

Morphological and Functional Characteristics of the Right Ventricle Functioning as a Systemic Ventricle for Decades After an Atrial Switch Procedure for Complete Transposition of the Great Arteries



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Described herein are certain clinical and cardiac morphologic findings in 4 adults with complete transposition of the great arteries who underwent the Mustard procedure in the newborn period or in childhood and each lived >30 years thereafter before either having orthotopic heart transplantation (3 patients) or dying while awaiting orthotopic heart transplantation. Compared with the wall of the left ventricle, the wall of the right ventricle (the systemic one) was much thicker, the myofibers much larger, and either grossly-visible or microscopic-sized scars were present in its wall. Additionally, some intramural coronary arteries in the right ventricular wall were numerous, large, had thick walls, and often narrowed lumens. That the Mustard operation provided the necessary time for the right ventricle (the systemic one) to develop to its fullest is a tribute to this procedure. © 2019 Published by Elsevier Inc. (Am J Cardiol 2019;123:1863–1867)

The introduction of the atrial switch operation in the late 1950s by Senning and later Mustard has provided remarkable longevity for many patients with complete transposition of the great arteries (CTGA) (Figure 1). Until the atrial switch procedure, patients with unoperated CTGA rarely lived longer than 1 year, an inadequate time for the right ventricle to become a fully developed systemic ventricle.¹ During the past 4 years we have studied the hearts of 4 patients with CTGA, each of whom survived >30 years following the atrial switch operation in infancy or childhood. This report describes certain morphologic and functional findings in the right ventricle (the systemic one) and compares them to those in the left ventricle (the pulmonic ventricle) in these 4 patients.

Methods

Of the 4 patients, 3 underwent orthotopic heart transplantation (OHT) and 1 died while awaiting OHT. The hearts were described, and the reports submitted by one of us (WCR). The clinical records were then examined. Photographs of the hearts were taken by Ms. Saba Ilyas. At least

4 sections of the cardiac ventricles were prepared in each patient and all sections were stained by both hematoxylin/eosin and trichrome.

Results

The findings in each of the 4 patients are summarized in Table 1. The 3 patients who underwent OHT were 43, 49, and 50 years of age and had the Mustard procedure performed at age 2, 1, and 14 years of age, respectively. The patient (#1, Table 1) who died at age 33 years while awaiting OHT had had a Mustard procedure during her first year of life. Thus, all 4 patients survived >3 decades

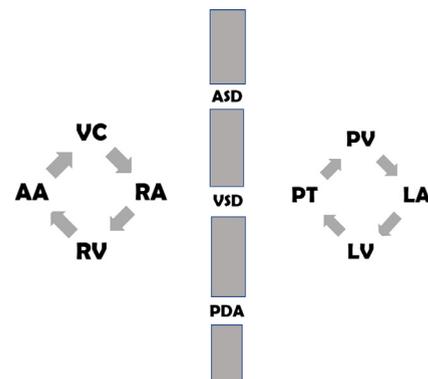


Figure 1. The 2 separate circulations in patients with complete transposition of the great arteries. The only means of survival is the presence of a communication between the 2 circulations: atrial septal defect (ASD), ventricular septal defect (VSD), and/or patent ductus arteriosus (PDA). AA = ascending aorta; LA = left atrium; LV = left ventricle; PT = pulmonary trunk; PV = pulmonary vein; RA = right atrium; RV = right ventricle; VC = vena cava.

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Table 1
Certain clinical findings in the 4 patients

Variable	Patient			
	1	2	3	4
Sex	M	F	M	M
Age at (Years):				
Atrial switch	0.75	14	2	1
Pacemaker	15	+	—	27
Cardioverter defibrillator implanted	22	+	41	36
Orthotopic heart transplantation	—	50	43	49
Death	33	50	—	—
Body measurements:				
Body weight (pounds)	259	173	217	251
Height (inches)	75	63	70	74
Body mass index (kg/m ²)	34	31	31	33
Events after atrial switch procedure:				
Heart failure	+	+	+	+
Arrhythmias	+	+	+	+
Baffle problems	+	0	0	+
Stroke	+	0	0	0
Electrocardiography findings:				
Sinus bradycardia	0	0	+	0
Right bundle branch block	+	+	+	+
Atrial fibrillation	+	+	+	0
Echocardiography findings: **				
Right ventricular (systemic) ejection fraction	—	—	15%	—
Tricuspid valve (systemic) regurgitation	+	—	+	—
Pulmonic valve regurgitation	—	—	+	—
Dilated left ventricular (pulmonic) cavity	+	+	0	+
Dilated right ventricular (systemic) cavity	+	+	+	+
Reduced right ventricular (systemic) systolic function (0-3+)	3+	—	3+	—
Pressures at catheterization (mm Hg):				
Pulmonary capillary wedge (a/v/mean)	22/27/20	27/51/25	10/13/10	15/24/17
Pulmonary artery (s/d)	52/24	80/27	20/13	39/15
Left ventricular (pulmonic) (s/d)	53/0	—	25/0	41/-3
Left atrial (pulmonic) (a/v/mean)	12/9/7	—	16/8/7	—
Systemic artery (s/d)	115/85	115/70***	110/80	110/87
Right ventricular (systemic) (s/d)	—	81/9	—	—
Cardiac output:				
Fick/thermodilution (cardiac output) - (L/min)	4.8/7.2	3.1/—	3.9/3.9	4.1/4.8
Fick/Thermodilution (cardiac index) - (L/min/m ²)	2.0/2.9	1.7/—	1.8/1.8	1.88/2.21
Heart weight (g)	845	390	595	590
Floating heart	+	+	+	+
Right ventricular scarring	+++	+++	++	+++
Left ventricular scarring	0	0	0	0
Abnormal intramural coronary arteries	—	+	0	0

Abbreviations: M = male; F = female; a = a wave; v = v wave; s = peak systolic; d = end-diastolic; — = no information available or not applicable.

* Age unclear.

** Last recorded before orthotopic heart transplant or death.

*** Indirect.

after the Mustard procedure. The duration of survival with the Mustard procedure in the 3 patients having OHT would have been even greater had not OHT been performed.

Discussion

Several studies have been performed concerning long-term follow-up of patients with CTGAs having had the Mustard procedure. Theissen et al² showed by using noninvasive imaging, such as echocardiogram and magnetic resonance imaging, that in such patients the right (systemic)

ventricular end-diastolic volumes are significantly higher than the left ventricular volumes. That study, performed in 30 children (mean age 11.5 years), also showed that the muscular mass in CTGA patients after the Mustard procedure had a ratio of 1.9:1 between right and left ventricles, whereas, in normal children it was 1:1.5. Plymen et al³ demonstrated by magnetic resonance imaging diffuse myocardial fibrosis in the systemic right ventricles after an atrial-switch operation for CTGAs. To the best of our knowledge, there are no published reports demonstrating such long-term morphological features in heart specimens of such patients.

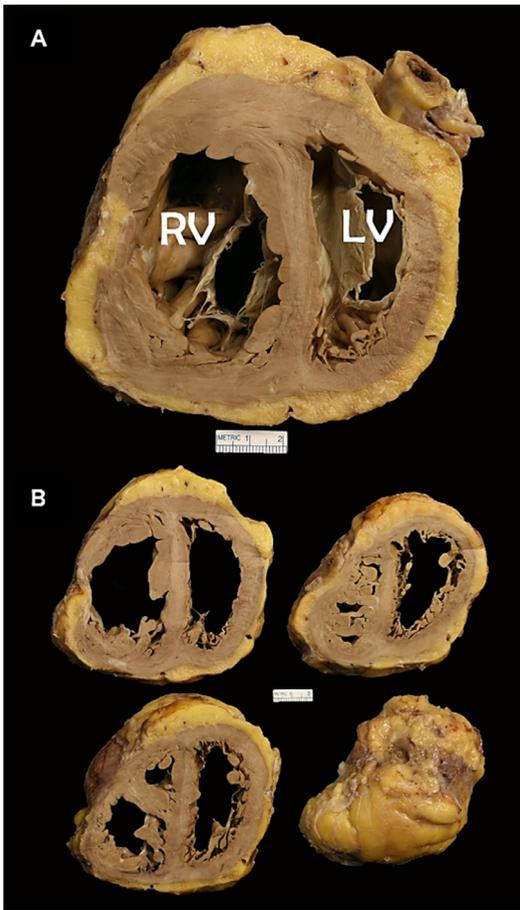


Figure 2. Case #1 (Table 1). (A) Shown here is a cross-section view of the ventricles just caudal to the atrioventricular valves. The wall of the right ventricle (RV), the systemic ventricle, is thicker than the wall of the left ventricle (LV). Both ventricular cavities are dilated. No grossly visible lesions are noted in the myocardial walls. The subepicardial adipose tissue covers all of LV and most of the RV. (B) Cross-sections of the ventricles caudal to the view shown in *a*.

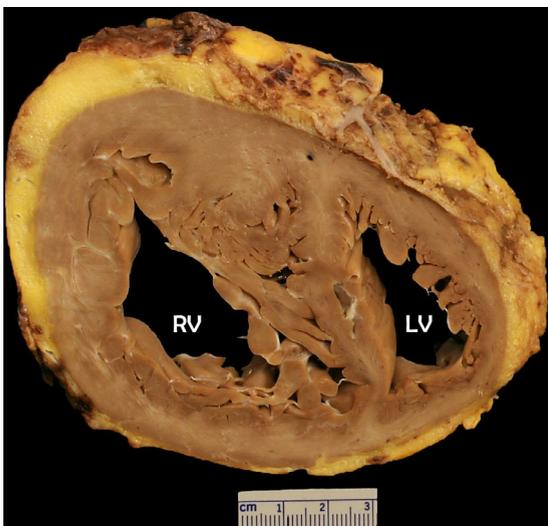


Figure 3. Case #2 (Table 1). This cross section of the ventricles just caudal to the atrioventricular valves shows massive hypertrophy of the right ventricle (RV) and no thickening of the wall of the left ventricle (LV). Some scarring is present in the wall of the RV. Subepicardial adipose tissue covers most of the ventricles.

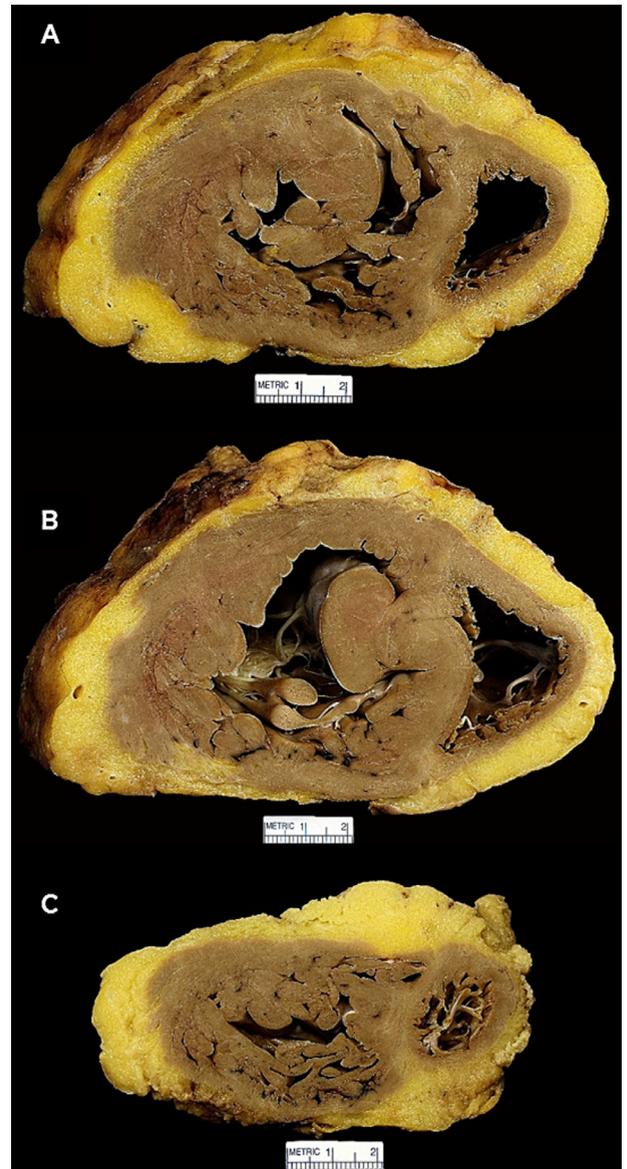


Figure 4. Case #3 (Table 1). Shown in A, B, and C are 3 views of the ventricles caudal to the atrioventricular valves. In all 3 views the right ventricular wall is much thicker than the left ventricular wall which is not thickened. The right ventricular free wall also is thicker than the ventricular septum. Some scarring is present in the right ventricular wall. Nearly the entire ventricles are covered by subepicardial adipose tissue.

Examination of the walls of the systemic (right ventricle) in the 4 patients described herein disclosed the walls to be much thicker than those of the left ventricle and to contain scars in contrast to their absence in the left ventricular walls (Figures 2–5). One of the 4 patients had marked enlargement, thickening of the walls and narrowing of the lumens of the intramural coronary arteries in contrast to their absence in the left ventricular walls. Similar findings have been observed in adults with severe isolated pulmonic valve stenosis.⁴ The myocytes in the wall of the right ventricle were much larger than those in the wall of the left ventricle (Figure 5).

Table 2

Previously reported findings in patients with complete transposition of the great arteries (CTGA), atrial switch, and orthotopic heart transplantation (OHT)

Case	First author	Year published	Number of patients with CTGA, atrial switch, and OHT	M	F	Age (years) at			
						Atrial switch	OHT	≤60	>60
1	Mayer	1990	1	—	—	—	“child”	—	—
2	Menkis	1991	1	—	—	—	“child”	—	—
3	Carrel	1994	2	—	—	—	14-51	0	0
4	Carrel	2000	2	—	—	—	—	—	—
5	Michielon	2003	5	—	—	—	0.33-19	1**	1***
6	Moons	2004	2	—	—	—	—*	—	—
7	Messner	2005	1	0	1	12	38	0	—
8	Muñoz-Guijosa	2008	4	1	3	0.5-3	13-25	0	1
9	Dobson	2013	1	—	—	—	—	—	—
10	Cuyppers	2014	2	—	—	<15	—	—	—
11	Vejlstrup	2015	8	—	—	1.9	—	—	—
12	Maly	2015	3	3	0	—	29-33	—	—
13	Cohen	2015	19	—	—	—	30	—	—
14	Menachem	2017	4	1	3	—	40-57	0	1

Abbreviations: F = female; M = male; (—) = no information available.

* OHT performed 17 and 21 years after the Mustard procedure.

** The child having an OHT at age 4 months died 1 day postoperatively.

*** Death occurred 3 months after OHT from graft infection.

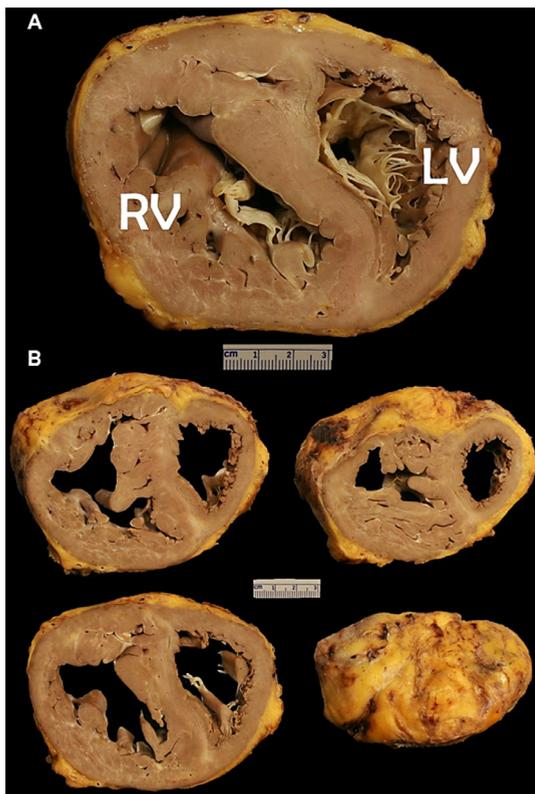


Figure 5. Case #4 (Table 1). (A) Cross-section of the ventricles at the level of the margins of the atrioventricular valves. The right ventricular wall is much thicker than the left ventricular free wall and some scars are visible in the right ventricular wall. Both ventricular cavities are dilated. The left ventricular free wall is not nearly as thick as the right ventricular free wall. (B) Cross-sections of the cardiac ventricles caudal to the atrioventricular valves. Again, the right ventricular wall is much thicker in all of the sections than is the left ventricular free wall and grossly visible scars are seen in the right ventricular wall. The subepicardial adipose tissue again is increased.

Relatively few patients with CTGAs have undergone OHT. Those previously reported are summarized in Table 2.^{5–18} Meaningful follow-up after OHT in the reported patients with CTGAs as in the present 3 patients is limited.

Disclosures

The authors have no conflicts of interest to disclose.

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