主　論　文

Pulmonary Stenosis with Intact Ventricular Septum : Assessment and Indication of Reconstructive Surgery for Residual Right-Ventricular Outflow Tract Obstruction

心室中隔欠損をともなわない肺動脈弁狭窄症：
残存右室流出路狭窄に対する外科的修復の評価と適応

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Key-word : Pulmonary stenosis, Residual RVOTO, Surgical indication, RVP/AP ratio, VS/BSA

Summary

If not all of the right ventricular outflow tract obstruction (RVOTO) is removed in the operation for pulmonary stenosis (PS), high right ventricular pressure can sometimes occur afterward. However, it is not easy to assess the amount of RVOTO that is to be removed, and there is no quantifiable method for selecting operative procedures.

The aim of this report is to discuss the formulation of a numerical indicator, based on the parameters peak systolic right-ventricular pressure (RVP), systolic systemic arterial pressure (AP), pulmonary valvular orifice size (VS), and body surface area (BSA), from the results obtained in sixty-four open heart surgeries for pulmonary stenosis with intact ventricular septum.

(1) A group, in which an outflow tract patch was not used and which had a higher pre-operative RVP/AP ratio, had a tendency to have a correspondingly higher RVP/AP ratio one month after the operation . Most patients with a high RVP/AP ratio one month after the operation showed a significant decrease in this ratio a long time after the operation. But, there were exceptions to this rule where the ratio remained high. Reconstruction of the right ventricular outflow was considered for some patients whose RVP/AP ratios remained high.

(2) Reconstruction of the RVOT by using an outflow tract patch worked well for patients with an associated infundibular stenosis. A subannular patch was used for patients with infundibular stenosis , and a transannular patch was used for patients with annular stenosis . (The optimal annulus size was such that VS/BSA was not less than $2cm^2 / m^2$. A transannular monocusp patch was applied to an area which was more than 10 mm wide).

(3) The correlation between the pre-operative RVP/AP and the pre-operative VS/BSA ratio was good. However, no correlation between the post-operative RVP/AP ratio and

the post-operative VS/BSA ratio was observed. Therefore, it seems impossible to predict the post-operative RVP only from the size of pulmonary valvular orifice.

(4) The pressure measurement during the operation gives an indication for determining the prognosis. That is, the RVP/AP ratio just after the operation (call this value x) and the RVP/AP ratio one month after the operation (call this value y) showed a good correlation. The RVP/AP just after the operation should be 0.7 or less. If this ratio is more than 0.7, reconstruction of the RVOT needs to be done even with repeated cardiopulmonary bypass (CPB).

Assessment of the operative application to PS needs careful study in every case, not only before but also during the operation.

Introduction

An open valvotomy is usually applied to pulmonary stenosis (PS) with intact ventricular septum. Some reconstruction of the right ventricle outflow tract obstruction (RVOTO), such as emplacement of a subannular or transannular outflow tract patch, is supplementally applied to severe infundibular stenosis. However, there are many cases where a certain measure of residual right ventricle outflow tract obstruction (residual RVOTO) is left, but it is reduced with time. This is one of the difficulties in choosing an operative method in each case. However, the assessment of operative methods is not easy, and no precise indices have been obtained.

In order to create a quantitative index, the prognoses of sixty-four cases of open heart surgery for PS with intact ventricular septum are analyzed and discussed in this report.

Patients and Methods

Sixty-four patients had open heart surgery for pulmonary stenosis (PS) with intact ventricular septum at Meijo Hospital. The results of their cardiac catheterizations and operations are discussed. Pulmonary atresia (PA) and two-chambered right ventricle (TCRV) were excluded.

The peak systolic right ventricular-systemic arterial pressure ratio (RVP/AP) was obtained from a ratio of peak systolic right ventricular pressure (RVP) and systolic systemic arterial pressure (AP), or maximum blood pressure (AP).

The minimum, maximum, and/or average, and standard deviation of these values were expressed. The paired t-test for paired two groups, and the analysis of variance

(F-test) for multi-comparisons among groups which were not paired were used in analyzing differences of average. The t-test was performed for correlation. Statistical significance was determined at the 0.05 level.

The sixty-four cases consisted of thirty-four males and thirty females. The age range was from one to twenty-three (7.1±5.3).

In addition to having PS, twenty-nine patients had arterial septal defect (ASD), or patent foramen ovale (PFO); two patients had ductus arteriosus (PDA); and seven patients among them were Noonan's syndrome; and thirty-four patients had no associated anomaly.

The pre-operative systolic right ventricular pressure (RVP) ranged from 58 to 250 (X±SD: 122.4±44.8) mmHg. The peak systolic right ventricular pressure-arterial pressure ratio (RVP/AP) was from 0.48 to 3.16(X±SD: 1.10±0.48).

There were three hospital deaths due to postoperative cardiac insufficiency before 1974.

The operations were performed under mild or moderate hypothermia cardiopulmonary bypass (CPB). In most of them, normothermia intermittent anoxic arrest was used. In some of them hypothermia cold crystalloid cardioplegia was used.

Open valvotomy was performed on all patients, and additional infundibular muscle resection was done on some of them.

(1) Fifty-five operations without outflow tract patch (op-1),
(2) four operations with subannular outflow patch (op-2),
(3) five operations with transannular outflow patch (op-3).

Most of op-1 were transpulmonary, but fourteen of them were transventricular for infundibular muscle resection. Results were, however, often unsatisfacyory, so that after 1982 op-2 was performed for severe infundibular stenosis, and op-3 was performed for severe annular stenosis. Dacron-patches were used in op-2, and Dacron-patches with autogenous pericardial monocusp were applied in op-3.

The pulmonary valvular orifice size (VS) was measured with Hegar's dilator at pre- and post-valvotomy while the

operations were performed.

The pressure just after the operation was measured with needle cannula as soon as the haemodynamics became stable after CPB was stopped.

Post-operative cardiac catheterization was performed one month later.

Additionally, cardiac catheterization from two to thirteen years later was done for eleven cases.

Results

< Methods of operation and post-operative peak systolic right ventricular-systemic arterial pressure ratio>

Cardiac catheterization was performed one month later for fifty-four cases, and both pre-operative and post-operative RVP/AP ratios were obtained in fifty-two cases. The RVP/AP ratios were categorized into three operation types, op-1, op-2, op-3.

- (op-1) : the group without outflow tract patch

Both pre-operative and post-operative RVP/AP ratios were obtained in forty-three cases. This pre-operative RVP/AP ratio had a significant decrease to the post-operative RVP/AP ratio <Fig. 1>. The pre-operative RVP/AP ratio and that taken one month later correlated well <Fig. 2>. Cases with higher pre-operative RVP/AP ratio had a tendency to remain higher one month after the operation. High RVP/AP ratios of more than 0.6 were observed in 9 cases (16.4 %), and of more than 0.7 in seven cases (12.7 %) after one month <Table 1>.

- (op-2) : the group with subannular outflow tract patch

Reconstruction of RVOT using a subannular outflow tract patch was performed in four cases. The pre-operative RVP/AP ratio was decreased significantly one month later <Fig. 1>.

One case had a high RVP/AP ratio of 0.71 one month after the operation, but the value decreased to 0.35 after two years and five months <Table 2>.

- (op-3) : the group with transannular outflow tract patch

Reconstruction of transannular RVOT, using a patch with autogenous pericardium-monocusp, was performed in

addition to valvotomy and infundibular resection for five cases.

The RVP/AP ratio in this group, and it decreased less than half the preoperative value one month after the operation in all cases <Fig.1>.

No correlation of the post-operative RVP/AP ratios among the three operation methods, op-1, op-2 and op-3, was detected by using the variance (F-test) analysis.

<The relationship between pulmonary valvular orifice size and peak systolic right ventricular pressure>

From the size of the pulmonary valvular orifice (VS) and body surface area (BSA) the ratio, VS/BSA (cm^2 / m^2), was determined . A significant correlation was found between pre-valvotomy VS/BSA and RVP/AP at the pre-operative cardiac catheterization considering all three groups <Fig. 3>.

No significant correlation was found, however, between post-valvotomy VS/BSA (cm^2 / m^2) and RVP/AP just after the operation <Fig. 4> or one month after the operation <Fig. 5>. Even after considering only the group without outflow tract patch no significant correlation between post-valvotomy VS/BSA (cm^2 / m^2) and RVP/AP one month after the operation was found <Fig. 6>.

There were six patients (five of op-1 ,and one of op-2) whose RVP/AP ratio one month after the operation was 0.7 or more, and seven cases (six of op-1, and one of op-2) with an RVP/AP of 0.6 or more, although their post-valvotomy VS/BSA was 2.0 cm^2 / m^2 or more <Fig. 5> which was the value aimed at.

Additionally, post-valvotomy VS/BSA and RVP/AP ratios were measured in nine out of eleven cases where cardiac catheterization was performed a long time after the operation. A negative correlation was significant between them <Fig. 7>.

<Right ventricular pressure during the operation, and pre-and post-operative right ventricular pressure>

Right ventricular pressure was measured immediately after the operation in twenty-four cases: fifteen cases of op-1, four cases of op-2 and five cases of op-3.

The RVP/AP ratio measured at the operation was : 0.60 ± 0.30 in op-1, 0.64 ± 0.24 in op-2, and 0.52 ± 0.07 in op-3. The differences are of no statistical significance (F-test).

Peak systolic right ventricular systemic arterial pressure (RVP/AP) ratios measured before, during, and after the operation were compared in all these cases regardless of the operative methods. The RVP/AP ratio decreased steadily <Fig. 8>.

The RVP/AP ratio just after the operation and the RVP/AP ratio one month after the operation showed a significant correlation ($r=0.796$, $p<0.01$, $n=23$). The regression line was of the form $y=a+bx$ with x= the RVP/AP ratio measured just after the operation and y= the RVP/AP ratio measured one month after the operation. The 95% confidence interval of the regression coefficient, b, was $0.32<b<0.65$ <Fig. 9>.

However, any correlation between the RVP/AP ratio just after the operation and the RVP/AP ratio measured much later could not be calculated because of the small number of cases (n=6).

<Peak systolic right ventricular-systemic arterial pressure ratio measured a long time after the operation>

A cardiac catheterization was performed from two to thirteen years after the operation in eleven cases; seven of op-1, one of op-2 and three of op-3. The age at the operation was from one to sixteen years. The seven cases with op-1 and the one case with op-2 showed a RVP/AP ratio more than 0.6 one month after the operation. Both five cases with op-1 and one case with op-2 showed a RVP/AP of

more than 0.7 one month after the operation <Table 2>.

As a whole, the pre-operative RVP/AP ratio (1.41 ±0.39) significantly dropped to 0.76 ±0.30 one month later ($p<0.01$), and to 0.42 ±0.13 at a much later time ($p<0.02$, $n=11$),<Fig. 10>. One case with op-1 and one case with op-2 , however, still showed high RVP/AP ratios, respectively, of 0.60 five years after the operation and 0.67 three years after the operation <Table 2>.

No significant correlation between the RVP/AP ratio one month later and the RVP/AP ratio much later was recognized in those eleven cases ($r=-0.427$, $n=11$) <Fig.11>.

Discussion

An agreement for operative methods for valvular pulmonary stenosis has not been reached although various attempts have been made[1, 3–11, 14, 16, 17, 21, 24, 26–29].

Open valvotomy is usually performed for this type of stenosis[4–7, 9–11, 14, 16, 26–29] except for palliative operations such as closed valvotomy in urgent cases of infants[1, 3, 17, 21, 24]. Severe cases with associated muscular hypertrophy, however, were not improved by removal of valvular stenosis alone. Therefore, the removal of the right ventricular outflow obstruction was necessary[11]. That is, it was reported that the infundibular resection was added for the cases in which the RVP was over 100 mmHg after removal of valvular stenosis [10], or that reconstructions by valvectomy or by outflow tract patches were performed for many cases whose pre-operative RVP was over 100 mmHg[5].

On the other hand, it has been stated that pulmonary valvotomy alone is an adequate procedure regardless of existence of infundibular stenosis, unless the right ventricular systolic pressure reaches more than 200 mmHg[9]. The reason for this is that if the pulmonary valvular pressure gradient is decreased by valvotomy, infundibular muscle hypertrophy is gradually improved[7].

Through our experience, too, many patients without the outflow tract patch operation (op-1) showed a decrease in systolic right ventricular pressure one month after the operation <Fig. 1>.

But, there was a tendency that the patients with a higher pre-operative RVP/AP ratio in group had a higher RVP/AP ratio one month later <Fig. 2>. The right ventricular pressure among some op-1 patients remained high <Table 1>. It is considered that those ratios remained high because of residual stenosis of the RVOT or residual stenosis of the annulus.

Eight patients in group op-1 had a high post-operative RVP/AP ratio of more than 0.7, and seven out of those patients were five years of age or older. Older children whose pre-operative RVP/AP ratio was higher showed a tendency to also have a higher right ventricular pressure; however, no detailed study of that point was done <Table 1>.

Using a transannular outflow patch can sometimes cause attending pulmonary regurgitation (PR). This happened in some of our cases. Although it has been reported that post-operative PR alone did not cause problems[15], we think that careful longer observation is necessary in these cases. To avoid pulmonary regurgitation, as much annulus as possible should remain intact[13]. However, we think that there are cases where transannular reconstruction is necessary[5, 6], such as annulus stenosis, marked valvular hypertrophy, and poor valvular movement.

Naito[18, 19], Pacifico[22], Shirotani[25], and others reported on the optimum annulus size necessary for tetralogy of Fallot. We used the standard annulus size (VS/BSA) for pulmonary stenosis of 2 cm^2 / m^2 and greater, according to Shirotani[25].

It has been reported that little or no difference was seen in the results between the transannular monocusp patch and the simple transannular patch in transannular reconstruction of RVOT[23]. However, we used an autogenous pericardial monocusp Dacron-patch in cases whose patch size was over 10mm wide.

It is considered that peak systolic right ventricular pressure is intricately related not only to the pulmonary valvular orifice size but also to the pulmonary valve flow[8], valve movement or degree of hypertrophy, existence or degree of outflow stenosis, and the difference between the pulmonary valvular orifice size during the operation and at pulsation. Thus, we conclude that it is difficult to predict post-operative right ventricular pressure only from the value of pulmonary valvular orifice size. The post-valvotomy VS/BSA ratio and the RVP/AP ratio taken

much later had a comparatively good correlation. But we would like to study this condition further because the number of cases was not enough to reach a definitive conclusion.

Pressure measurements taken during the operation were most helpful: it is possible to predict, with a reasonable certainty, the prognosis of the right ventricular pressure from the results of pressure measurement taken during the operation, but long-term variations are to be expected.

In two cases, the RVP/AP ratio taken a long time after the operation was much greater than 0.6. In one special case, after a transannular outflow patch was performed, the RVP/AP ratio was 0.45 one month after the operation. Surprisingly, this ratio rose to 0.67 after three years. This increase was found by re-operation, due to a distortion on the bifurcation of the pulmonary artery caused by the outflow tract patch. The second of these two, aged sixteen-years-old at the time of the operation, did not have an outflow tract patch. One month after the operation her RVP/AP ratio was 1.00, and this ratio remained at 0.60 five years after the operation. This case demonstrated that right ventricular outflow tract obstruction can remain for very long periods of time.

These results suggest that the pressure measurement should be done just after the operation. Reconstruction of the RVOT should be done even with repeated cardio-pulmonary bypass if the peak systolic right ventricular-systemic arterial pressure ratio (RVP/AP) does not decrease enough after an open valvotomy,or even after additional infundibular muscle has been resected.

At present we think that the optimal value of the RVP/AP after the operation should be 0.7 or less. We chose this value because a RVP/AP ratio of 0.7 can be expected to decrease to 0.4-0.6, or less, and bring good prognosis.

Recently, percutaneous balloon valvotomy (PBV) is chosen in many centers as a treatment of valvular PS. Naturally, not all cases of valvular PS are indications for this

procedure[2, 12], but the relative, if not complete, non-invasiveness and cosmetic merits make this treatment an attractive alternative[12].

Since March, 1988, our co-workers performed PBV in 15 cases of valvular PS (2 - 17 years old, mean 5.6 years old) [20] other than those presented in this paper. In these cases, the pulmonary valvular annulus diameter determined by preoperative right ventriculography was 12 - 22 mm, and balloons with diameters 1.2 - 1.4 times larger were employed for PBV. The peak systolic right ventricular pressure decreased in two of these cases from 89.1 ±20.3 mmHg before PBV to 56.1 ±16.9 mmHg after PBV, and the peak systolic pulmonary artery - right ventricular pressure gradient from 65.8 ±21.4 mmHg to 32.5 ±17.8 mmHg. In these cases dilation was not adequate. No decrease in the right ventricular pressure was observed in one other case immediately after PBV, but echocardiography showed the pressure gradient was reduced on the next day. Pulmonary regurgitation increased after PBV in some patients, but none of these increases posed clinical problems. Changes in electrocardiograms suggestive of reductions in the right ventricular load were noted in 12 of the 13 cases in which PBV was effective. Long-term results have not been evaluated in many of these cases, but our conclusions obtained from the findings in the surgical cases presented in this paper are considered to contribute much to prediction of the outcome of PBV cases.

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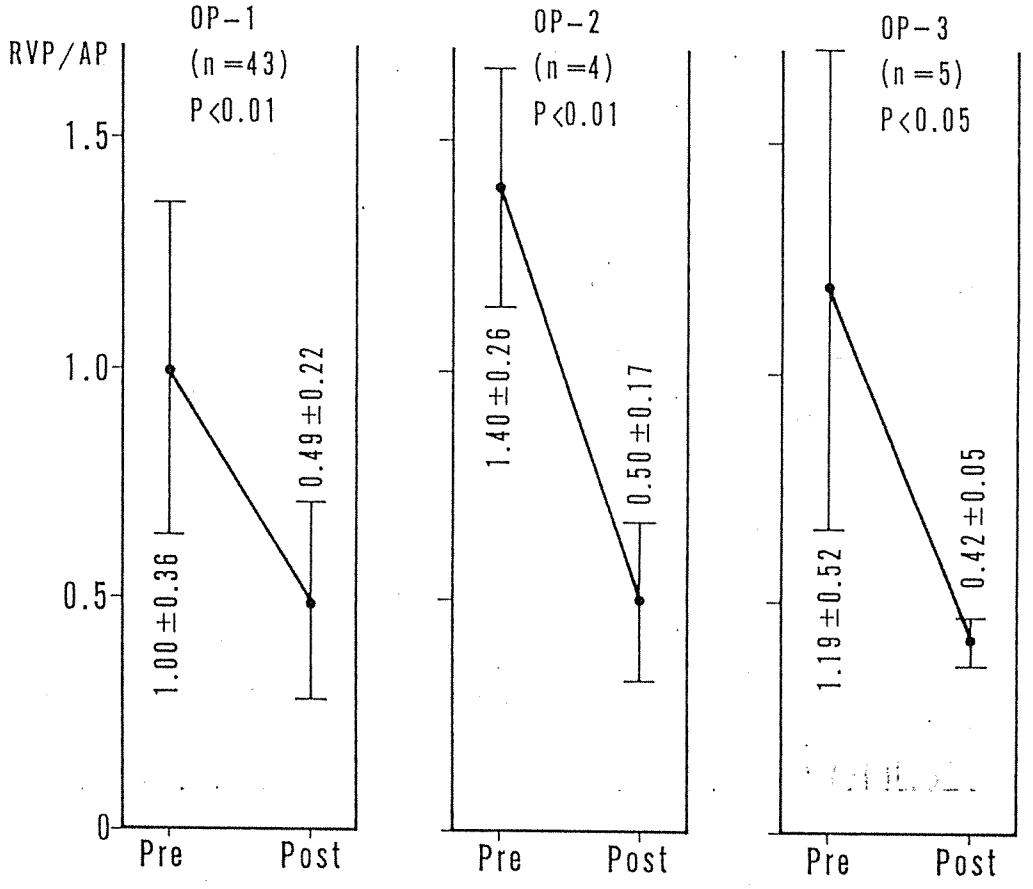
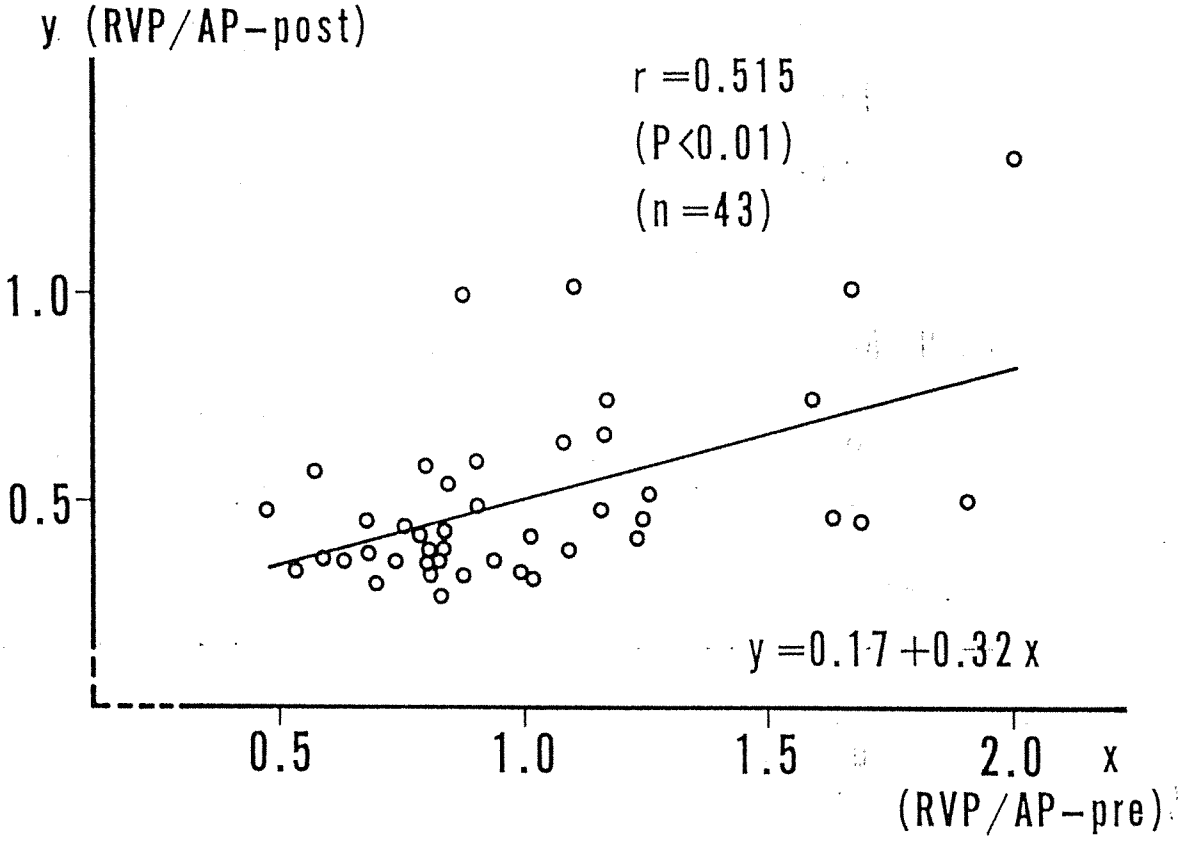
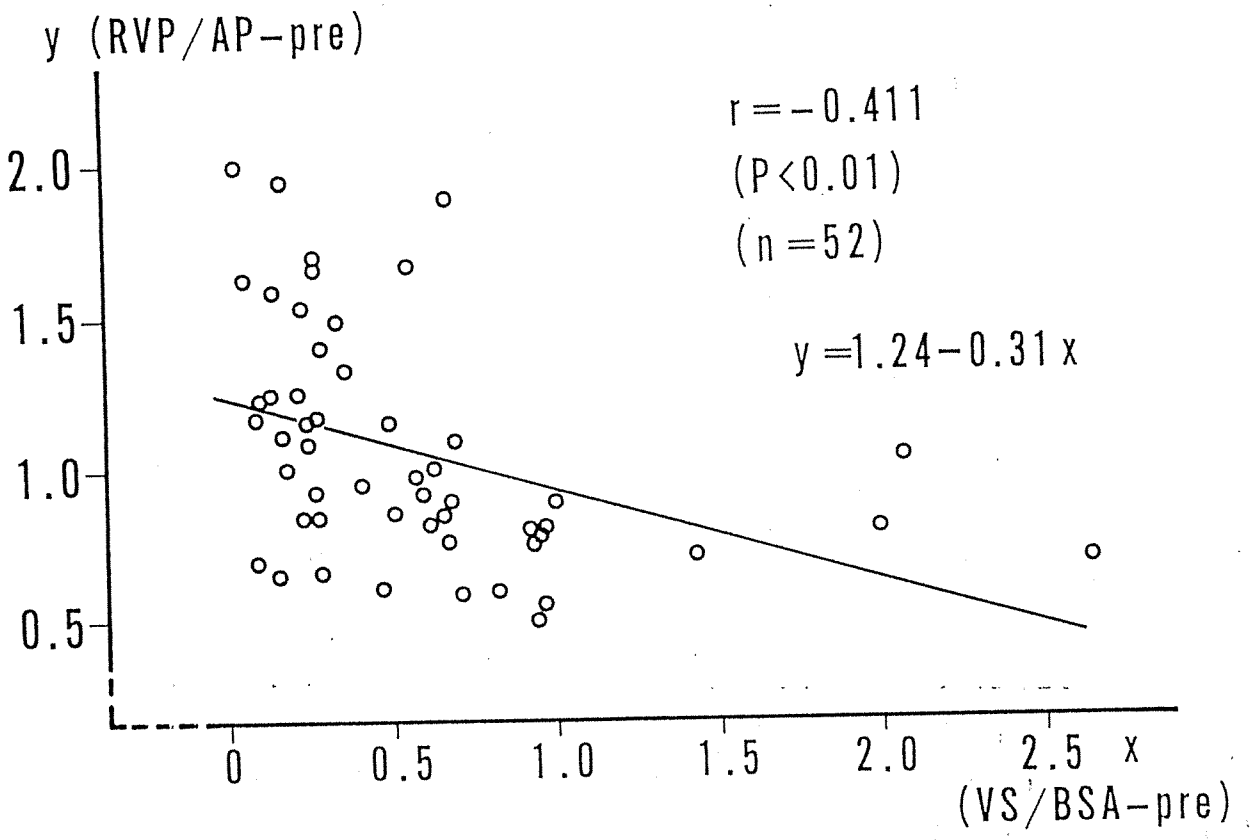


<Fig. 1> Methods of operation and RVP/AP ratios.
pre : pre-operative RVP/AP
post : RVP/AP one month after operation
op-1 : Valvotomy without Outflow Patch
op-2 : Valvotomy with Simple Outflow Patch
op-3 : Valvotomy with Transannular Monocusp Outflow Patch



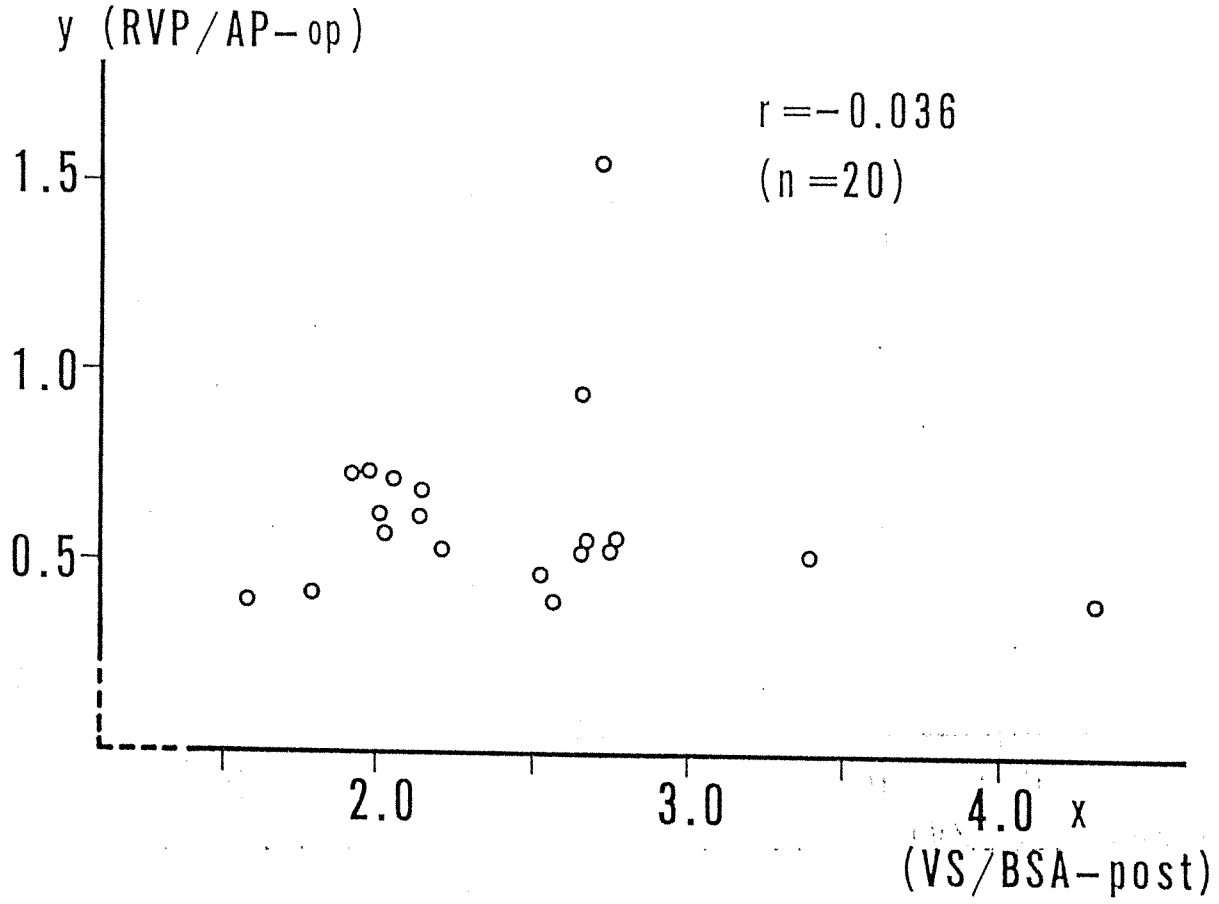
<Fig. 2> Relationship between pre-operative RVP/AP and post-operative RVP/AP (op-1 : Valvotomy without Outflow Patch).



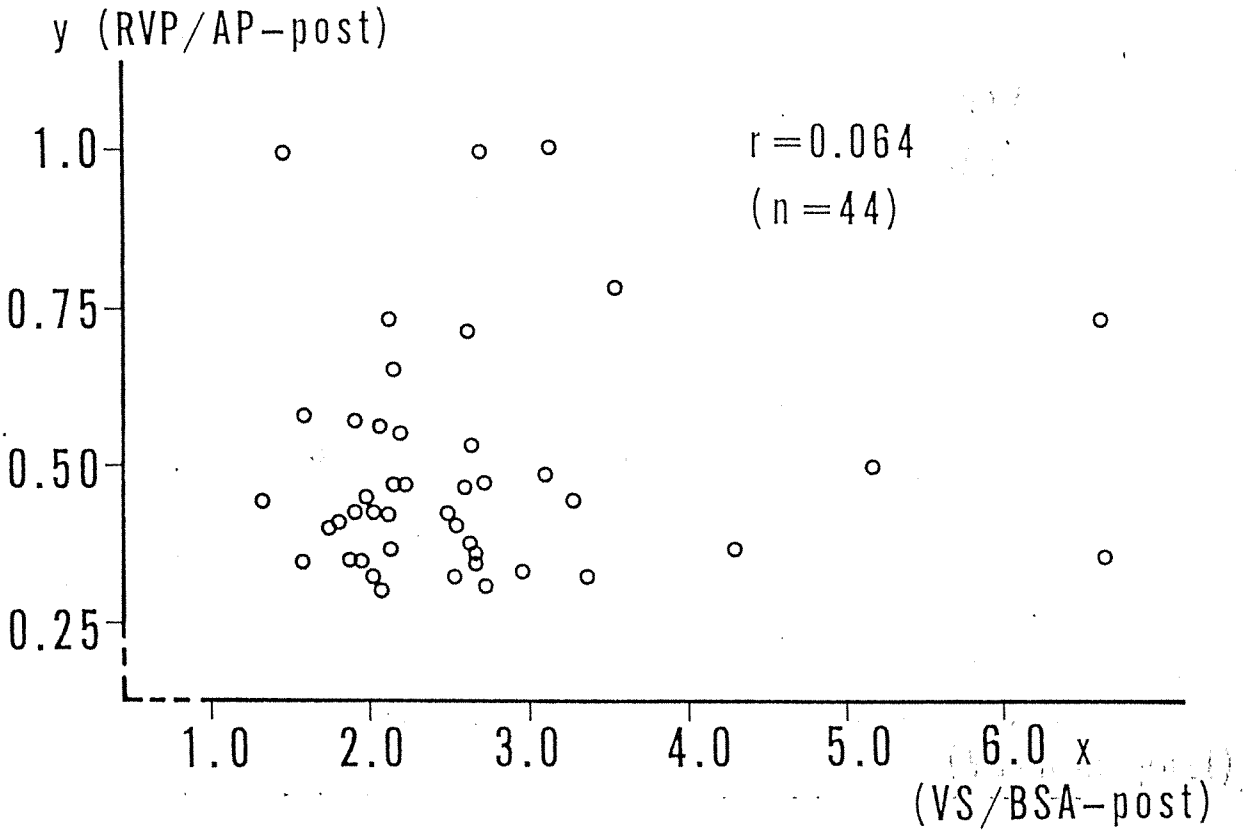
<Fig. 3> Relationship between pre-operative pulmonary valvular orifice size (VS/BSA-pre) and pre-operative RVP/AP.

VS : pulmonary valvular orifice size (cm^2)

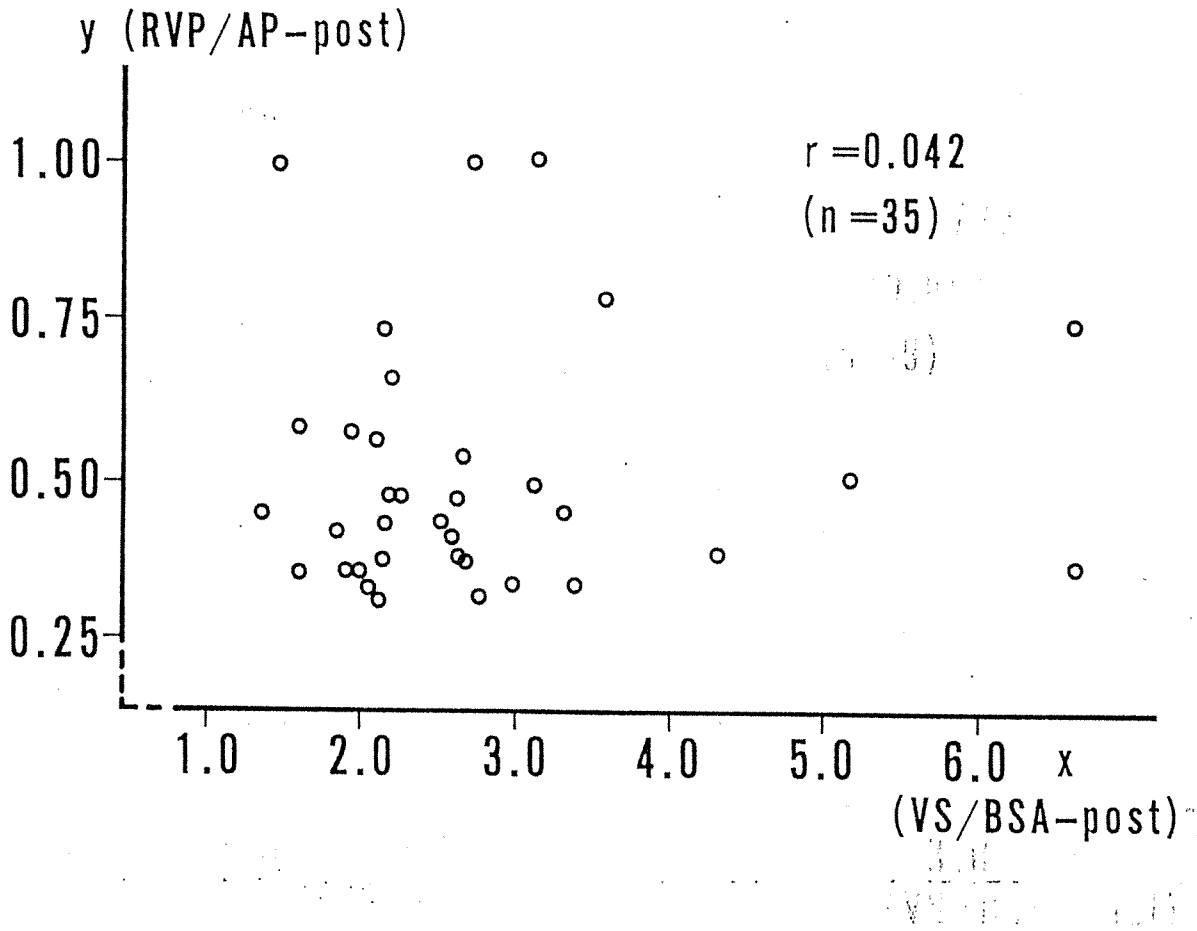
BSA : body surface area (m^2)



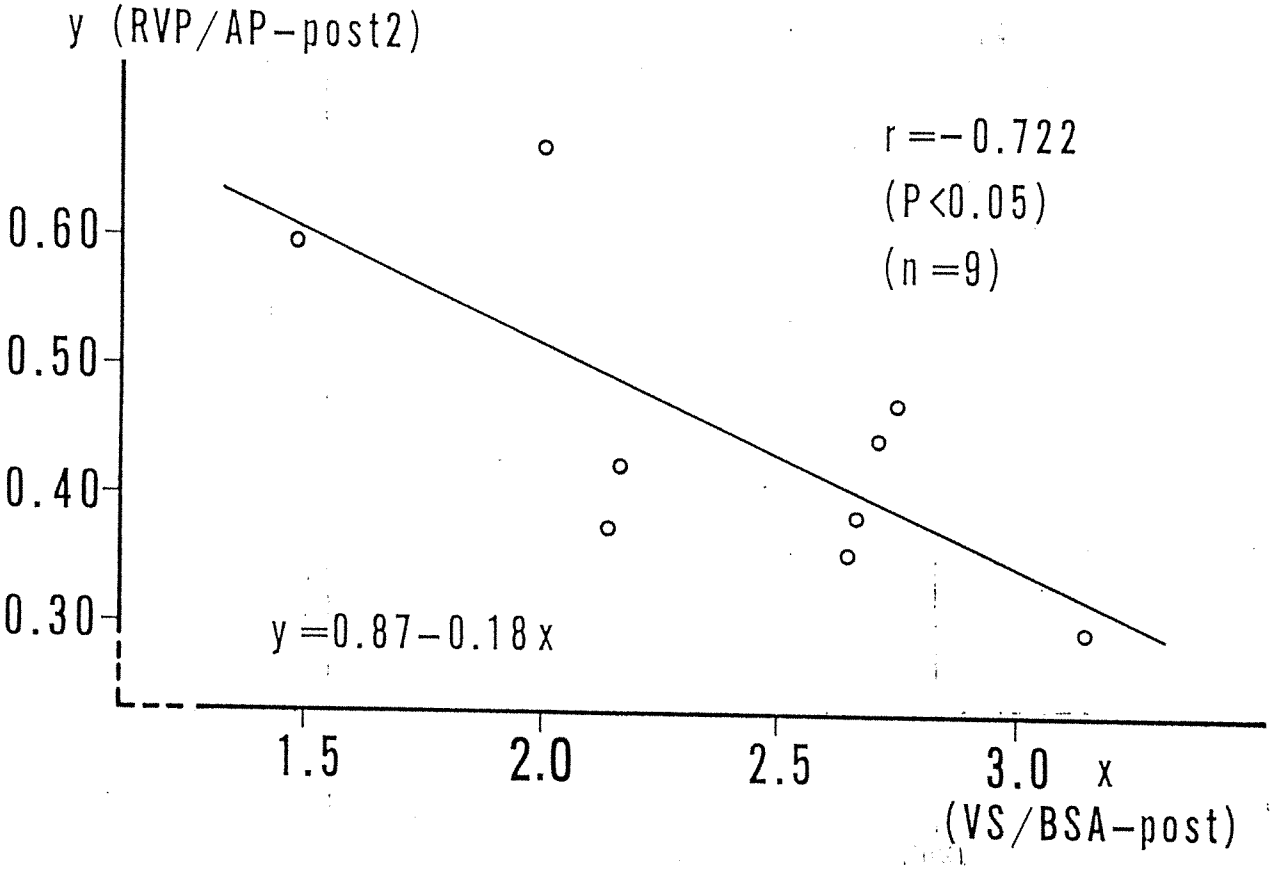
<Fig. 4> Relationship between post-valvotomy pulmonary valvular orifice size (VS/BSA-post) and RVP/AP immediately after operation (RVP/AP-op).



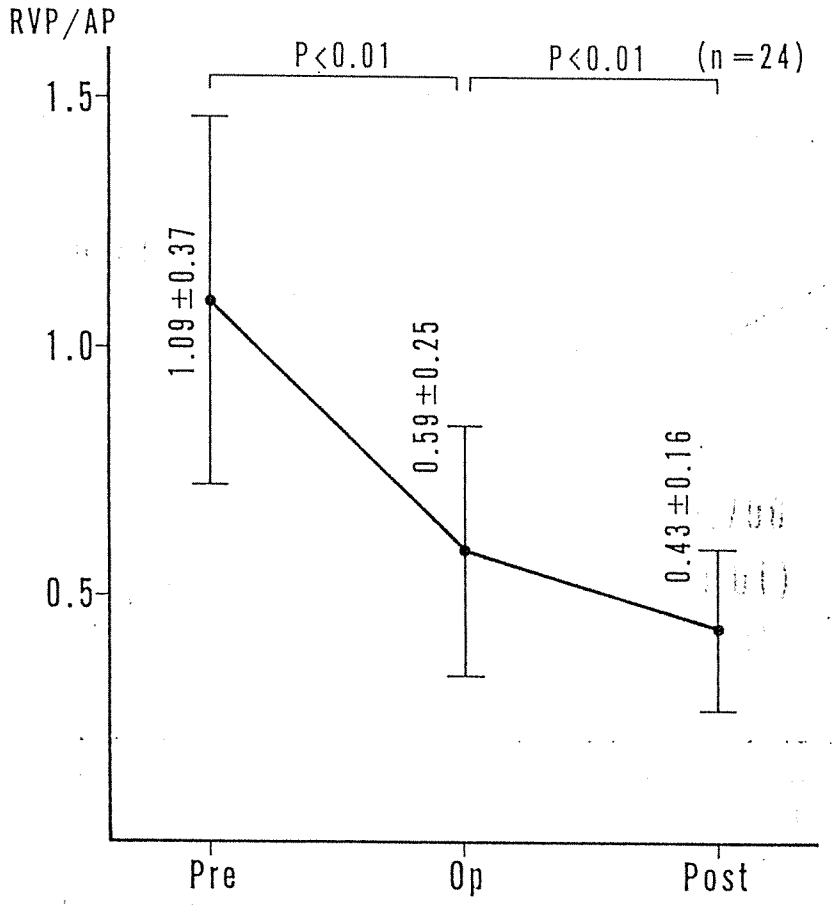
<Fig. 5> Relationship between post-valvotomy pulmonary valvular orifice size (VS/BSA-post) and RVP/AP one month after operation (RVP/AP-post) (all op-1,2,and 3).



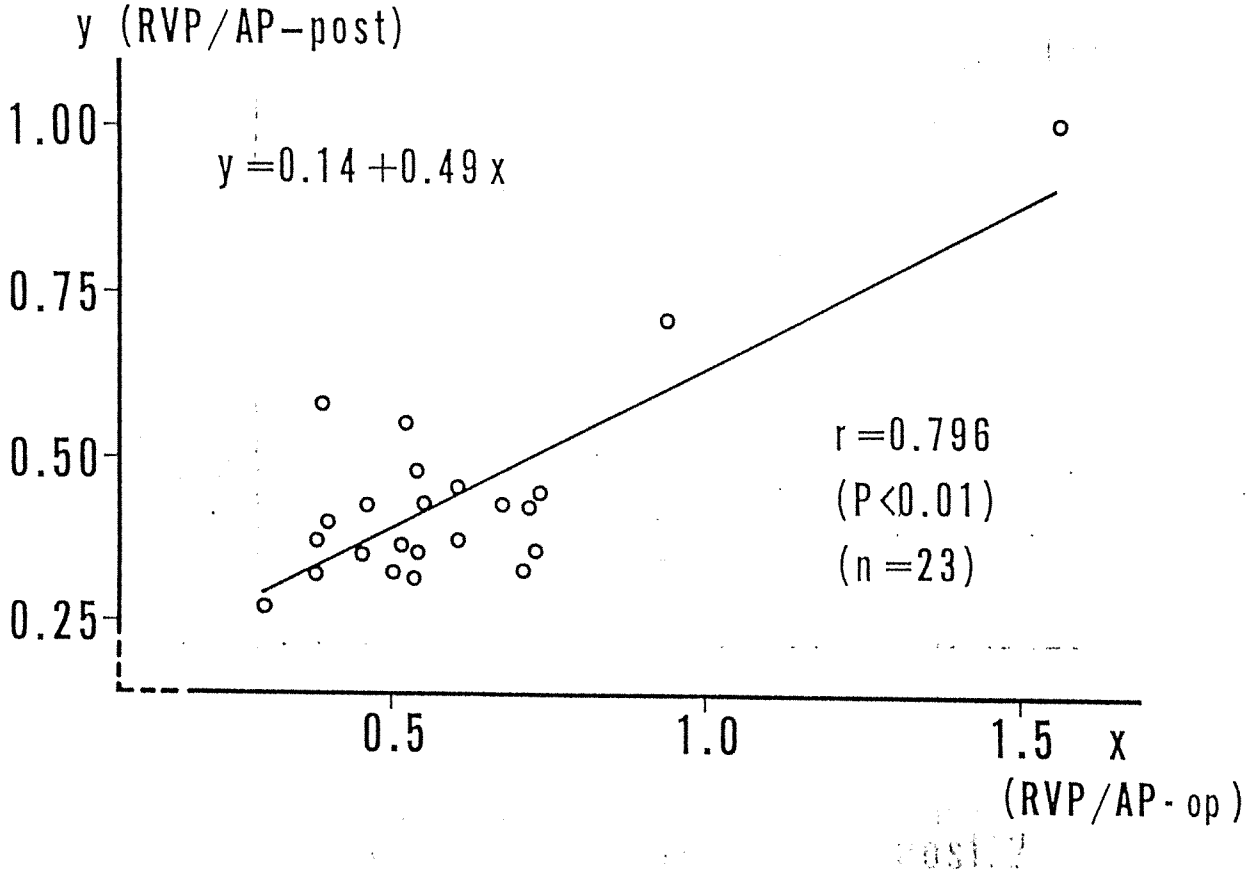
<Fig. 6> Relationship between post-valvotomy pulmonary valvular orifice size (VS/BSA-post) and RVP/AP one month after operation (RVP/AP-post) (only group without outflow patch : op1).



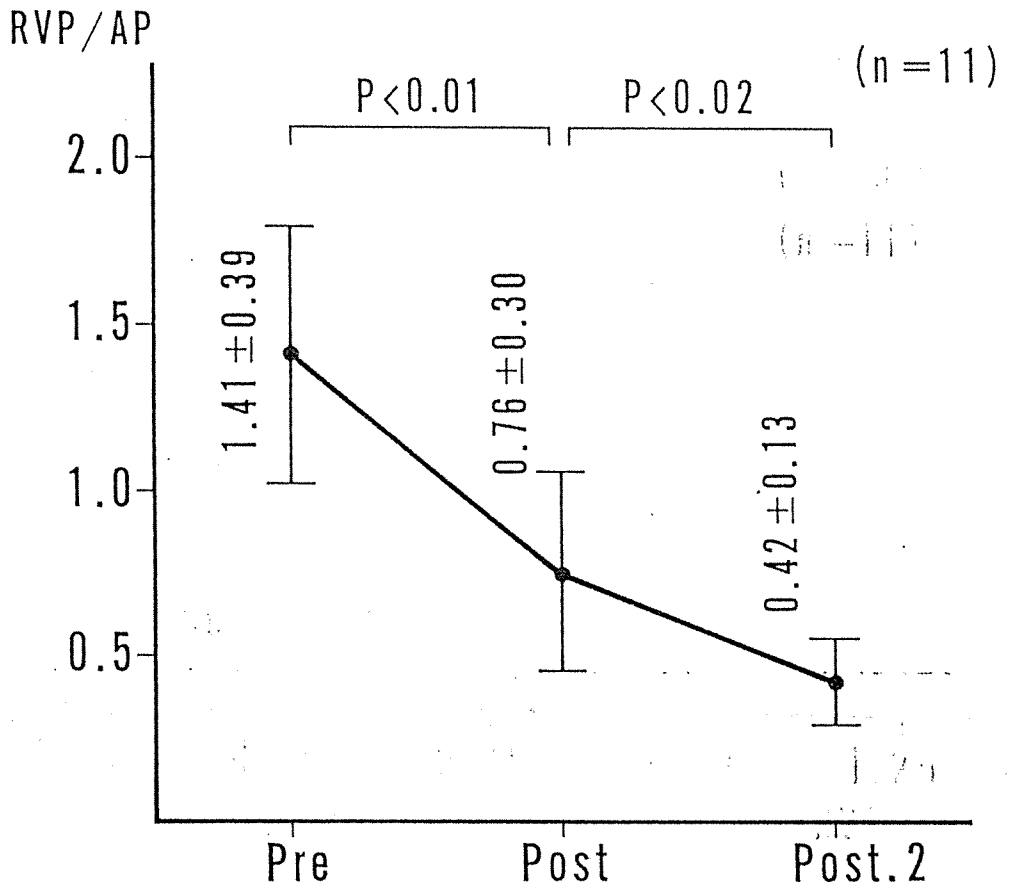
<Fig. 7> Relationship between post-valvotomy pulmonary valvular orifice size (VS/BSA-post) and RVP/AP a long time following operation (RVP/AP-post2).



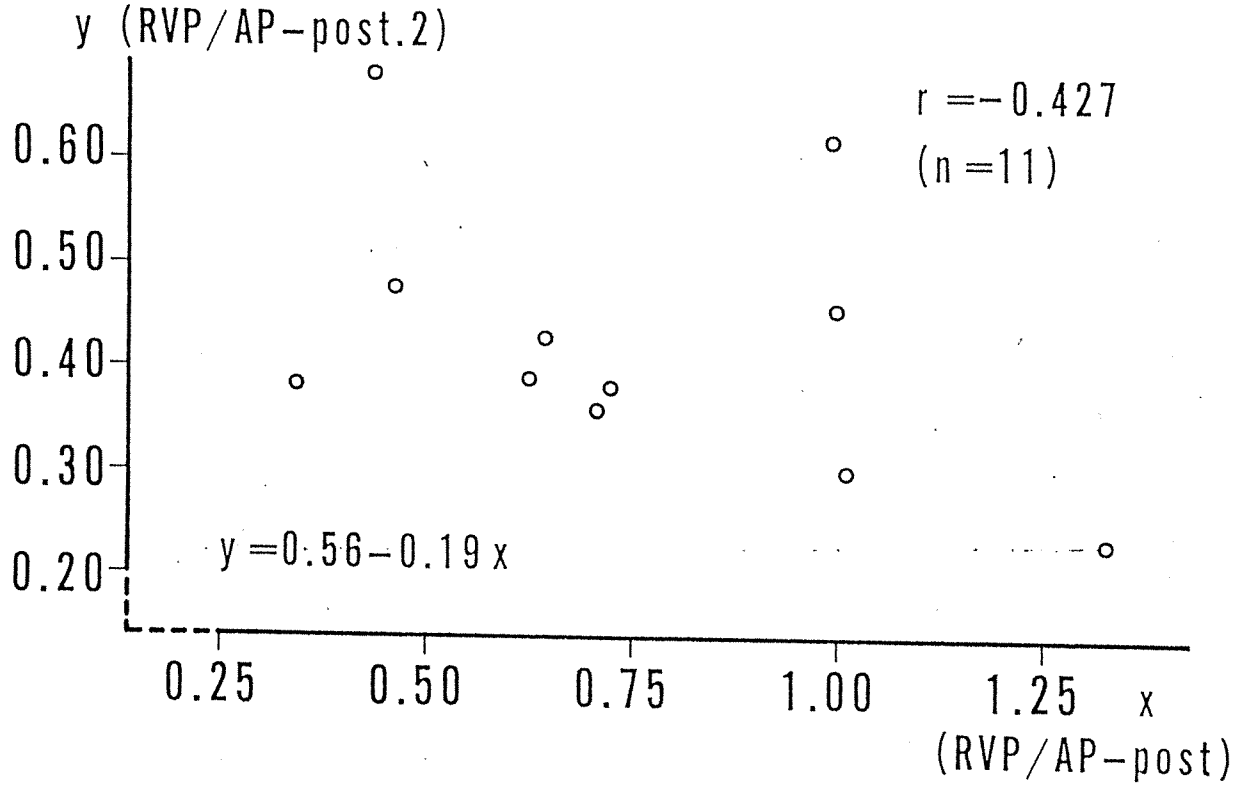
<Fig. 8> RVP/AP ratio during operation, and pre- and post-operative RVP/AP ratios



<Fig. 9> Relationship between RVP/AP ratio just after operation (RVP/AP-op) and RVP/AP ratio one month following operation (RVP/AP-post)



〈Fig. 10〉 RVP/AP, pre-operative (Pre), one month later (Post), and then a much later (Post.2)



<Fig. 11> Relationship between RVP/AP ratio one month later (-post) and a much later (-post.2) after operation.

age	sex	op	RVP/AP pre	RVP/AP post
16	F	1	0.88	1.00
3	M	1	1.16	0.65
6	F	1	1.67	1.00
3	M	1	1.10	1.01
6	M	1	1.59	0.73
8	F	1		0.78
5	M	1	2.00	1.32
6	M	1	1.17	0.73
6	M	1	1.08	0.63
6	M	2	1.67	0.71

<Table 1.> Residual RVP/AP ratios exceeding 0.6 were observed in 9 cases (16.4%), and higher than 0.7 in 7 cases (12.7%) one month following the operation.

RVP/AP pre : pre-operative RVP/AP ratio

RVP/AP post : RVP/AP ratio one month after operation

age	sex	op	RVP/AP post	RVP/AP op	term	RVP/AP post.2
6	M	1	0.73		3	0.37
5	M	1	1.32		13	0.22
16	F	1	1.00		5	0.60
3	M	1	1.01	0.28	6	0.29
3	M	1	0.65			0.42
6	F	1	1.00	1.57	7	0.44
6	M	1	0.63		11	0.38
6	M	2	0.71	0.94	2	0.35
6	F	3	0.45	0.61	3	0.67
3	F	3	0.47	0.54	3	0.47
1	F	3	0.35	0.54	3	0.38

<Table 2.> Cardiac catheterizations were conducted over a long period of time (2 to 13 years) following operation in eleven cases.
RVP/AP post : RVP/AP ratio one month after operation
RVP/AP op : RVP/AP ratio measured immediately after operation
RVP/AP post.2 : RVP/AP ratio measured a long time after operation
term : period (years) from operation to post.2 catheterization