PS/PA were 92 and 71 %, respectively (Fig. 1). No pre-, intra-, or post-operative factors were significantly associated with death after physiologic repair; however, more than mild TR after the repair was prone to be associated with death (Table 3).

Patient's status and medication

Twelve of all the 13 survivors were doing well in NYHA I or II at the latest visit and were engaged in social activities. With regard to medication, 43 % of patients took beta-blocker and 54 % of patients took renin-angiotensin system inhibitor.

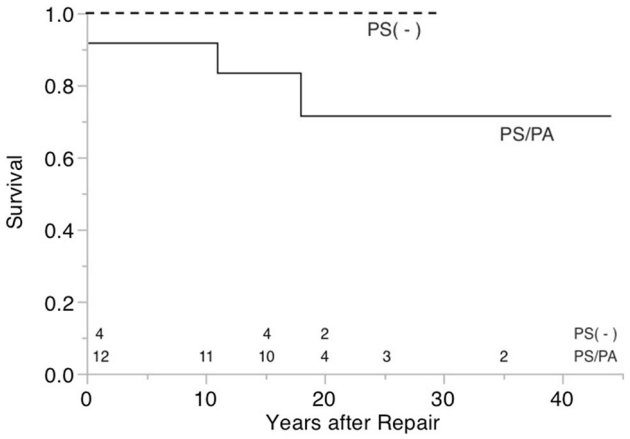

Fig. 1 Survival after repair for ccTGA patients with PS/PA (*solid line*) and without PS (*dashed line*)

Table 3 Pre-, intra-, and post-repair risk factor analyses for death

	Alive	Dead	p value
Pre-repair			
Age@repair	7.1 ± 1.5	6.3 ± 3.2	0.84
PA/PS	9/13	3/3	0.26
TR ≥ Sellers I[a]	4/11[a]	2/3[a]	0.35[a]
RVEDV (% of N)	104 ± 8	111 ± 17	0.71
RVEF (%)	63 ± 6	64 ± 6	0.42
Intra-repair			
Cross-clamp time	125 ± 16	103 ± 31	0.54
CPB time	248 ± 32	191 ± 61	0.43
RV tomy	1/13	1/3	0.23
Post-repair			
cAVB	8/13	2/3	0.87
TR > mild	5/13	3/3	0.054

PA pulmonary atresia, *PS* pulmonary stenosis, *TR* tricuspid regurgitation, *RVEDV* right ventricular end-diastolic volume, *% of N* percent of normal, *RVEF* right ventricular ejection fraction, *CPB* cardiopulmonary bypass, *cAVB* complete atrioventricular block

[a] Two patients' data were not obtained

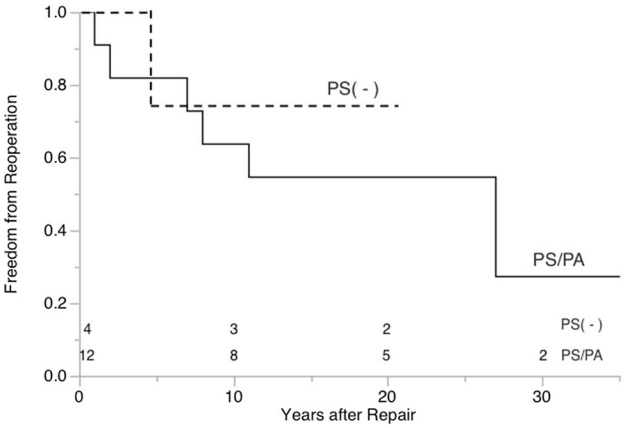

Fig. 2 Freedom from reoperation after repair for ccTGA patients with PS/PA (*solid line*) and without PS (*dashed line*)

Reoperation

As shown in Fig. 2, one ccTGA without PS patient underwent tricuspid valve replacement (TVR) 6 years after VSD closure. The patient subsequently underwent cardiac resynchronization therapy at the age of 20. Among ccTGA with PS/PA patients, four patients underwent left ventricular-pulmonary artery conduit exchange with no mortality and two underwent TVRs; one patient survived TVR being performed 1 year after conventional Rastelli procedure, the

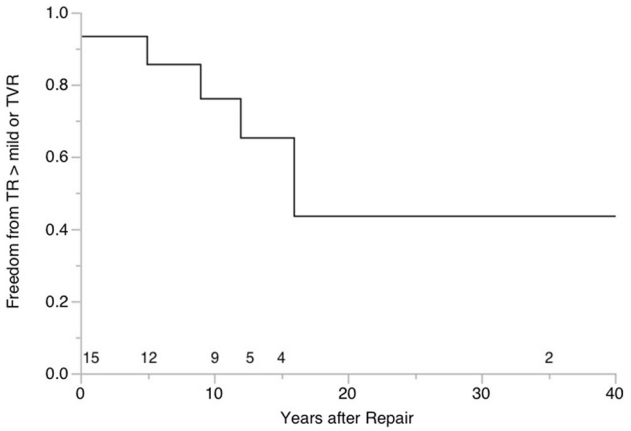

Fig. 3 Overall freedom from TR > mild or TVR after repair

Table 4 Pre-, intra-, and post-repair risk factor analyses for significant tricuspid regurgitation after repair

	TR ≥ moderate	TR < moderate	*p* value
Pre-repair			
Age @ repair	4.7 ± 2.2	8.5 ± 1.8	0.19
PA/PS	4/5	7/10	0.68
TR ≥ Sellers I[a]	2/4[a]	4/9[a]	0.85[a]
RVEDV (% of N)	136 ± 9	96 ± 6	0.019
RVEF (%)	62 ± 4	64 ± 2	0.76
Intra-repair			
X clamp time	109 ± 28	129 ± 19	0.57
CPB time	196 ± 54	258 ± 36	0.37
RV tomy	1/5	1/10	0.59
Post-repair			
cAVB	2/5	7/10	0.26

PA pulmonary atresia, *PS* pulmonary stenosis, *TR* tricuspid regurgitation, *RVEDV* right ventricular end-diastolic volume, *% of N* percent of normal, *RVEF* right ventricular ejection fraction, *CPB* cardiopulmonary bypass, *cAVB* complete atrioventricular block

[a] Two patients' data were not obtained

other patient died from congestive heart failure after TVR being performed 11 years after conventional Rastelli procedure.

Tricuspid regurgitation

Among 15 survivors of repair, incremental TR was observed over the follow-up period after physiologic repair (Fig. 3). Twenty-year freedom from more than mild TR or TVR was 44 %. Pre-repair right ventricular end-diastolic volume was significantly associated with more than mild TR after repair ($p = 0.019$); however, intriguingly, preoperative TR (Sellers I or more) was not associated with more than mild TR after repair ($p = 0.85$) (Table 4).

Discussion

Optimal surgical management of patients with ccTGA and associated lesion remains controversial. The classical physiologic repair of this condition has been valid option since the 1950s [12]. However, inherent concerns about the long-term morphologic RV dysfunction and systemic tricuspid valve insufficiency have been raised. The guarded sequelae of the morphologic RV in the systemic circulation generate the impetus for the surgical management of ccTGA to evolve from physiologic repair to anatomic repair, which restores the morphologic left ventricle into the systemic circulation [5]. Although several centers reported excellent short-term outcomes of anatomic repair albeit more complicated procedure, long-term outcomes, especially in the condition of ccTGA with PS/PA, were not always superior to those of physiologic repair [13, 14]. Some relatively large-scale reports in the same era as the one for our patients' showed that mortality was 55–75 % over decades of years after anatomic repair for ccTGA patient with PS/PA [7, 11, 14]. These are equivalent to that of our long-term results after physiologic repair for ccTGA with PS/PA [2, 4, 14].

Specifically, double switch operation, including atrial switch combined with Rastelli procedure for ccTGA with PS and non-committed and/or restrictive VSD, carries a substantial risk of systemic ventricular outflow tract obstruction and consequent systemic ventricular dysfunction. Physiologic repair consisting of VSD closure and LV-PA conduit may be preferable to anatomic repair for this subset of ccTGA patients. Recently, Hoashi et al. reported excellent mid-term outcome of anatomic repair for ccTGA with PS/PA [9]. In their series, the outcome was remarkably improved by liberal use of Damus–Keye–Stansel anastomosis to prevent systemic ventricular outflow obstruction. Their cohort was, in fact, registered since 1997; hence, their long-term outcome needs to be evaluated. Aortic root translocation, such as Bex/Nikaidoh or half turn truncal switch, is an alternative surgical option to ensure straight and non-obstructive systemic ventricular outflow tract for ventriculoarterial discordance. The combination of atrial switch and aortic root translocation is expected to provide a better long-term result in ccTGA with PS and non-committed and/or restrictive VSD, although the procedure is technically demanding.

In our retrospective study, we could confirm that the survival rate long after physiologic repair for ccTGA was almost equivalent to those after anatomic repair reported in the literature. Notably, a significant TR was observed in more than half of physiologically repaired patients over the 20 years of follow-up after the initial repair in our cohort. This aspect should not be overlooked, since a significant

TR is considered to be a strong risk factor of systemic right ventricle failure [4, 12, 14]. In this study, the severity of pre-repair TR did not correlated with the long-term death or significant TR after physiologic repair. Minimal TR might turn to be significant after physiologic repair. Kral Kollars et al. reported that decreasing the LV/RV pressure ratio after physiologic repair results in a more spherical right ventricle, increased tethering of tricuspid valve leaflets, diminished tricuspid valve coaptation, and an increase in the degree of TR [15]. This observational report supports our clinical experience that significant TR could develop in ccTGA patients with mild or even less pre-repair TR. The degree of pre-repair TR could not predict the long-term function of tricuspid valve after physiologic repair. Preoperative enlargement of RV rather than the severity of TR may limit the indication of physiologic repair, since it appears to be related to the development of postoperative TR that is associated with the long-term mortality in ccTGA patients. With these in our mind, excessive volume overload should be avoided when systemic to pulmonary shunt is required for ccTGA with PS/PA patient preceding physiologic repair.

Recently, some reports revealed that the morbidity and mortality suddenly deteriorated due to RV dysfunction in the ultra-long-term period beyond 30 years. The lifelong follow-up is mandatory for ccTGA patients [14, 16].

Study limitation

This is a retrospective descriptive study and the cohort included a limited number of cases, all from a single institute, under various treatment strategies, and over decades of years. Some of pre-repair cardiac catheterization data were not obtained, because they were assessed in the 1970s. Since post-repair catheterizations were carried out only for half of the present cohort and only when some hemodynamic impairments were detected by other modality, thus, we did not include post-repair RVEDV or RVEF as a parameter into the present comparative analysis with regard to post-repair death and post-repair TR to avoid potential bias. However, post-repair RVEDV and RVEF in all the patients need to be analyzed in a sophisticated manner to examine the impact of those parameters on the long-term outcomes.

Conclusion

Although the long-term outcomes of physiologic repair for ccTGA were equivalent to those of reported anatomic repair performed in several centers during the same era, significant TR was observed in more than half of physiologically repaired patients over the 20 years after repair. Pre-repair enlargement of RV rather than the severity of TR may limit the indication of physiologic repair, since it appears to be related to the development of postoperative TR that is associated with the long-term mortality in ccTGA patients.

Compliance with ethical standards

Conflict of interest The authors have declared that no conflict of interest exists.

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