Right Ventricular Function after Extracardiac Conduit Repair for Tetralogy of Fallot

A Comparison among Surgical Approaches

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SUMMARY

Right ventricular volume measurements and hemodynamic studies were performed in 20 patients after total correction of tetralogy of Fallot. There were 6 patients with an extracardiac conduit and Hancock xenograft (G-1), 8 with an outflow tract patch (G-2) and 6 without or with a minimal right ventriculotomy and repair of pulmonary valve (G-3). The age at the time of operation was over 3 years in each patient and averaged 5 ± 2 (mean $\pm$ SD) years. Right ventricular systolic pressure averaged 81 ± 22 , 55 ± 22 and 58 ± 30 mmHg in G-1, G-2 and G-3, respectively. Right ventriculography showed no contraction of the right ventricular free wall at the anastomosis to the conduit and poor contraction around the anastomosis in G-1. The right ventricular end-diastolic volume index (RVEDVI) was 114 ± 31 , 155 ± 57 and 115 ± 28 ml/m² in G-1, G-2 and G-3, respectively. The right ventricular ejection fraction (RVEF) was 0.42 ± 0.11 in G-1, 0.53 ± 0.04 in G-2 ($p < 0.05$, vs G-1) and 0.57 ± 0.04 in G-3 ($p < 0.02$, vs G-1). Pulmonary regurgitation was evident in 17 patients, and RVEDVI correlated well with degrees of pulmonary incompetence.

Fourteen patients in G-2 and G-3 were divided into G-A and G-B to evaluate right ventricular function with or without pressure overloading of the right ventricle. G-A consisted of 7 patients with a right ventricular systolic pressure of more than 50 mmHg (74 ± 26) and G-B of 7 patients with a value less than 50 mmHg (39 ± 4). There was no difference in RVEDVI and RVEF between G-A and G-B. RVEF was significantly lower in G-1 than G-A ($p < 0.02$)

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and G-B ($p < 0.05$).

These results suggested that an extracardiac conduit with Hancock xenograft reduced the contraction of the right ventricular free wall and induced a depressed right ventricular pump function in patients with a high right ventricular pressure.

Additional Indexing Words:

Tetralogy of Fallot Conduit operation Right ventricular volume Right ventricular ejection fraction Pulmonary insufficiency

RIGHT ventricular function studies in postoperative patients with tetralogy of Fallot have revealed an abnormal right ventricular ejection fraction both at rest¹⁾ and with exercise.²⁾ These data were limited to patients treated with a right ventricular outflow tract patch or large right ventriculotomy. Operative mortality is reported to be significantly higher in conduit operations than in conventional operations without a conduit in tetralogy of Fallot, even when the postoperative right to left ventricular pressure ratio is similar in these 2 groups.³⁾ Cardiac performance after repair was reported to be worse in patients with a valved extracardiac conduit than in those with a transannular patch.⁴⁾ Late postoperative studies have reported abnormal cardiac performance at rest and during exercise in patients with either a conduit operation^{5),6)} or repair by conventional surgical methods. However, there have been no reports concerning right ventricular function with an extracardiac conduit in postoperative patients with tetralogy of Fallot. We attempted to assess right ventricular volume characteristics and the ejection fraction after correction with an extracardiac conduit and to compare these results with findings in postoperative patients without a conduit.

PATIENTS AND METHODS

The postoperative study included 20 patients with tetralogy of Fallot after total correction. The age at the time of operation ranged from 3 to 12 (5 ± 2) years (mean $\pm$ standard deviation). The age at the time of this study ranged from 4 to 14 (7 ± 3) years. These patients were divided into 3 groups according to the surgical methods applied. Group 1 included 6 patients with a Dacron conduit and a porcine aortic valve (Hancock xenograft) to establish continuity between the right ventricle and the pulmonary artery. Group 2 included 8 patients with reconstruction of the right ventricular outflow tract with a patch and group 3 consisted of 6 patients in whom the right ventricular outflow tract was reconstructed without or with minimal right ventriculotomy

and repair of the pulmonary valve.⁷⁾ The 14 patients in groups 2 and 3 were also divided into groups A and B according to right ventricular pressure, to evaluate right ventricular function with high pressure and to compare these results with data from patients with a conduit. Group A consisted of 7 patients with a postoperative right ventricular systolic pressure of more than 50 (74 ± 26) mmHg and group B consisted of 7 patients with a pressure less than 50 (39 ± 4) mmHg. In group 1, a Hancock porcine xenograft with a diameter of 18 mm was used in 4 patients and one with a 16 mm diameter was applied in 2 patients. The Hancock xenograft was anastomosed to the outflow tract of the right ventricle. All patients were asymptomatic postoperatively.

The age at the time of operation averaged 5 ± 2 , 5 ± 3 and 5 ± 2 years in groups 1, 2 and 3, respectively. All the patients had corrective surgery at age greater than 3 years. The age at the time of this study averaged 8 ± 2 , 8 ± 3 and 6 ± 2 years in groups 1, 2 and 3, respectively.

Complete right and left cardiac catheterization was performed in all patients. For premedication, meperidine (1.0 mg/Kg) was given intramuscularly at least 30 min before the cineangiocardiology. Patients under 8 years of age were sedated with a modified neuroleptic combination of diazepam (0.3 mg/Kg) as required. Right and left heart pressure measurements were performed prior to cineangiocardiology using a National Institute of Health catheter with zero reference to the mid chest.

The right ventricular volumes were calculated from biplane cineangiocardiology with 80 exposures / second after the injection of contrast medium into the right ventricle. Ectopic and postectopic beats were excluded from the analysis. The area-length method was used to estimate the right ventricular volume. The regression equation of $V_t = 0.76V_c - 0.2$ (ml)⁸⁾ was used for volume estimation of the right ventricle, where V_t and V_c are the true and calculated volumes, respectively. An extracardiac valved conduit did not change shape and capacity during the cardiac cycle (Fig. 1). The intraconduit volume remained unaltered during systole and diastole. The intraconduit cavity is a hemodynamic dead space, and the ratio of the cavity volume to the right ventricular volume was not identical for all patients in group 1. Therefore, the intraconduit volume between the right ventricle and the Hancock porcine aortic valve was not included in the volume determination and functional analysis of the right ventricle in 6 patients after conduit operation.

There was no patient with a tricuspid regurgitation. Contrast medium was injected into the pulmonary artery and the degree of pulmonary regurgitation was graded according to a modified version of Cohn's classification for aortic regurgitation. Pulmonary regurgitation was classified into 4 grades: grade 1 (mild), grade 2 (moderate), grade 3 (moderately severe) and grade 4

(severe). Contrast medium was also injected in the left ventricle for visualization of a residual left-to-right shunt, and no patient had a residual shunt.

Comparison of data from 2 groups was done by Student's t-test and statistical significance was inferred if the probability of the event occurring by chance was less than 0.05.

RESULTS

Hemodynamic data:

The right ventricular systolic pressure ranged from 35 to 117 (64 ± 26) mmHg, and right to left ventricular systolic pressure ratio (RV/LV) ranged from 0.32 to 1.15 (0.60 ± 0.24). The right ventricular systolic pressure and RV/LV were significantly higher in group 1 than in group 2 ($p < 0.05$). Although they were apparently higher in group 1 than in group 3, differences were not significant. The pulmonary arterial systolic pressure was more than 30 mmHg in 3 of 6 patients in group 1, 6 of 8 in group 2 and 2 of 6 in group 3. The pulmonary arterial mean pressure was significantly higher in group 1 than in group 3 ($p < 0.05$). It was apparently higher in group 1 than in group 2, but the difference was not significant (Table I).

Right ventriculographic findings:

Right ventriculography showed no contraction of the right ventricular free wall at the anastomosis to the conduit and hypokinetic contraction around the anastomosis to the conduit. However, contraction of the sinus portion of the right ventricle was good in group 1 patients with a low right ventricular systolic pressure (Fig. 1). The contraction of the sinus portion of the right ventricle was poor in group 1 patients with a high right ventricular systolic pressure (Fig. 2). The contraction of the right ventricular free wall was good in group 3 patients who underwent reconstruction of the right ventricular outflow tract without a conduit or a patch, and contraction was also good in group 2 patients.

Right ventricular volume and ejection fraction:

The right ventricular end-diastolic volume index ranged from 81 to 268 (131 ± 48) ml/m², which corresponds to 102–406 (188 ± 75) percent of the normal right ventricular volume. Although this value was apparently greater in group 2 than in groups 1 and 3, the difference was not significant. The right ventricular ejection fraction ranged from 0.28 to 0.60 (0.51 ± 0.09), and was lower in group 1 than in group 2 ($p < 0.05$) and in group 3 ($p < 0.02$). In 17 patients in whom pulmonary regurgitation was evident, 14 patients had grade

Table I. Hemodynamic and Ventricular Volume Data

Group 1: Conduit operation

No.	Age at operation (y)	Age at re-study (y)	RVP	RV/LV	PAP	RVEDVI (% of normal)	RVEF	Grade of PR
1	3	5	64/ 4	0.70	29/ 6(13)	129(187)	0.33	2
2	6	7	110/ 7	0.97	40/16(27)	84(121)	0.37	—
3	7	9	74/ 8	0.70	38/18(25)	132(189)	0.48	2
4	3	9	104/10	1.02	48/16(28)	160(213)	0.28	2
5	6	9	56/ 6	0.56	30/ 6(16)	98(126)	0.51	—
6	6	7	76/ 7	0.59	27/ 8(14)	81(110)	0.57	—
	5±2	8±2	81±22/ 7±2	0.76 ±0.19	(21±7)	114±31 (158±44)	0.42 ±0.11	1.0 ±1.0

Group 2: RV reconstruction with a patch

7	3	10	72/ 5	0.63	44/ 2(16)	115(153)	0.58	1
8	5	14	101/13	0.87	36/ 6(14)	87(102)	0.54	1
9	3	4	52/ 9	0.50	28/ 8(15)	136(227)	0.60	2
10	3	6	43/ 8	0.42	40/ 2(16)	268(406)	0.51	4
11	5	8	38/ 2	0.37	34/ 5(17)	220(316)	0.51	3
12	12	13	66/ 9	0.49	40/ 4(17)	156(174)	0.49	2
13	3	6	35/ 9	0.47	32/ 5(16)	147(216)	0.47	2
14	4	6	35/ 9	0.33	22/ 7(13)	111(167)	0.56	2
	5±3	8±3	55±22*/ 8±3	0.51* ±0.16	(16±1)	155±57 (220±98)	0.53** ±0.04	2.1 ±1.0

Group 3: With minimal RV-tomy and PV repair

15	3	5	117/ 9	1.15	16/ 7(12)	94(149)	0.55	1
16	9	10	60/10	0.56	34/ 3(14)	111(139)	0.59	1
17	4	5	50/ 7	0.50	10/ 3(5)	126(196)	0.57	2
18	3	4	36/ 4	0.32	24/ 4(11)	171(276)	0.50	3
19	4	5	40/ 5	0.39	20/ 5(12)	85(128)	0.60	1
20	5	6	44/10	0.37	39/ 8(19)	104(155)	0.60	1
	5±2	6±2	58±30/ 8±2	0.55 ±0.28	(12±5)*	115±28 (111±30)	0.57** ±0.04	1.5 ±0.8

* $p < 0.05$ vs Group 1, ** $p < 0.02$ vs Group 1. y=years of age; RVP=right ventricular pressure (mmHg); RV/LV=right to left ventricular systolic pressure ratio; PAP=pulmonary arterial pressure (mmHg); RVEDVI=right ventricular end-diastolic volume index (ml/m²); RVEF=right ventricular ejection fraction; PR=pulmonary regurgitation; RV=right ventricle; PV=pulmonary valve.

1 or 2 pulmonary regurgitation, and 3 had grade 3 or 4. The right ventricular end-diastolic volume index increased with the severity of pulmonary regurgitation (Fig. 3).

Fig. 1. Lateral views of right ventriculograms in patients with a conduit showing low systolic pressure in the right ventricle. Left: end-diastolic phase, right: end-systolic phase.

Fig. 2. Lateral views of right ventriculograms in patients with a conduit showing high systolic pressure in the right ventricle. Left: end-diastolic phase, right: end-systolic phase.

The effects of a conduit on hemodynamic and right ventricular function in patients with a high right ventricular pressure; comparison of group 1 (conduit) and group A (no conduit):

There were no significant differences in the right ventricular systolic pressure (84 ± 22 mmHg in group 1; 74 ± 26 mmHg in group A), the right ventricular end-diastolic pressure (7 ± 2 vs 9 ± 2 mmHg) or the right ventricular end-diastolic volume index (114 ± 31 vs 118 ± 24 ml/m²) between groups 1 and

Fig. 3. Relationship between the right ventricular end-diastolic volume index (RVEDVI) and grade of pulmonary regurgitation.

A (Fig. 4). Three of 6 group 1 patients and 3 of 7 group A patients had a pulmonary regurgitation more severe than grade 2. The right ventricular ejection fraction was 0.42 ± 0.11 in group 1 and 0.56 ± 0.04 in group A ($p < 0.02$) (Fig. 5).

Hemodynamic and right ventricular function in patients without a conduit:

The right ventricular systolic pressure averaged 74 ± 26 and 39 ± 4 mmHg in groups A and B, respectively ($p < 0.05$). There were no significant differences in the right ventricular end-diastolic volume index and right ventricular ejection fraction between groups A and B (Figs. 4 and 5).

DISCUSSION

We have used an extracardiac conduit for patients who had pulmonary atresia when they were more than 3 years of age. Pathohistological studies of the right ventricular muscle from patients with tetralogy of Fallot has re-

Fig. 4. Right ventricular end-diastolic volume index (RVEDVI) in groups 1, A and B. There are no significant differences between groups.

vealed that degenerative changes of the right ventricular muscle are related to the patients' age.^{9),10)} Therefore, we selected the patients who underwent correction at more than 3 years of age, and there were no differences in ages at the time of correction and the time of study among these 3 groups. Graham et al¹⁾ reported that there were no differences in the right ventricular ejection fraction in patients with low arterial oxygen saturation (79%) and those with a slightly higher oxygen saturation (87%). Since patients in group 1 had a patent ductus arteriosus or large aortopulmonary collaterals, the preoperative oxygen saturation in group 1 averaged $82 \pm 2\%$, although they were associated with pulmonary atresia. Therefore, we considered that these groups were comparable, although preoperative ventricular function studies were not performed in all patients.

The extracardiac conduits did not change their shapes or volumes during the cardiac cycle. Their volumes varied among patients, and the ratio of the volume of the conduit to the volume of the right ventricle was not identical in each patient. Since the conduit volume is a physiologic dead space and a longer conduit results in a decrease of the right ventricular ejection fraction,

Fig. 5. Right ventricular ejection fraction (RVEF) in groups 1, A and B. The RVEF was significantly lower in group 1 than in group A ($p < 0.02$) and in group B ($p < 0.05$).

it is inappropriate to include the conduit volume in the evaluation of right ventricular performance. Therefore, we excluded the conduit volume from determination of the right ventricular end-diastolic and end-systolic volume.

Right ventriculography showed that an extracardiac conduit reduced the contraction of the right ventricular free wall and resulted in a diminution of the right ventricular pump function. Good contraction of the sinus portion of the right ventricle seemed to lead to reasonable right ventricular pump function in patients with a conduit and a low right ventricular systolic pressure. This contraction of the sinus portion of the right ventricle may be a compensatory mechanism. It was also evident in patients with a patch reconstruction of the right ventricular outflow tract and high systolic pressure of the right ventricle. The contraction of the right ventricular free wall was better in patients with minimal right ventriculotomy, even when the right ventricular systolic pressure was as high as that in patients with a conduit. These findings suggest that right ventricular function should be well preserved under stress in patients with minimal right ventriculotomy.⁷⁾

Right ventricular contraction appeared hypokinetic and the ejection fraction of the right ventricle was reduced in patients with a conduit and a high right ventricular systolic pressure. The pressure overload on the right

ventricle reportedly did not always reduce the right ventricular pump function in congenital heart disease,¹¹⁾ in other postoperative tetralogy patients¹⁾ and in patients of groups 2 and 3 in our study. Although our study included a small number of patients with a conduit, the right ventricular pump function was significantly reduced in patients with a conduit, as compared to patients without a conduit who had the same pressure overload on the right ventricle. This reduced ejection fraction of the right ventricle in patients with a conduit seemed to be related to the partial lack of contraction of the right ventricular free wall. In the present study, the right ventricular ejection fraction was inversely correlated with the ratio of right to left ventricular systolic pressure in patients with a conduit. These findings suggest that a rigid conduit may prevent the right ventricular free wall from good contraction in patients with a high right ventricular pressure. Thus, it is important to decrease the right ventricular systolic pressure in order to obtain adequate right ventricular function.

Pulmonary arteriography was useful to rule out pulmonary incompetence. The right ventricular end-diastolic volume index correlated well with the grade of pulmonary regurgitation. Pulmonary regurgitation is probably a major factor associated with the increase in right ventricular volume. A high grade of pulmonary regurgitation was more frequently seen in patients reconstructed with a patch in the right ventricular outflow tract than in patients with a minimal right ventriculotomy. This suggests that pulmonary valve repair surgery prevents pulmonary regurgitation 1 year after correction.

This study demonstrated that an extracardiac valved conduit in patients with a high right ventricular systolic pressure depressed the right ventricular ejection fraction. Causes of the increase in right ventricular systolic pressure were high pulmonary arterial pressure and stenosis at the sites of anastomosis and/or the implanted valve. The conduit with a Hancock xenograft between the right ventricle and the pulmonary artery leads to degenerative changes and results in stenosis of the conduit and dysfunction of the valve late after implantation, necessitating reoperation.^{12),13)} Our study did not include patients with a homograft which was pliable and quite different from a Dacron tube. Right ventricular volume studies in patients with a homograft may show different results from those in group 1, because a homograft with semilunar valve is not likely to be stenotic.¹⁴⁾

These data suggest that an extracardiac valved conduit should be used only for patients with a discontinuity between the right ventricle and pulmonary arteries, and should not be used for those with anatomical continuity between them. If an extracardiac conduit is necessary for repair, a homograft would be advisable.

REFERENCES

1. Graham TP, Cordell D, Atwood GF, Boucek RJ Jr, Boerth RC, Bender HW, Nelson JH, Vaughn WK: Right ventricular volume characteristics before and after palliative and reparative operation in tetralogy of Fallot. *Circulation* **54**: 417, 1976
2. Reduto LA, Berger HJ, Johnstone DE, Hellenbrand W, Wakers FJT, Whittemore R, Cohen LS, Gottschalk A, Zaret BL: Radionuclide assessment of right and left ventricular exercise reserve after total correction of tetralogy of Fallot. *Am J Cardiol* **45**: 1013, 1980
3. Kirklin JW, Blackstone EH, Kirklin JK, Pacifico AD, Aramendi J, Barger LM: Surgical results and protocols in the spectrum of tetralogy of Fallot. *Ann Surg* **198**: 251, 1983
4. Alfieri O, Blackstone EH, Kirklin JW, Pacifico AD, Barger LM Jr: Surgical treatment of tetralogy of Fallot with pulmonary atresia. *J Thorac Cardiovasc Surg* **76**: 321, 1978
5. Rocchini AP: Hemodynamic abnormalities in responses to supine exercise in patients after operative correction of tetrad of Fallot after early childhood. *Am J Cardiol* **48**: 325, 1981
6. Bailey WW, Kirklin JW, Barger LM Jr, Pacifico AD, Kouchoukos NT: Late results with synthetic valved external conduits from venous ventricle to pulmonary arteries. *Circulation* **56** (suppl 2): 73, 1977
7. Kawashima Y, Kitamura S, Nakano S, Yagihara T: Corrective surgery for tetralogy of Fallot without or with minimal right ventriculotomy and with repair of the pulmonary valve. *Circulation* **64** (suppl 2): 147, 1981
8. Shimazaki Y, Kawashima Y, Mori T, Beppu S, Yokota K: Angiographic volume estimation of right ventricle. Re-evaluation of the previous methods. *Chest* **77**: 390, 1980
9. Jones M, Ferrans VJ, Morrow AG, Roberts WC: Ultrastructure of crista supraventricularis muscle in patients with congenital heart diseases associated with right ventricular outflow tract obstruction. *Circulation* **51**: 39, 1975
10. Kato M: Right ventricular hypertrophy in tetralogy of Fallot: pathohistologic study. *Nippon Kyobu Gekagakkai Zasshi* **24**: 1435, 1976
11. Nakazawa M, Marks RA, Isabel-Jones J, Jarmakani JM: Right and left ventricular volume characteristics in children with pulmonary stenosis and intact ventricular septum. *Circulation* **53**: 884, 1976
12. Bisset GS III, Schwartz DC, Benzing G III, Helmsworth J, Schreiber JT, Kaplan S: Late results of reconstruction of the right ventricular outflow tract with porcine xenografts in children. *Ann Thorac Surg* **31**: 437, 1980
13. Agarwal KC, Edwards WD, Feldt RH, Danielson GK, Puga FJ, McGoon DC: Clinicopathological correlates of obstructed right-sided porcine-valved extracardiac conduits. *J Thorac Cardiovasc Surg* **81**: 591, 1981
14. Kawashima Y, Naito Y, Kitamura S, Nakano S, Miyamoto T, Fujita T, Fujino M, Kozuka T, Manabe H: Use of large homograft artery with semilunar valve for correction of tetralogy of Fallot. *J Thorac Cardiovasc Surg* **67**: 685, 1974