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Long-term follow-up of patients with extracardiac valved conduits.

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Abstract

Seventeen patients having extracardiac valved conduits placed between the right ventricle and pulmonary artery were followed for 7 to 87 months postoperatively (mean, 42 months), at the Heart Institute, Kenritsu Amagasaki Hospital, Japan. There were no late deaths in the study group. Three conduits have been replaced, all because of conduit stenosis. In two-dimensional echocardiographic examinations, commissural fusion and calcification of the valve were noted in 6 out of 16 xenograft valved conduits. Mechanical valve immobility was found in one patient. Neointimal peel of the dacron graft was noted in 6 out of 17 cases, and marked left ventricular deformity in the short axis view was found in 6. Late cardiac catheterization was done in 6 patients who were suspected of having valve failure and right ventricular hypertension by two-dimensional echocardiography. All 6 of these patients showed a high pressure gradient between the pulmonary artery and right ventricle and also had elevated right ventricular pressure. In conclusion, two-dimensional echocardiography is a simple, non-invasive and very accurate method for detecting conduit stenosis and valve failure. An echocardiographic series should be performed for a long-time postoperatively because obstructions of valved conduits may be progressive, and an operation may be advisable in order to prevent the development of advanced right ventricular hypertrophy and deterioration.

KEYWORDS: extracardiac valved conduit, conduit stenosis, two-demensional echocardiography

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Long-Term Follow-Up of Patients with Extracardiac Valved Conduits

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Seventeen patients having extracardiac valved conduits placed between the right ventricle and pulmonary artery were followed for 7 to 87 months postoperatively (mean, 42 months), at the Heart Institute, Kenritsu Amagasaki Hospital, Japan. There were no late deaths in the study group. Three conduits have been replaced, all because of conduit stenosis. In two-dimensional echocardiographic examinations, commissural fusion and calcification of the valve were noted in 6 out of 16 xenograft valved conduits. Mechanical valve immobility was found in one patient. Neointimal peel of the dacron graft was noted in 6 out of 17 cases, and marked left ventricular deformity in the short axis view was found in 6. Late cardiac catheterization was done in 6 patients who were suspected of having valve failure and right ventricular hypertension by two-dimensional echocardiography. All 6 of these patients showed a high pressure gradient between the pulmonary artery and right ventricle and also had elevated right ventricular pressure. In conclusion, two-dimensional echocardiography is a simple, non-invasive and very accurate method for detecting conduit stenosis and valve failure. An echocardiographic series should be performed for a long-time postoperatively because obstructions of valved conduits may be progressive, and an operation may be advisable in order to prevent the development of advanced right ventricular hypertrophy and deterioration.

Key words : **extracardiac valved conduit, conduit stenosis, two-dimensional echocardiography**

In 1966, Ross and Somerville (1) reported the repair of tetralogy of Fallot with pulmonary atresia using an aortic homograft as a conduit from the systemic venous ventricle to the pulmonary artery. The use of aortic homograft was extended to the correction of truncus arteriosus and to complex transposition of the great vessels (2, 3). In 1972, Bowman *et al.* (4) first used clinically a glutaraldehyde preserved porcine valve and a dacron tube graft. Many variations in the use of the conduit to establish right ventricle-to-pulmonary artery continuity have been described and have permitted repair of a wide variety of complex congenital heart diseases for which only palliative procedures were previously available.

Although several institutions have reported satisfactory early results with the use of extracardiac conduits, long-term results of such operations revealed that calcific stenosis of aortic homografts and obstruction of porcine valved extracardiac con-

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duits may be a significant late postoperative complication (5-9).

We were concerned about the long-term performance of extracardiac valved conduits and established a protocol to evaluate patients over an extended period of time. This report emphasizes the usefulness of two-dimensional echocardiography in arriving at a correct decision concerning catheterization and the possibility of having to reoperate.

Patients and Methods

Between July 1972 and June 1985, 35 patients had 38 valved conduits placed from the hemodynamic right sided ventricle to the pulmonary artery in the Heart Institute of Kenritsu Amagasaki Hospital. The primary diagnosis of these 35 patients and the surgical outcome are listed in Table 1.

Fifteen patients had severe forms of tetralogy of Fallot, including 2 with pulmonary atresia. Thirteen had transposition of the great arteries, 5 had truncus arteriosus, 1 had double-outlet right ventricle and 1 had double-outlet left ventricle. The age of the patients at the time of repair ranged from 63 days to 16.5 years (mean, 5.4 years). Conduit operations were performed on 11 patients who were 2 years of age or under. Of the 35 valved extracardiac conduit operations, 28 were according to the Rastelli-type procedure and 7 were according to the Damus-Kaye-Stansel procedure (Table

Table 1 Congenital defects necessitating valved conduit repair

Diagnosis	No. of patients	Hospital deaths	
		No.	Mortality rate (%)
TF, PA	15	2	13
TGA	13	6	46
Truncus arteriosus	5	3	60
DORV	1	1	100
DOLV	1	0	0
Total	35	12	34

Abbreviations: TF, tetralogy of Fallot; PA, pulmonary atresia; TGA, transposition of the great arteries; DORV, double-outlet right ventricle; DOLV, double-outlet left ventricle.

Table 2 Operations and results

Operative techniques and diagnosis	No. of patients	Hospital deaths	
		No.	Mortality (%)
Rastelli type	28	8	29
TF, PA	15	2	13
TGA	7	3	43
Truncus arteriosus	5	3	60
DOLV	1	0	0
Damus-Kaye-Stansel	7	4	57
TGA	6	3	50
DORV	1	1	100
Total	35	12	34

Abbreviations: TF, tetralogy of Fallot; PA, pulmonary atresia; TGA, transposition of the great arteries; DOLV, double-outlet left ventricle; DORV, double-outlet right ventricle.

Table 3 Valves used and results

Valves used	No. of cases	Hospital deaths	
		No.	Mortality (%)
Hancock xenograft	25	9	36
Björk-Shiley	5	2	40
SJM[a]	5	1	20
Carpentier-Edwards xenograft	2	0	0
Aortic homograft	1	0	0
Total	38[b]	12	32

a: SJM, St. Jude Medical valve.
b: Three patients underwent a reoperation.

2). The types of valved conduits are listed in Table 3.

Twenty-three patients survived. Of these patients, 17 underwent periodic two-dimensional echocardiographic examination to assess the extracardiac valved conduits from the right ventricular outflow tract to the pulmonary arteries, and to determine the right ventricular-over-left ventricular peak systolic pressure ratio (P RV/LV). The other 6 patients were followed up at other institutions and were excluded from the echocardiographic study. Cardiac catheterization was routinely recommended for all patients 1 month postoperatively. Late follow-up hemodynamic data were obtained in 6 patients in whom conduit stenosis and elevation of P RV/LV were suspected by two-dimensional echocardiography. The follow-up period of the 17 patients was from 7 to 87 months postoperatively (mean, 42 months).

Results

There were 12 deaths among the 35 patients (34%). Eight deaths were among patients who underwent Rastelli-type procedures, and 4 were among those who underwent Damus-Kaye-Stansel procedures (Table 2). There were 7 deaths among the 11 patients who were under 2 years of age (64%). Of the 23 hospital survivors there have been no late deaths.

Two-dimensional echocardiographic examination revealed commissural fusion of the valve in 9 out of 16 xenografts and calcification of the valve in 6 out of 16 xenografts. One patient in whom a 19 mm Björk-Shiley valved conduit was used was noted to have a half-open and fixed valve. Valve findings could not be obtained in 2 patients, both of whom had transposition of the great arteries and valved conduits which were anastomosed to the right side of the aorta. Neointimal peel formation within the conduits was noted in 6 out of the 17 patients, and marked left ventricular deformity in the short axis view

Table 4 Clinical data of long-term follow-up patients

No.	Age, Sex	Diagnosis	Valve used	Follow-up period (months)	Valve findings	Two-D echo findings		P RV/LV
						Neointimal peel	LV deformity	
1	12 y, M	TF	B-S19	87	Fixed		Marked	0.77
2	6 y, F	Truncus (IV)	Hx. 22	71	Fused	+	Mild	
3	2m, M	Truncus (II)	Hx. 12	64	Fused & calcified	+	Marked	1.09
4	11m, M	TGA (II)	Hx. 20	60	Not visible		Moderate	
5	11m, M	TGA (II)	Hx. 20	52	Fused	+	Moderate	
6	5 y, F	TF	Hx. 20	52	Clear		Mild	
7	11 y, F	PA	Hx. 22	51	Clear		Mild	
8	5 y, F	TF	Hx. 22	48	Fused & calcified	+	Marked	0.77
9	1 y, M	TGA (II)	Hx. 20	54	Not visible		Marked	0.81
10	3 y, M	TF	Hx. 20	46	Fused & calcified		Moderate	
11	4 y, F	TGA (II)	Hx. 20	44	Fused & calcified	+	Moderate	
12	6 y, M	TF	Hx. 22	44	Fused		Marked	0.88
13	10 y, M	TF	Hx. 25	39	Fused & calcified		Moderate	
14	8 y, M	PA	Hx. 22	36	Fused & calcified	+	Marked	1.04
15	4 y, M	TGA (III)	C-E16	11	Clear		Mild	
16	7 y, M	TF	Hx. 18	10	Clear		Mild	
17	4 y, M	TF	Hx. 16	7	Clear		Mild	

Abbreviations: B-S, Björk-Shiley; C-E, Carpentier-Edwards; Hx, Hancock; PA, pulmonary atresia; TF, tetralogy of Fallot; TGA, transposition of the great arteries; P RV/LV, right ventricular-over-left ventricular peak systolic pressure ratio.

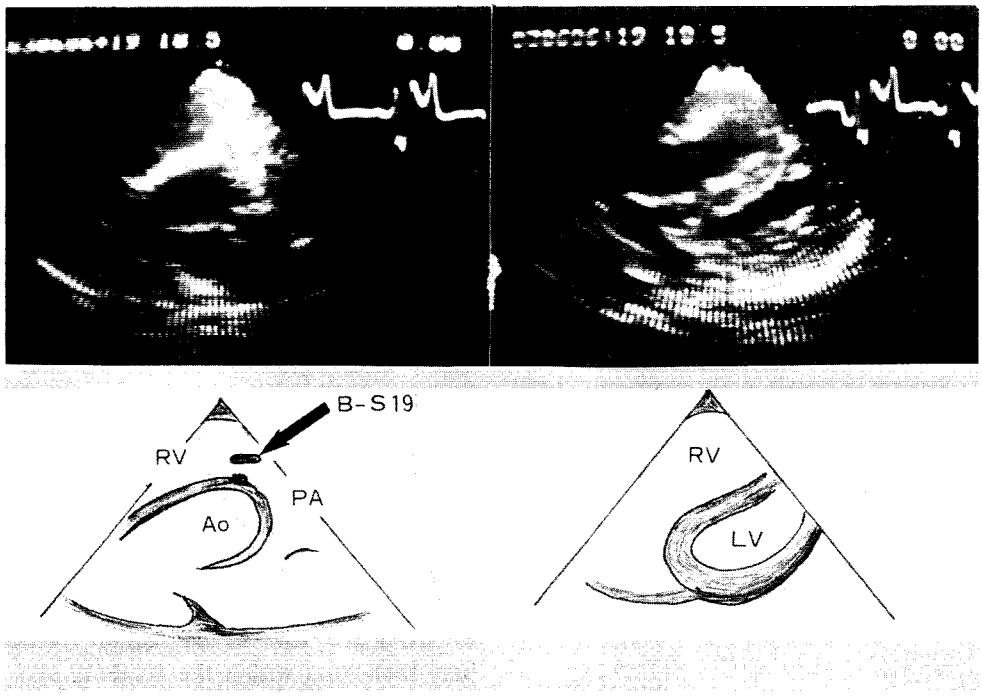

Fig. 1 Two-dimensional echocardiograms of case No. 1 taken 36 months after operation. Half open and fixed Björk-Shiley valve and marked left ventricular deformity are seen.

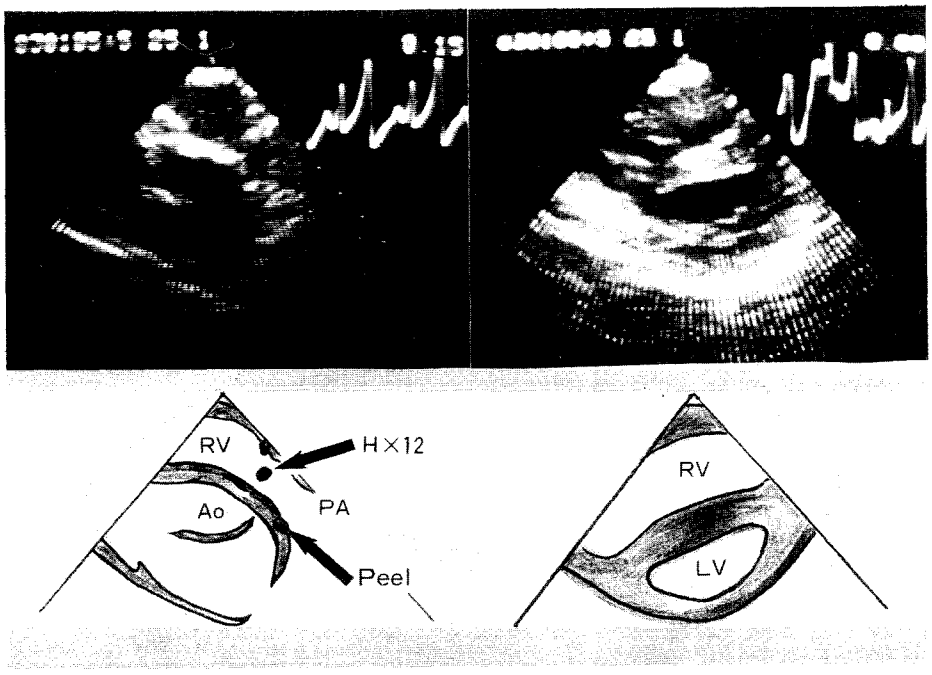

Fig. 2 Two-dimensional echocardiograms of case No. 3 demonstrate calcified Hancock valve, valvular stenosis and marked left ventricular deformity.

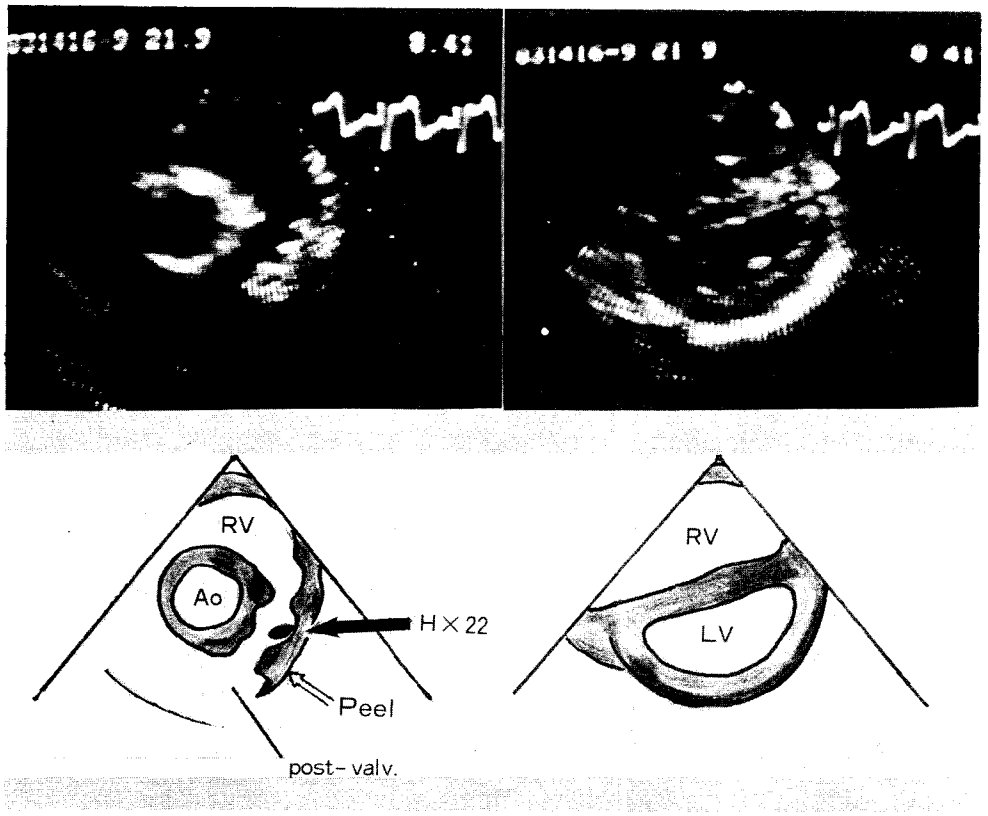

Fig. 3 Two-dimensional echoardiogram of case No. 8 demonstrates calcified Hancock valve and thick neointimal peel.

Table 5 Hemodynamic data of 3 patients having undergone reoperation

Patient No.	Diagnosis	Age at operation (yrs)	Conduit size (mm)	Peak systolic gradient (mmHg)		P RV/LV		Site of major obstruction	Interval between initial op & reop (months)
				Early	Late	Early	Late		
3	Truncus (II)	2/12	Hx. 12	7	90	0.54	1.09	Valve	64
8	TF absent pulm. valve	5	Hx. 22	22	64	0.46	0.77	Valve	48
14	PA	8	Hx. 22	81	74	1.08	1.04	Distal	54

Abbreviations: TF, tetralogy of Fallot; PA, pulmonary atresia; Hx, Hancock; pulm, pulmonary; P RV/LV, right ventricular-over-left ventricular peak systolic pressure ratio.

was noted in 6. Among the 14 patients who were followed up for more than 36 months, 10 patients were noted to have valve dysfunction and 6 were noted to have marked LV deformity (Table 4 and Figs. 1-4).

Late cardiac catheterization was done in 6 patients who had been confirmed to have valve dysfunction and marked LV deformity on two-dimensional echocardiograms. The pressure gradient across the valved conduits ranged from 11 to 90 mmHg (average, 61 mmHg). The P RV/LV ratio ranged from 0.77 to 1.09 (average, 0.89) (Table 4).

Three of the 23 survivors have undergone reoperation because of conduit stenosis (Table 5). The mean interval from the time of

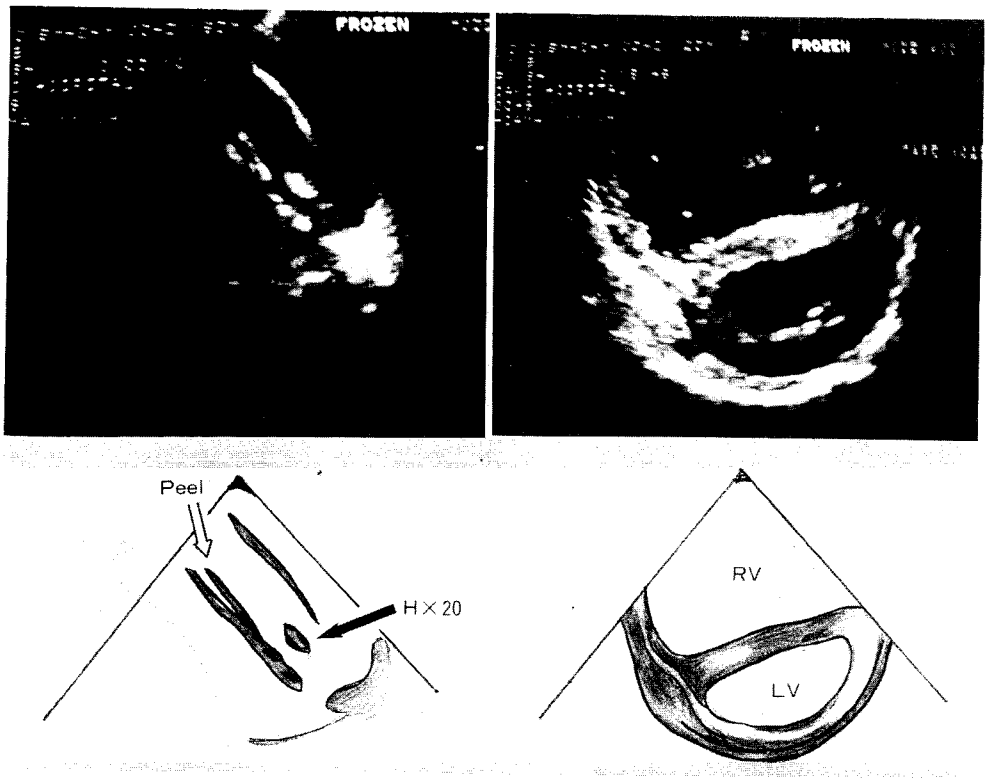

Fig. 4 Two-dimensional echoardiogram of case No. 14. Hancock valve is fused and calcified but still retains movement. Non-obstructing, neointimal peel is seen proximally in the conduit.

insertion of the conduit to the time of replacement was 4 years 7 months. Obstruction was due to a combination of valvular obstruction and neointimal peel in 2 patients and to distal anastomosis in one. All 3 valves were fused and calcified. A St. Jude Medical (SJM) valve was used for replacement in all patients, and a polytetrafluoroethylene (PTFE) graft patch was used to enlarge the distal anastomosis in one patient. There were no hospital deaths at the time of conduit replacement.

Discussion

The use of an extracardiac conduit between the right ventricle and the pulmonary artery has allowed repair of pulmonary atresia, persistent truncus arteriosus, transposition of the great arteries with pulmonary stenosis, and other complex forms of congenital heart disease. Conduit repair may provide dramatic improvement in clinical status with elimination of cyanosis and considerable improvement in exercise tolerance.

Several types of composite conduits have been used, including those with aortic homograft valves, xenograft valves, pericardial valves, and mechanical valves placed within dacron tubes. Initial results with woven dacron conduits containing glutaraldehyde fixed porcine valves were encouraging, but long-term follow-up has documented progressive conduit obstruction and valve dysfunction (8, 10-14). In 1982 McGoon *et al.* (5) reported follow-up data on 333 patients who had received Hancock conduits together with

those on 130 patients who had received irradiated homografts and 5 who had received non-valved conduits. Ninety patients underwent serial catheterization. The initial transconduit gradient at the time of insertion in patients with the Hancock prosthesis was 25 mmHg with a mean increase of 5 mmHg over a mean period of 1.7 years. The early results with Hancock conduits seemed quite good, with the probability of reoperation for obstruction being 6% at 5 years. However, systematic invasive and non-invasive evaluation of the cardiovascular status was not performed.

Soon after these early encouraging results, however, failures with the dacron valved conduits began appearing. Neointimal proliferative obstruction and heterograft valve degeneration were the leading causes of obstruction. In 1981, Ben-Shachar *et al.* (15) reported the possibility of acute failure of tightly woven dacron conduits. At autopsy, the thick neointimal peel in a right atrial to pulmonary artery conduit had dissected away from the dacron, possibly causing acute occlusion. Agarwall *et al.* (16) have outlined potential sites of conduit stenosis, including extrinsic compression by the sternum, obstructive proximal anastomosis, valvular stenosis, fibrous neointimal peel and conduits which are not of adequate size. They also reported that thickening of the neointima may occur primarily along the interface between the neointima and conduit by repeated minor dissection followed by thrombus organization.

Bisset and co-workers (6) documented a 6 year failure rate of 30% in patients having conduit repair of tetralogy of Fallot. In our 13 patients with Hancock valved conduits who have been followed up for more than 36 months, severe valve dysfunction was noted in 6 patients, mild to moderate valve degeneration in 3, and only 2 were noted to have good valve function.

Patients receiving mechanical valves must commonly be treated with the anticoagulant warfarin, the efforts of which are difficult to control, especially in small infants and children. In our series one patient with a Björk-Shiley valved conduit who refused the anticoagulation therapy was noted to have a fixed valve. Pass *et al.* (17) reported no thromboembolic complication in 18 patients in the pediatric and adolescent age groups who received a St. Jude Medical prosthesis and who were not maintained on anticoagulants. However, we have recently experienced a thromboembolic complication in an infant who had a St. Jude Medical prosthesis inserted in the pulmonary valve position for absent pulmonary valve syndrome.

Aortic homografts have largely been abandoned as extracardiac conduits because of limited availability and reports of homograft leaflet calcification and development of a pressure gradient (5, 9-11). However, fresh homografts sterilized in antibiotic solution have been shown to have a much lower incidence of calcific obstruction than homografts prepared by physical-chemical means (18-20). Saravelli *et al.* (18) observed that in 37 of 40 patients (92%) with congenital heart disease, calcification developed in aortic homografts preserved by various techniques used for right ventricular outflow reconstruction. However, only one patient needed reoperation for calcified obstructive leaflet, and in all of the remaining patients the valve leaflets were free from calcification and looked freely mobile. Most recently, Kay *et al.* (21) have reported postoperative catheterization data on 16 patients with homograft conduits in whom the mean follow-up period was 6 years. The mean transconduit gradient was 24 ± 15 mmHg and only 3 patients had a gradient greater than 50 mmHg. However, the site of obstruction in these 3 patients was in the dacron tube and not at the level of the valve. Although the

antibiotic-sterilized aortic homograft is currently the best alternative, it is not available in Japan.

In 1983, Stewart *et al.* (22) reported late clinical results and late cardiac catheterization findings in 15 long-term survivors of 6 to 9 years after insertion of a Hancock conduit. Cardiac catheterization demonstrated a gradient of 50 mmHg or greater across the conduit in 2 of 16 patients 1 year after operation and in 7 of the 15 patients 6 years after operation. Nevertheless, all patients were essentially asymptomatic. A number of studies have emphasized the importance of serial catheterization in patients with right ventricular-to-pulmonary arterial conduits because of the lack of symptoms, despite moderate obstruction (7, 14).

Repeated cardiac catheterization, however, has many problems with its attendant risks, costs and complications. Thus, a simple, reliable, non-invasive method to determine right ventricular hypertension would be of considerable practical value. Recent development of two-dimensional echoardiography predicted right ventricular hypertension (23-25).

Abnormalities of interventricular septal motion and configuration have been described in patients with right ventricular pressure overload (24, 25). A normal left ventricle is nearly circular, but when right ventricular systolic hypertension is present, the interventricular septum shifts toward the left ventricle and becomes flattened. Recently, we (25) reported a good correlation between the right ventricular-over-left ventricular systolic pressure ratio at end-systole and the left ventricular deformity index obtained by two-dimensional echocardiography. Among the present 17 long-term follow-up patients, 6 patients showed marked left ventricular deformity, and in all of these patients the right ventricular-over-left ventricular systolic pressure ratios were over 0.77.

Two-dimensional echocardiography is very useful for detecting degeneration of the valve, neointimal peel within dacron grafts, and the site of stenosis. To date, we have replaced the conduit in 3 out of 17 long-term survivors. The general appearance of these excised conduits was very similar to that of the two dimensional echocardiograms. Furthermore, the recent application of continuous wave Doppler echocardiography enabled us to determine the transvalvular pressure gradients noninvasively (26-28). When used in conjunction with clinical evaluation and continuous-wave echocardiography, two-dimensional echocardiography should aid in deciding which children with extracardiac valved conduits require a long-term follow-up and cardiac catheterization.

In summary, although the long-term performance of the porcine valved woven dacron conduit has proven to be unsatisfactory, it continues to be necessary in certain forms of complex congenital heart disease. Should replacement of an obstructed extracardiac valved conduit become necessary long after the initial operation, conduits containing mechanical valves should be used if the patient is old enough for easy management of anticoagulation therapy. Surgery is advisable in order to prevent the development of advanced right ventricular hypertrophy and deterioration. Careful and periodic follow-up of such patients is imperative. Two-dimensional echocardiography is a simple, non-invasive and very accurate method for detecting conduit stenosis and valve failure. It should be performed over a prolonged post-operative period, as obstruction of valved conduits seems to be progressive.

References

1. Ross DN and Somerville J: Correction of pulmo-

nary atresia with a homograft aortic valve. Lancet (1966) **2**, 1446-1447.
2. McGoon DC, Rastelli GC and Ongley PA: An operation for the correction of truncus arteriosus. J Am Med Assoc (1968) **205**, 69-73.
3. Rastelli GC, McGoon DC and Wallace RB: Anatomic correction of transposition of the great arteries with ventricular septal defect and subpulmonary stenosis. J Thorac Cardiovasc Surg (1969) **58**, 545-562.
4. Bowman FO Jr, Hancock WD and Malm JR: A valve-containing dacron prosthesis: Its use in restoring pulmonary artery-right ventricular continuity. Arch Surg (1973) **107**, 724-728.
5. McGoon DC, Danielson GK, Puga FJ, Ritter DG, Mair DD and Ilstrup DM: Late results after extracardiac conduit repair for congenital cardiac defects. Am J Cardiol (1982) **49**, 1741-1749.
6. Bisset GS Ⅲ, Schwartz DC, Benzing G Ⅲ, Helmsworth J, Schreiber JT and Kaplan S: Late results of reconstruction of right ventricular outflow tract with porcine xenografts in children. Ann Thorac Surg (1981) **31**, 437-443.
7. Jonas RA, Freed MD, Mayer JE Jr and Castaneda AR: Long-term follow-up of patients with synthetic right heart conduits. Circulation (1985) **72** (Suppl. 11) 77-83.
8. Hick HA Jr, Schieken RM, Laver RM and Doty DB: Conduit repair for complex congenital heart disease: Late follow-up. J Thorac Cardiovasc Surg (1978) **75**, 806-814.
9. Moodie DS, Mair DD, Fulton RE, Wallace RB, Danielson GK and McGoon DC: Aortic homograft obstruction. J Thorac Cardiovasc Surg (1976) **72**, 553-561.
10. Bailey WW, Kirklin JW, Bargeron LH, Pacifico AD and Kouchoukos NT: Late results with synthetic valved external conduits from venous ventricle to pulmonary arteries. Circulation (1976) **56** (Suppl. 11) 73-79.
11. Norwood WI, Freed MD, Rocchim AP, Bernhard WF and Castaneda AR: Experience with valved conduits for repair of congenital cardiac lesions. Ann Thorac Surg (1977) **24**, 223-232.
12. Agarwal KC, Edwards WD, Feldt RH, Danielson GK, Puga FJ and McGoon DC: Pathogenesis of non-obstructive fibrous peels in right-sided porcine-valved extracardiac conduits. J Thorac Cardiovasc Surg (1982) **83**, 584-589.
13. Kirklin JW and Bailey WW: Valved external conduits to pulmonary arteries. Ann Thorac Surg (1977) **24**, 202-205.
14. Downing TP, Danielson GK, Schaff HV, Puga FJ, Edwards WD and Driscoll DJ: Replacement of obstructed right ventricular-pulmonary arterial valved conduits with non-valved conduits in children. Circulation (1985) **72** (Suppl 11) 84-87.
15. Ben-Shachar CT, Nicoloff DM and Edwards J: Separation of neointima from dacron graft causing obstruction. J Thorac Cardiovasc Surg (1981) **82**, 268-271.
16. Agarwal KC, Edwards WD, Feldt RH, Danielson GK, Pugar FJ and McGoon DC: Clinicopathological correlates of obstructed right-sided porcine-valved extracardiac conduits. J Thorac Cardiovasc Surg (1981) **81**, 591-601.
17. Pass HI, Sade RM, Crawford FA, Donahoo J and Gardner T: St. Jude prosthesis without anticoagulation in children. Am J Cardiol (1982) **49**, 1035.
18. Saravelli OA, Somerville J and Jefferson KG: Calcification of aortic homografts used for reconstruction of the right ventricular outflow tract. J Thorac Cardiovasc Surg (1980) **80**, 909-920.
19. Fontan F, Choussant A, Deville C, Doutremepinch C, Coupilland J and Vosa C: Aortic valve homografts in the surgical treatment of complex cardiac malformations. J Thorac Cardiovasc Surg (1984) **87**, 649-657.
20. DiCarlo D, de Leval MR and Stark J: "Fresh" antibiotic sterilized aortic homografts in extracardiac valved conduits. Long-term results. Thorac Cardiovasc Surg (1984) **32**, 10.
21. Kay PH and Ross DN: Fifteen years, experience with the aortic homograft: The conduit of choice for right ventricular outflow tract reconstruction. Ann Thorac Surg (1985) **40**, 360-364.
22. Stewart S, Manning J, Alexson C and Harris P: The Hancock external valved conduit. J Thorac Cardiovasc Surg (1983) **86**, 562-569.
23. Tanaka H, Tei C, Nakas S, Tahara M, Sakurai S, Kashima T and Manehisa T: Diastolic bulging of the interventricular septum toward the left ventricle. Circulation (1980) **62**, 558-562.
24. Ryan T, Petrovic O, Dillon JC, Feigenbaum H, Conley MJ and Armstrong WF: An echocardiographic index for septation of right ventricular volume and pressure overload. J Am Coll Cardiol (1985) **5**, 918-927.
25. Sano S, Yokoto Y, Setsuie N, Okamoto F, Kiyoto Y, Fujiwara K and Makino S: Left ventricular deformity as a predictor of right ventriular systolic hypertension in children: A cross-sectional echocardiographic study. J Jpn Assoc Thorac Surg (1985) **34**, 818-822.
26. Hatle L and Angelsen B: Doppler Ultrasound in Cardiology. Physical Principles and Clinical Applications, Lea & Febiger, Philadelphia (1982) p 61.
27. Lima CO, Sahn DJ, Valdo-Cruz LM, Goldberg SJ, Barron JV, Allen HD and Grenadier E: Non-invasive prediction of transvalvular pressure gradient in patients with pulmonary stenosis by quantitative two-dimensional echocardiographic Doppler studies. Circulation (1983) **67**, 866-871.
28. Fyfe DA, Currie PJ, Seward JB, Tajik AJ, Reeder GS, Mair DD and Hagler DJ: Continuous-wave

Doppler determination of the pressure gradient across pulmonary artery bands: Hemodynamic correlation in 20 patients. Mayo Clin Proc (1984) **59**, 744-750.

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