FACTORS AFFECTING BIVENTRICULAR FUNCTION FOLLOWING SURGICAL REPAIR OF TETRALOGY OF FALLOT

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Right and left ventricular functions were assessed in children following surgical repair of tetralogy of Fallot. The results were analyzed with regard to the relative contribution of preoperative, perioperative and postoperative factors to postoperative functional abnormalities. Pulmonary regurgitation of our Grade 3 or more depressed right and left ventricular ejection fractions and enlarged right ventricular end-diastolic volume. Right and left ventricular ejection fractions in patients with residual right ventricular outflow pressure gradients over 30 mmHg were significantly lower than those in patients with pressure gradients of 30 mmHg or less. The majority of those pressure gradients were at the pulmonary annulus or central pulmonary artery. Right and left ventricular ejection fractions were significantly lower in patients with a preoperative aortic oxygen saturation of less than 80% than in patients with one of 80% or more. The 3 variables of pulmonary regurgitation, residual pulmonary stenosis, preoperative aortic oxygen saturation were statistically independent. Left ventricular ejection fraction and end-diastolic volume correlated with the right ventricular ejection fraction and end-diastolic volume, respectively ($r = 0.63$, $r = 0.68$). These results show that severe pulmonary regurgitation, significant annular or central pulmonary stenosis and preoperative hypoxia are major contributing factors to right ventricular dysfunction after surgical repair of tetralogy of Fallot. The postoperative left ventricular dysfunction can be largely attributed to dysfunction of the right ventricle.

TOTAL repair of tetralogy of Fallot (TOF) can now be accomplished with a low operative mortality and excellent long-term symptomatic benefits. However, cardiovascular performance at rest¹⁻⁶ or during exercise⁷⁻¹² is often below normal. There may be multiple associated factors, including severity of the

preoperative anatomy and hypoxia, the surgical procedure itself, residual right ventricular (RV) outflow tract obstruction, pulmonary regurgitation (PR), and a noncontractile patch. The relative contribution of these factors to the postoperative functional abnormalities remains uncertain. The purpose of the present study was to determine:

- 1) The influence of preoperative hemodynamics and perioperative factors on postoperative right and left ventricular (LV) functions.
- 2) The influence of RV outflow tract recon-

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TABLE I METHODS USED FOR RELIEF OF RIGHT VENTRICULAR OUTFLOW TRACT OBSTRUCTION

	Method	Patients
Group 1	Transannular patch (+) CSAI > 2.5 cm ² /m ²	9 (18%)
Group 2	Transannular patch (+) CSAI ≤ 2.5 cm ² /m ²	8 (16%)
Group 3	Valvotomy (+) outflow patch (–) patch on RV only	25 (50%) 21 4
Group 4	Valvotomy (–) or PVR Infundibulectomy only PVR	8 (16%) 7 1
Total		50 (100%)

CSAI = cross-sectional area index ie.; the degree of relief of right ventricular outflow tract obstruction; RV = right ventricle; PVR = pulmonary valve replacement

struction on RV function.

- 3) The influence of RV function on LV function.

MATERIALS

TOF in this study was defined as a combination of a large ventricular septal defect (VSD) with an "overriding" aorta, allowing equalization of right and left ventricular pressures and RV outflow tract obstruction, causing a bidirectional interventricular shunt with a net right-to-left shunt. The study population consisted of 50 Japanese children undergoing surgical repair for TOF and with no significant residual VSD. Eight had associated cardiac anomalies: patent ductus arteriosus in 2 and atrial septal defect in 6.

In 38 of these patients, preoperative cardiac catheterization data were available. Twenty-five patients underwent cardiac catheterization 1 to 2 months after surgery (early postoperative study), and 43 patients in the late postoperative periods (0.8 to 12 (4.9 ± 3.5) years after surgery) (late postoperative study). Eighteen underwent cardiac catheterization in both the periods with a time lapse of 5.2 ± 1.8 years. Although all the patients were initially maintained on digitalis in the early postoperative period, no patient was symptomatic nor on digitalis at the time of the

TABLE II THE MEASURED AND ANALYZED VARIABLES WITH REGARD TO POSTOPERATIVE CARDIAC FUNCTION

1. Preoperative variable
1. Aortic oxygen saturation (SaO ₂)
2. Pulmonary artery index (PA index)
3. Left ventricular end-diastolic volume (LVEDV)
4. Right ventricular end-diastolic volume (RVEDV)
2. Perioperative variable
Cardiopulmonary bypass time (CBT)
3. Variable related to the method of right ventricular outflow tract reconstruction
1. Residual pulmonary stenosis (PS)
2. Pulmonary regurgitation (PR)

late follow-up study.

Ages at the time of operation ranged from 0.5 to 8.8 (2.6 ± 1.4) years. Forty-five (90%) were 3 years of age or younger at the time of surgery. Repair was performed utilizing total cardiopulmonary bypass. Intermittent aortic cross-clamping was used for 24 patients. For the last 26 patients, we used cold blood cardioplegia combined with a topical application of ice-slush. Various methods used to relieve the RV outflow tract obstruction are summarized in Table I. The patients were grouped into 4 according to the methods and degree of relief of the RV outflow tract obstruction. Infundibular muscle resection was carried out to various degrees in all patients. The degree of relief of the RV outflow tract obstruction was expressed as the cross-sectional area index (CSAI) of the pulmonary annulus after enlargement. The CSAI was obtained using the following equation; CSAI = $\pi(d/2)^2/BSA$ (in cm²/m²), where d is the diameter of the pulmonary annulus after enlargement at operation and BSA is the body surface area (m²). On the basis of our early experiences,^{13,14} the RV outflow tract was enlarged so as to obtain a CSAI greater than 1.75 cm²/m². A transannular patch (TAP) with a monocusp was used whenever the pulmonary annulus was judged at operation to be too small to obtain a CSAI greater than 1.75 cm²/m², by muscular resection and pulmonary valvotomy alone.

METHODS

Cardiac catheterization was performed under

light sedation using pethidine (2 mg/kg) and promethazine (1 mg/kg) given 30 min before the procedure. Left and right heart pressures were obtained using a Millar micro-tip transducer catheter. Oxygen saturation in the blood was determined using reflectance oxymetry. The X-ray equipment consisted of a Bipane Gigantos RS 100G, Sirecon-2-duplex 25/15 high resolution (Siemens) and a Arritechno 35 cinecamera (R-150) (Arnold-Richter).

The variables measured and analyzed in relation to the postoperative cardiac function are shown in Table II. Pulmonary artery index (PA index) means the sum of the maximum diameters of the left and right pulmonary arteries just before take-off of the first branch, normalized to the diameter of the descending aorta at the level of the diaphragm.¹⁵ These diameters were

measured from anterior-posterior views of the cineangiocardigrams. Cardiac volumes were obtained from biplane cineangiocardigrams (70 frames/sec) filmed after injecting 1–1.5 ml/kg of body weight of Conraxis-H into the RV, LV, main pulmonary artery or left atrium. Ectopic and postectopic beats were excluded from analysis. LV volumes were calculated, using the area-length method.¹⁶ RV volumes were calculated according to the Simpson's rule method.¹⁷ These volumes were expressed as a percent of the normal predicted values, using the body surface area.¹⁸ Residual pulmonary stenosis (PS) was evaluated as pressure gradients between RV and pulmonary artery. The degree of PR was assessed by judging the extent and density of opacification of the RV in the lateral view of the pulmonary arteriogram and was graded from Grade 0 to 4. The details of this method have been given in a previous report.⁶

Statistical analyses were performed using F test or Fisher's exact probability test with a P value of <0.05 considered statistically significant.

RESULTS

Data on preoperative and postoperative measurements are shown in Tables III and IV.

1. Early postoperative study

Right and left ventricular end-diastolic vol-

TABLE III PREOPERATIVE CARDIAC VOLUME VARIABLES AND OTHER MEASUREMENTS

	<i>n</i>	Mean $\pm$ SD	Range
SaO ₂ (%)	38	81 $\pm$ 8	63–92
PA index	34	1.98 $\pm$ 0.37**	1.59–3.18
LVEDV (% of normal)	33	89 $\pm$ 19**	57–138
RVEDV (% of normal)	29	99 $\pm$ 16	67–131

See Table II for abbreviations.

***p* < 0.01 compared with normal.

TABLE IV EARLY AND LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES, PULMONARY REGURGITATION AND PULMONARY STENOSIS

	Early			Late		
	<i>n</i>	Mean $\pm$ SD	Range	<i>n</i>	Mean $\pm$ SD	Range
Age at examination	25	2.9 $\pm$ 1.6 y	0.6–8.8 y	43	7.3 $\pm$ 4.0 y	2.5–17.4 y
Time after operation	25	within 2 months		43	4.9 $\pm$ 3.5 y	0.8–13.0 y
Body surface area (m ²)	25	0.54 $\pm$ 0.13	0.34–0.95	43	0.89 $\pm$ 0.33	0.45–1.85
LVEDV (% of normal)	25	113 $\pm$ 19*	83–149	42	121 $\pm$ 23**	84–181
LVSF (% of normal)	25	99 $\pm$ 17	67–128	42	107 $\pm$ 18	80–155
LVEF	25	0.59 $\pm$ 0.06**	0.49–0.69	42	0.57 $\pm$ 0.05**	0.42–0.66
RVEDV (% of normal)	22	112 $\pm$ 16**	76–147	43	147 $\pm$ 43**	77–248
RVSF (% of normal)	22	100 $\pm$ 16	75–128	43	115 $\pm$ 28**	69–191
RVEF	22	0.53 $\pm$ 0.05**	0.43–0.63	43	0.48 $\pm$ 0.07**	0.26–0.64
The grade of PR	25	1.60 $\pm$ 0.96	0–3	42	2.43 $\pm$ 1.13	0–4
PS (mmHg)	24	13 $\pm$ 6	5–26	41	17 $\pm$ 16	0–65

y = years; LVSF = left ventricular stroke volume; RVSF = right ventricular stroke volume.

See Table II for other abbreviations. **p* < 0.05, ***p* < 0.01 compared with normal.

Fig.1. Correlation between right ventricular end-diastolic volume (RVEDV) and left ventricular end-diastolic volume (LVEDV) in the late postoperative period (n = 42).

Fig.2. Correlation between right ventricular ejection fraction (RVEF) and left ventricular ejection fraction (LVEF) in the late postoperative period (n = 42).

TABLE V THE RELATION OF PREOPERATIVE SaO_2 TO LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES

Preoperative SaO_2	RVEDV (%)	RVSF (%)	RVEF	LVEDV (%)	LVSV (%)	LVEF
$\text{SaO}_2 < 80\%$	163 ± 42	120 ± 29	0.44 ± 0.06	130 ± 20	109 ± 20	0.55 ± 0.06
[15]	[15]	[15]	[15]	[15]	[15]	[15]
$\text{SaO}_2 \geq 80\%$	142 ± 34	117 ± 25	0.50 ± 0.05	120 ± 22	109 ± 17	0.58 ± 0.04
[21]	[21]	[21]	[21]	[20]	[20]	[20]
F test	ns	ns	$p < 0.01$	ns	ns	$p < 0.05$

ns = not significant. See Tables II and IV for other abbreviations.
[] = number of patients. Values are mean $\pm$ SD.

umes (EDV) were increased slightly over the normal, while right and left ventricular ejection fractions (EF) were significantly depressed (Table IV).

Preoperative variables were available for 20 patients. None of the preoperative variables correlated significantly with the postoperative RVEF or LVEF.

Cardiopulmonary bypass time (CBT) ranged from 73 to 310 (145 ± 60) min for 13 patients for whom cardioplegic solution was used. Six of those patients required an outflow patch and the CBT exceeded 150 min. In seven without an outflow patch, the CBT was under 150 min. The postoperative LVEF averaged 0.54 ± 0.04 (range 0.49 to 0.58) for patients with a CBT over 150 min and 0.63 ± 0.03 (range 0.56 to 0.66) for patients with a CBT under 150 min. The dif-

ference between the groups was statistically significant ($p < 0.01$). The postoperative RVEF averaged 0.51 ± 0.05 (range 0.43 to 0.57) in patients with a CBT over 150 min, compared with 0.55 ± 0.04 (range 0.51 to 0.62) in patients with a CBT under 150 min. This difference did not reach statistical significance.

The degree of PR was Grade 0 in 4 patients, Grade 1 in 6, Grade 2 in 11 and Grade 3 in 4. No patient had a residual RV outflow pressure gradient over 30 mmHg (Table IV). The degree of PR and PS did not correlate significantly with the postoperative volume variables or with the operative methods used for RV outflow tract reconstruction.

2. Late postoperative study

RVEDV, RVSF and LVEDV were signifi-

cantly increased over the normal. RVEF and LVEF were significantly depressed (Table IV). There was a significant correlation of $r = 0.68$, $p < 0.01$ between RVEDV and LVEDV, and also of $r = 0.63$, $p < 0.01$ between RVEF and LVEF (Fig. 1, 2).

TABLE VI THE RELATION OF OPERATIVE METHODS TO PULMONARY REGURGITATION IN THE LATE POSTOPERATIVE PERIOD

PR (Grade)	Operative groups				Total
	1	2	3	4	
0				2	2
1			5	1	6
2	2	4	8	1	15
3	4	1	5		10
4	3	2	4		9
Total	9	7	22	4	42

PR = pulmonary regurgitation.
Values indicate the number of patients.

Preoperative LVEDV, RVEDV and PA indices were available for 32 patients. These variables did not correlate significantly with either postoperative RVEF or LVEF. Aortic oxygen saturation (SaO_2) data were available for 36 patients. The postoperative RVEF and LVEF in patients with a preoperative SaO_2 of less than 80% were significantly lower than those in patients with a preoperative SaO_2 of 80% or more (Table V). Preoperative LVEDV in patients with an SaO_2 of less than 80% was significantly smaller than that in patients with an SaO_2 of 80% or more ($78 \pm 17\%$ vs $92 \pm 15\%$, $p < 0.05$). An outflow patch was required for 11 of 15 patients with an SaO_2 of less than 80% and for 7 of 21 patients with an SaO_2 of 80% or more ($p < 0.05$).

CBT ranged from 98 to 310 (152 ± 44) min in 23 patients for whom cardioplegic solution was used. Twelve of those patients required a CBT over 150 min. There were no significant differences in the postoperative RVEF and LVEF between patients with a CBT over 150 min and those with a CBT under 150 min.

The degree of PR and its relation to operative

TABLE VII THE RELATION OF PULMONARY REGURGITATION TO LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES

PR (Grade)	RVEDV (%)	RVSF (%)	RVEF	LVEDV (%)	LVSF (%)	LVEF
0-2 [23]	119 ± 27 [23]	98 ± 18 [23]	0.50 ± 0.06 [23]	111 ± 16 [23]	101 ± 13 [23]	0.58 ± 0.05 [23]
3-4 [19]	177 ± 33 [19]	132 ± 26 [19]	0.45 ± 0.06 [19]	130 ± 20 [18]	110 ± 19 [18]	0.54 ± 0.05 [18]
F test	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	ns	$p < 0.05$

ns = not significant. See Tables II and IV for other abbreviations.
[] = number of patients. Values are mean $\pm$ SD.

TABLE VIII THE RELATION OF PRESENCE OF RV PATCH TO LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES

RV patch	RVEDV (%)	RVSF (%)	RVEF	LVEDV (%)	LVSF (%)	LVEF
(-) [23]	146 ± 41 [23]	114 ± 27 [23]	0.48 ± 0.08 [23]	115 ± 18 [23]	104 ± 17 [23]	0.57 ± 0.05 [23]
(+) [20]	148 ± 44 [20]	116 ± 29 [20]	0.47 ± 0.04 [20]	127 ± 25 [19]	109 ± 20 [19]	0.56 ± 0.05 [19]
F test	ns	ns	ns	ns	ns	ns

ns = not significant. See Tables II and IV for other abbreviations.
[] = number of patients. Values are mean $\pm$ SD.

TABLE IX THE RELATION OF F PULMONARY STENOSIS TO LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES

PS (mmHg)	RVEDV (%)	RVSF (%)	RVEF	LVEDV (%)	LVSF (%)	LVEF
PS $\geq$ 30 mmHg [8]	149 $\pm$ 36 [8]	102 $\pm$ 18 [8]	0.42 $\pm$ 0.07 [8]	124 $\pm$ 13 [7]	101 $\pm$ 10 [7]	0.51 $\pm$ 0.05 [7]
PS < 30 mmHg [33]	146 $\pm$ 36 [33]	118 $\pm$ 28 [33]	0.49 $\pm$ 0.06 [33]	119 $\pm$ 22 [33]	106 $\pm$ 18 [33]	0.58 $\pm$ 0.05 [33]
F test	ns	ns	p < 0.01	ns	ns	p < 0.01

ns = not significant. See Tables II and IV for other abbreviations.
[] = number of patients. Values are mean $\pm$ SD.

TABLE X THE RELATIONSHIPS OF PREOPERATIVE Sao_2 , LATE POSTOPERATIVE PS AND PR TO ONE ANOTHER

Sao_2	PS	PR	PS	Sao_2	PR	PR	Sao_2	PS
Sao_2 < 80%	15 $\pm$ 14	2.6 $\pm$ 1.2	PS < 30 mmHg	81 $\pm$ 7	2.6 $\pm$ 1.0	PR 0-2	81 $\pm$ 7	19 $\pm$ 17
Sao_2 $\geq$ 80%	18 $\pm$ 15	2.4 $\pm$ 1.0	PS $\geq$ 30 mmHg	82 $\pm$ 8	2.1 $\pm$ 1.2	PR 3-4	81 $\pm$ 8	15 $\pm$ 15
F test	ns	ns	F test	ns	ns	F test	ns	ns

ns = not significant. See Table II for other abbreviations. Values are mean $\pm$ SD.

TABLE XI SERIAL CHANGES OF CARDIAC VOLUME VARIABLES AND OTHER MEASUREMENTS

	RVEDV (%)	RVSF (%)	RVEF	LVEDV (%)	LVSF (%)	LVEF	PR	PS
1 st	117 $\pm$ 22	104 $\pm$ 20	0.53 $\pm$ 0.05	116 $\pm$ 21	102 $\pm$ 17	0.59 $\pm$ 0.06	1.8 $\pm$ 0.7	15 $\pm$ 7
2 nd	147 $\pm$ 40	118 $\pm$ 28	0.49 $\pm$ 0.05	122 $\pm$ 24	109 $\pm$ 20	0.57 $\pm$ 0.04	2.7 $\pm$ 1.1	15 $\pm$ 12
F test	p < 0.01	ns	p < 0.01	ns	ns	ns	p < 0.01	ns

ns = not significant. See Tables II and IV other abbreviations.
Values are mean $\pm$ SD.

methods are shown in Table VI. In the patient undergoing pulmonary valve replacement, the PR was considered absent on auscultation. In one patient, the PR could not be evaluated because the catheter could not be inserted into the pulmonary artery. The occurrence of PR of Grade 3 or more was more frequent in group 1 than in groups 2 to 4 ($p < 0.05$). The influence of PR on postoperative volume variables is shown in Table VII. RVEDV, RVSF and LVEDV were significantly larger, and both RVEF and LVEF were significantly lower in patients with PR of Grade 3 or more than in patients with PR of Grade 2 or less. There were no significant differences in postoperative volume variables between patients with an outflow patch and those without one (Table VIII).

Eight patients had RV outflow pressure gradients over 30 mmHg. A significant gradient existed at the distal end of an outflow patch or supravalvular level in 4 with a TAP, and at the annular or valvular level in 3 without an outflow patch. In the remaining one patient without an outflow patch, the major gradient was at the bifurcation of the main pulmonary artery. In 6 of those 8 patients, early postoperative pressure data were available and the gradients increased with time, from 22 $\pm$ 11 mmHg in the early postoperative period to 46 $\pm$ 13 mmHg in the late postoperative period (time lapse 34-147 (88 $\pm$ 41) months). Most of those patients had a slight to moderate aneurysmal dilatation of the RV outflow tract. RVEF and LVEF were lower in patients with residual RV outflow pressure

gradients over 30 mmHg than in patients with gradients of 30 mmHg or less (Table IX).

The 3 variables of preoperative SaO_2 , PR and residual PS were statistically independent and did not correlate with the age of the patient at the time of surgical repair (Table X).

3. Serial changes of the volume variables after surgical correction (Table XI).

RVEDV increased and RVEF was further depressed in the late postoperative period. The degree of PR also increased further in the late postoperative period.

DISCUSSION

Influence of preoperative hemodynamics and perioperative factors on postoperative right and left ventricular functions

Left or right ventricular volume is often small in TOF before operation.¹⁵ Earlier, we reported that a critically small LV or RV might increase the potential risk of low cardiac output immediately after repair.¹⁵ In the present study, however, preoperative LVEDV or RVEDV did not significantly correlate with the postoperative LVEF or RVEF, which was measured more than 1 month after the repair. Thus, a small LV or RV is not a significant contributing factor to the postoperative LV or RV dysfunction more than 1 month after repair.

Several authors have shown that the preoperative long-standing pressure overload or hypoxia in case of TOF induces structural changes in the myocardium, the degree of which increases with age.¹⁹⁻²¹ Kato et al²¹ did histological studies and arrived at the conclusion that corrective surgery for TOF should be performed at or before the age of 3 years, in order to prevent an irreversible alteration of the RV muscle fibers. In relation to this finding, several clinical studies have shown that early repair is associated with a better result in terms of RV or LV function than repair later in childhood.²²⁻²⁴ In the present study, the vast majority of patients underwent surgical repair at the age of 3 years or less. Nevertheless, in the late postoperative period, patients with a preoperative SaO_2 of less than 80% had a poor postoperative RV and LV function, as compared with patients with a preoperative SaO_2 of 80% or more. SaO_2 reflects the severity of the preoperative anatomy.¹⁵ Therefore, this result can be related to the severe preoperative anatomy in patients with severe

preoperative hypoxia. However, we found no significant relationship between the postoperative LVEF and RVEF and the preoperative variables, except for SaO_2 . Further, SaO_2 did not correlate significantly with CBT, PS, PR or age at the time of operation. Although there was a significant difference between the groups in the use of an outflow patch, the presence of an outflow patch had no apparent effect on the late postoperative RVEF and LVEF. These findings suggest that severe preoperative hypoxia affects the postoperative RV and LV function, despite surgical repair at an early age, although cumulative effects of the hypoxia-related factors may not be negligible in RV dysfunction. Surgery at a much younger age may be needed to lessen the influence of the preoperative hypoxia.

Open heart surgery with cardiopulmonary bypass does produce some degree of myocardial damage. We found a significant depression of the early postoperative LVEF in patients with a long CBT. None of the other variables correlated significantly to the LVEF. These findings indicate that myocardial damage during cardiopulmonary bypass may well be a principal cause of LV dysfunction in the early postoperative period. It may also be linked to early postoperative RV dysfunction, although differences in the RVEF between the CBT groups did not reach statistical significance. There is no doubt that the patients requiring a long CBT had difficult anatomy to correct, thus undergoing extensive surgical procedures for the RV outflow tract. The added effect of the surgical procedure itself is difficult to quantify, but does contribute to RV dysfunction in the early postoperative period. On the other hand, these factors were not significant in the late postoperative period, presumably because preoperative hypoxia, PS or PR became relatively more significant in the late postoperative period.

Influence of RV outflow tract reconstruction on RV function

Residual PS and PR are inevitable in the majority of repairs of TOF, although they vary in degree. Differences in opinion have centered around the long-term relative importance of residual PS versus PR and seem to stem mainly from disagreements concerning the effects of PR on the postoperative RV function. Wessel and colleagues⁷ noted a decreased exercise tolerance in patients with PR. Lange et al² showed that the RVEDV increased and the RVEF

decreased with an increasing RV volume overload secondary to PR and/or residual VSD. Bove and associates⁴ found RV dysfunction to be worse in patients with PR. In the present study, PR of Grade 3 or more was found to impair the late postoperative RV function in terms of RVEDV and RVEF. In contrast, other workers²⁵⁻³⁰ concluded that PR appeared to be well tolerated if there was no significant distal residual obstruction.

There may be several contributing factors to this controversy. First, PR may very considerably in extent and there have been no accurate methods to estimate the degree. The cineangiographic technique used in this study gives only a semiquantitative approximation of PR. However, it is considered an acceptable method for evaluating the effects of PR on RV function because the grades of PR coincide with volumetric or hemodynamic data.⁶ Second, the majority of authors who found that PR did not impair RV function evaluated their patients largely based on symptomatic status. Symptomatic views give only limited information on the long-term effects of PR. In fact there were no apparent symptoms even in our patients with severe PR and resultant RV dysfunction. Third, factors other than PR may affect RV function after the repair of TOF. RV volume overload alone cannot account for RV dysfunction, in view of the finding that RVEF does not decrease in children with atrial septal defect.³¹ The cumulative effects of various factors may enhance the deleterious effect of PR, resulting in an earlier appearance of RV dysfunction.

In the light of all these findings, we conclude that moderate to severe PR impairs postoperative RV function.

Significant residual PS has been shown to result in an increased rate of hospital deaths and poor late results,³³ although there is no general agreement as to what degree of residual PS is an acceptable compromise. Apart from the degree, the other important influence is location of the PS. Nakazawa et al³² found no significant correlation between the postoperative RV systolic pressure and RVEF. In their patients, the main cause of RV hypertension was a residual infundibular stenosis. In our study, significant PS depressed the RVEF. The major pressure gradients in such PS were at the central pulmonary artery or pulmonary valve annulus. These findings suggest that central or annular PS is more likely than infundibular stenosis to depress

RVEF. This may be related partly to a paradoxical expansion of the RV outflow tract during systole, as observed in patients with a central or annular PS, and partly to the fact that EF varies inversely with afterload, at any level of myocardial contractility.

These adverse effects of PS and PR were not significant in the early postoperative period. Administration of digitalis and the lesser degree of PS and PR in the early postoperative period may be the cause. The degree of PS or PR in several patients increased with time to become significant in the late postoperative period.

The question arises as to whether patch graft reconstruction of the outflow tract is advisable in borderline situations,³³ in relation to the influence of PR or PS. The insertion of an outflow patch across the pulmonary valve always results in some degree of PR. However, use of a TAP does not always induce a severe PR. Too much enlargement using a TAP ($\text{CSAI} > 2.5 \text{ cm}^2/\text{m}^2$) very likely induces a severe PR, while an adequate enlargement using a TAP with a monocusp ($\text{CSAI} \leq 2.5 \text{ cm}^2/\text{m}^2$) probably preserves pulmonary valve function to some extent. On the other hand, not using a TAP does not necessarily guarantee against a severe PR. In this study, some patients without a TAP had a severe PR postoperatively, which seems to be the result of extensive pulmonary valvotomy such as an enforced enlargement of the pulmonary annulus by a Hegar dilator. These were "borderline situations" where we hesitated to use a TAP to obtain a CSAI greater than $1.75 \text{ cm}^2/\text{m}^2$.^{13,14} In addition, some borderline cases for whom a TAP was not used showed a significant central or annular PS in the late postoperative period.

From the viewpoint of the late postoperative results, it is important to avoid too much enlargement with a TAP ($\text{CSAI} > 2.5 \text{ cm}^2/\text{m}^2$) and extensive pulmonary valvotomy. The insertion of a TAP is preferable to extensive pulmonary valvotomy, in a borderline situation.

Influence of RV function on LV function

The enlarged LVEDV and depressed LVEF corresponds to previous reports of LV dysfunction, evaluated by a variety of techniques.^{1,2,4,5,24,34} Prolonged hypoxia and an additional hemodynamic load from residual VSD have been suggested as causative factors for postoperative LV dysfunction.^{1,2,5,24,34} Little attention has been paid to the right to left ventricular interrelationship, especially the effect on LV function

of RV volume overload due to PR. Indeed, the LV performance is not independent of the RV functional status, as shown clinically³⁵ and experimentally.^{36,37} In addition, biochemical^{38,39} and morphologic changes⁴⁰ were found in the LV of animals with isolated RV failure, experimentally produced. In the present study, significant PS or PR was found to depress LVEF as well as RVEF. Further, there was a significant linear correlation between LVEF and RVEF. Bove and associates⁴ noted a depression in the LVEF, which occurred to a greater degree in patients with PR than in those without it. These findings indicate that postoperative LV dysfunction in TOF is largely due to RV dysfunction resulting from PR, residual PS, etc, although the direct effect of hypoxia on LV is an additional untoward factor. Efforts to preserve RV function will no doubt improve the LV function.

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