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Original Article

Qualitative Evaluation of Diminished Pulmonary Blood Flow of Congenital Cyanotic Heart Disease by the Pulmonary Venous Wedge Pressure Measurement and Its Surgical Consideration

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Abstract: In 27 cyanotic heart patients with complication of stenosis or atresia involving ventricular septal defect or single ventricle, we evaluated the diminished pulmonary blood flow by the pulmonary venous wedge pressure (PVWP) measurement.

There were significant correlations between mean PVWP and arterial oxygen saturation ($r=0.71$, $P<.01$) and right pulmonary arterial/ascending aortic diameter ratio ($r=0.65$, $P<.01$). Of the 27 patients, 14 (except one with mean PVWP above 13 mmHg) survived, but seven of 12 with mean PVWP below 12 mmHg died from sudden hypoxic attack or postoperative low cardiac output syndrome/late congestive heart failure.

Mean PVWP value is useful as an indirect parameter affected by diminished pulmonary blood flow. In patients with mean PVWP below 12 mmHg, the urgent and/or initial shunt operation is recommended, in view of the threatened hypoxic state and/or unadequate size of pulmonary arteries vis a vis surgical reconstruction of the right ventricular outflow tract.

Key words: Pulmonary venous wedge pressure, Cyanotic heart disease, Diminished pulmonary blood flow, Surgical indication

INTRODUCTION

In congenitally cyanotic heart patients, it is most important to evaluate pulmonary blood flow for deciding surgical indications. In patients with pulmonary arterial stenosis or atresia, however, it is usually difficult to introduce a catheter into a pulmonary artery to assess its pressure. Direct measurement of effective pulmonary blood flow is also impossible. Several affected factors—hemoglobin content (Hb), arterial oxygen saturation (SaO_2) and main pulmonary arterial/ascending aortic (PA/Ao) diameter ratio—have therefore been used as indirect parameters of diminished pulmonary blood flow. On the other hand, it is believed that pulmonary venous wedge (PVWP) might accurately reflect pulmonary arterial pressure in the normal range[1-3)].

The present paper proposes 1) that measured mean pulmonary venous wedge pressure is an indirect parameter of diminished pulmonary blood flow. 2) that it is therefore useful in determining time

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Table 1. Clinical details in 27 cyanotic heart patients with diminished pulmonary blood flow.

Case	Age (years)	Diagnosis	Mean PVWP (mmHg)	SaO_2 (%)	Hb (g/dl)	RPA/Ao ratio	Cause of death
Group A:	Patients treated with corrective surgery.						
1.	11 m	T/F	5	—	18.5	0.50	postop. 7 mon. CHF
2.	2	T/F	16	—	18.9	0.52	
3.	2	T/F	16	83	15.7	0.58	
4.	3	T/F	10	—	14.9	0.35	postop 12 day LOS
5.	5	T/F	20	89	14.9	0.67	
6.	5	T/F	18	86	21.0	0.75	
7.	5	T/F	8	—	20.2	0.48	
8.	7	T/F	10	58	24.2	0.43	postop 14 day LOS
9.	13	T/F (B-T)	13	—	17.1	0.62	
10.	16	T/F (B-T)	17	—	16.0	0.60	
11.	20	SV, PS	19	85	22.2	0.86	
12.	22	T/F	20	82	23.4	0.60	
13.	27	T/F (B-T)	20	93	18.1	0.38	
Group B:	Patients treated with palliative or shunt surgery,						
14.	5 m	TGA, SV, PS	15	—	23.5	0.47	
15.	2	TGA, VSD, PS	14	66	22.4	0.50	
16.	3	TGA, SV, PS	10	68	26.3	0.68	
17.	4	TA, PS	13	—	12.3	0.58	postop 10 mon. SVC syndrome
18.	4	TGA, SV, PA	9	—	25.3	0.18	
19.	6	T/F	10	—	23.4	0.36	
Group C:	Patients treated without surgery.						
20.	2 m	T/F	11	81	15.5	0.28	hypoxic attack
21.	1	TA, PS	12	74	23.5	0.50	
22.	1	PS, TR, ASD	11	—	18.6	0.30	hypoxic attack
23.	1	T/F	7	—	19.0	0.20	hypoxic attack
24.	2	TGA, VSD, PS	12	72	29.0	0.45	hypoxic attack
25.	4	DORV, PS	16	91	13.5	0.68	
26.	5	DORV, PS	17	89	17.8	0.55	
27.	6	T/F	16	—	16.5	0.35	

Abbreviations: PVWP: pulmonary venous wedge pressure; SaO_2: arterial oxygen saturation; Hb: hemoglobin content; RPA/Ao: right pulmonary arterial/ascending aortic diameter ratio; T/F: tetralogy of Fallot; B-T: Blalock-Taussig shunt; SV: single ventricle; PS: pulmonary stenosis; TGA: transposition of great arteries; VSD: ventricular septal defect; PA: pulmonary atresia; TA: tricuspid atresia; TR: tricuspid regurigitation; ASD: atrial septal defect; DORV: double outlet right ventricle; CHF: congestive heart failure; LOS: low cardiac output syndrome; SVC: superior vena cava.

of surgery (urgent or elective) and type of operative procedure (palliative or corrective) in patients with congenital cyanotic heart disease.

Subjects and Methods

The hemodynamic records of patients undergoing cardiac catheterization for diagnosis of congenital cyanotic heart disease

at Niigata University Hospital, JR Tokyo General Hospital and Yamanashi Medical College Hospital were analyzed. The subjects had congenital heart diseases with diminished pulmonary blood flow resulting from pulmonary stenosis or atresia with ventricular septal defect or single ventricle, excluding nonconfluent bilateral pulmonary arteries and major pulmonary collateral arteries. Patients ages varied from two months to 27 years.

Infants were generally anesthetized with ketamin-KCl and atropine sulfate; older children/adults were studied under local anesthesia with sedative premedication during cardiac catheterization. The catheter used varied from 6 to 8 French end-hole type. Pressure, measured with Statham P23-GB transducers, were recorded by a Fukuda Electronics Recorder. The pulmonary venous wedge pressures (PVWP) were obtained at one or more pulmonary venous wedge positions through the atrial septal defect or the patent foramen ovale. The criteria for accepting a PVWP as satisfactory were the appearance of an arterial pressure-wave contour and an abrupt change in pressure contour and level when the catheter was withdrawn from the wedge to a free pulmonary vein position. However, obtained pulse pressures in patients with diminished pulmonary blood flow were limited; therefore the mean PVWP values were analyzed as a parameter. On angiography, the diameters of the right pulmonary artery one centimeter distant from the pulmonary bifurcation and of the ascending aorta at the same horizontal level were calculated and compared as to size.

Clinical details in 27 patients are shown in Table 1. The patients were divided into three groups according to surgical procedures, as follows;

Group A : 13 cases treated with correcrective surgery.

Group B : 6 cases treated with palliative or shunt surgery.

Group C : 8 cases treated without surgery.

Statistical comparisons were made between mean PVWP and other affected parameters—hemoglobin (Hb) content, arterial oxygen saturation (SaO_2) and right pulmonary arterial/ascending aortic (RPA/Ao) diameter ratio—in subjects. Comparisons were also made of mean PVWP and other parameters in patient groups with sufficient or insufficient pulmonary blood flow, as estimated via mean PVWP, and in surviving or deceased patient groups. Paired observations were statistically compared via regression equation and correlation coefficient.

Results

I. Statistical correlation between mean PVWP and other parameters.

1. Correlation between mean PVWP and arterial oxygen saturation (SaO_2). (Fig. 1)

Significant correlation was obtained ($y=2.03X+49.2$, $r=0.71$, $P<0.01$). The overall value of distribution of SaO_2 ranged from 58 to 93%. In three patients with highest mean PVWP of 20 mmHg, SaO_2 varied from 82 to 93%, but in five patients with SaO_2 of less than 80%, mean PVWP ranged from 10 to 14 mmHg.

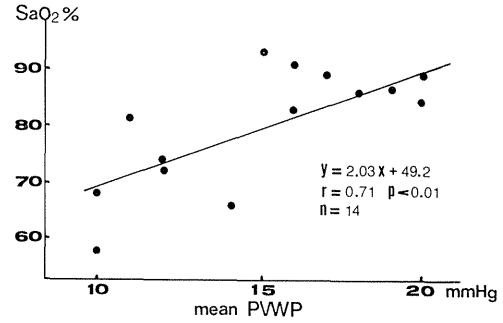


Fig. 1. Correlation between mean PVWP and arterial oxygen saturation (SaO_2).

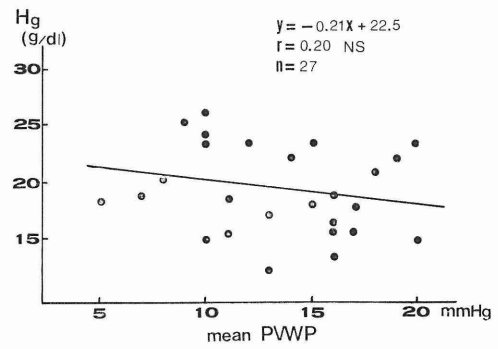


Fig. 2. Correlation between mean PVWP and hemoglobin (Hb) content.

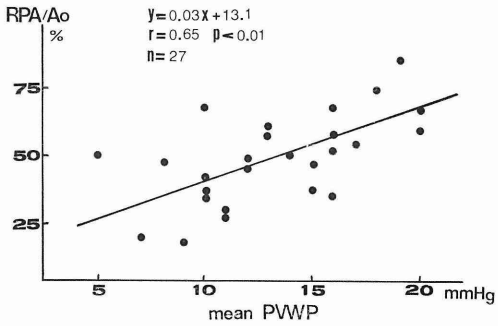


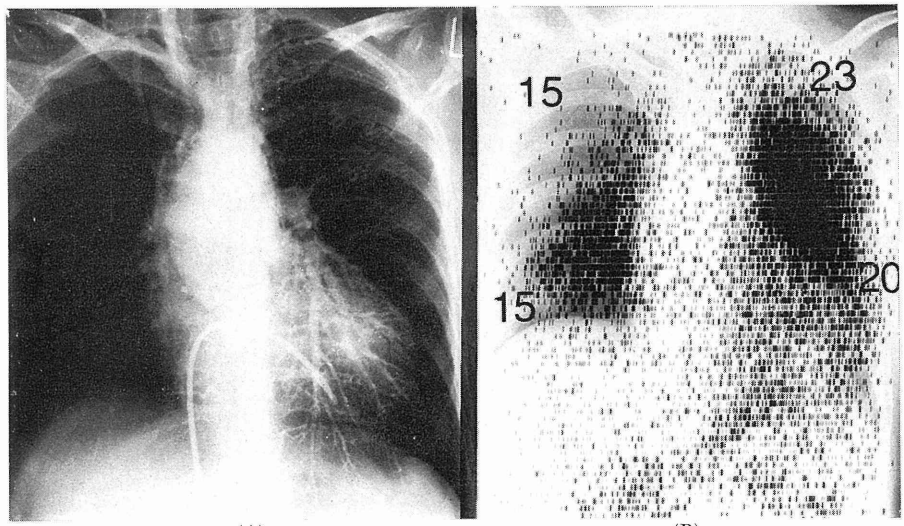
Fig. 3. Correlation between mean PVWP and right pulmonary arterial/ascending aortic (RPA/Ao) diameter ratio.

2. Correlation between mean PVWP and hemoglobin (Hb) content. (Fig. 2)

Very poor correlation was found here (y=−0.21X+22.5, r=0.20, NS). The range of hemoglobin values was 12.3 to 29.0 g/dl.

3. Correlation between mean PVWP and right pulmonary arterial/ascending aortic (RPA/Ao) diameter ratio. (Fig. 3)

These parameter showed good correlation (y=0.03X+0.13, r=0.65, P<0.01). The range of RPA/Ao ratio was 0.18 to 0.86. In 9 of 10 patients with PRA/Ao ratio above 0.55, the values of mean PVWP ranged from 13 to 20 mmHg. On the other hand, the values were below 12 mmHg in 11 out of 15 patients with RPA/Ao ratio below 0.50. However, in a patient (case 13) with an RPA/Ao ratio of 0.38, mean PVWP in the left upper lobe, affected by left Blalock-Taussig shunt, showed 23 mmHg, but was 15 mmHg in the right upper and lower lobes. The values of mean PVWP in both lungs are shown in comparison with radioisotope pulmonary perfusion scanning in Fig. 4.



(A) (B)

Fig. 4. Case 13. 27-year-old female, Tetralogy of Fallot with left Blalock-Taussig shunt; right ventriculogram demonstrated right pulmonary arteries less hypoplastic than those of left lung (A). Radioisotope pulmonary perfusion scanning showed different blood distribution on both lungs, whose mean PVWP (mmHg) are noted in (B).

Table 2. Interrelation of several parameters in two groups according to range of mean PVWP.

Parameters	Mean PVWP		P-value
	>13 mmHg n=15	<12 mmHg n=12	
Hemoglobin (g/dl)	18.2 ±3.6	21.5 ±4.4	<0.05
SaO_2 (%)	84.9 ±8.0	70.6 ±8.5	<0.01
RPA/Ao diameter ratio	0.58±0.13	0.39±0.14	<0.01

Table 3. Interrelation of several parameters in 19 surviving and 8 deceased patients groups.

Parameters	Surviving n=19	Deceased n=8	P-value
Mean PVWP (mmHg)	15.0 ±3.7	8.4 ± 2.5	<0.01
Hemoglobin (g/dl)	19.6 ±4.1	20.0 ± 5.0	NS
SaO_2 (%)	82.4 ±9.2	70.3 ±11.6	NS
RPA/Ao diameter ratio	0.55±0.15	0.36± 0.11	<0.01

II. Statistical comparisons of several parameters in two clinical groups.

1. Interrelation of several parameters in two groups according to the range of mean PVWP. (Table 2)

In 15 patients with mean PVWP above 13 mmHg, in comparison with 12 patients of below 12 mmHg, all parameters showed significant differences; Hb (18.2 in the former vs 21.5 g/dl in the latter patients, $P<0.01$), SaO_2 (84.9 vs 70.6%, $P<0.01$) and RPA/Ao ratio (0.58 vs 0.39, $P<0.01$).

2. Interrelation of several parameters in 19 surviving and 8 deceased patients. (Table 3)

Two parameters showed statistical significance: mean PVWP (15.0 in the surviving vs 8.4 g/dl in the deceased, $P<0.01$) and RPA/Ao ratio (0.55 vs 0.36, $P<0.01$). There were no statistical differences of Hb content and SaO_2, however. Because SaO_2 was compared in a small number of deceased patients, whose data was satisfactory, the comparison was not statistically significant.

3. Clinical results, followed by operative procedures, in the groups in accordance with mean PVWP. (Fig. 5)

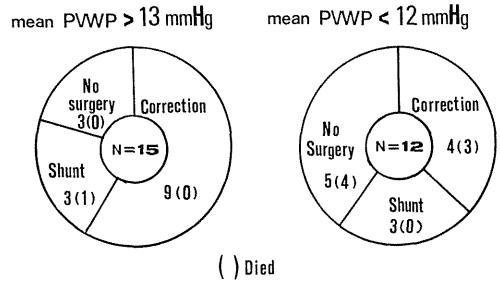


Fig.5. Clinical results followed by operative procedures in two groups according to mean PVWP.

Of 27 patients, seven died from sudden hypoxic attack before surgery or post-operative low cardiac output syndrome/late congestive heart failure. These latter had belonged to the group with mean PVWP below 12 mmHg. Retrospectively, their clinical results were unexpectedly very poor. On the other hand, in the group with mean PVWP above 13 mmHg, only one (case 17) with a mean PVWP of 13 mmHg died ten months later from superior vena cava syndrome after Glenn shunt.

Discussion

In congenitally cyanotic heart patients

with complication of stenosis or atresia involving ventricular septal defect or single ventricle, survival prognosis depends upon adequacy of the pulmonary blood flow. We have used hemoglobin (Hb) content or arterial oxygen saturation (SaO_2) values as physiological parameters, and pulmonary arterial/aortic (PA/Ao) diameter ratio as an anatomical parameter in indirectly evaluating diminished pulmonary blood flow. However, these parameters are somewhat controversial. Concerning Hb content, polycythemia could be observed in older patients, but we sometimes encounter more anemic infants with those heart conditions. Therefore, this parameter showed the least correlation in our results. As well, SaO_2 might be affected easily by blood sampling conditions, during crying or at rest.

From the surgical viewpoint, it is most important to know whether the pulmonary arteries of both lungs have adequate flow and size to sustain life and as regards indications for surgical correction. Consequently, we wish to obtain a more accurate parameter for evaluating diminished pulmonary blood flow.

Pulmonary venous wedge pressure (PVWP) is sometimes used as an indirect measurement of pulmonary artery pressure (PAP) in cases of congenital heart disease when catheterization of the pulmonary artery is unsuccessful. It is known that the correlation is poor in the presence of severe pulmonary hypertension. But Hewker and Celermajer[2] reported that mean PVWP correlated well with mean PAP below 30 mmHg in patients with increased pulmonary blood flow, and also had a good correlation in patients with diminished pulmonary blood flow, in which mean PAP were frequently below 8 mmHg. Our previous study[3] also showed similar results, the mean PVWP showing better correlation than systolic and diastolic pressures. In the present study, we used the mean PVWP values for statistical analysis. It was thought that the correlation of mean pressures would be more meaningful, since they might to be less affected by the dumping effect on the pressure wave transmitted through the pulmonary vascular bed. Moreover, mean PVWP, almost equal to mean PAP in the normal range of pressures, is used in evaluating pulmonary vascular resistance and resistance ratio, and in the assessment of pulmonary vascular disease[2].

In discussing usefulness of mean PVWP, however, it is necessary to recognize that the wedging phenomena depends on the lack of anastomosis between pulmonary arterioles and large veins, the absence of valves in the veins, and the rich capillary network in the lungs. Wilson et al.[4] also state that by occluding the flow, the catheter becomes the extension of a column of blood which transmits pressure from the opposite side of the lung bed. Reflex pulmonary vein distension has also been well established[5], but it seems unlikely that the wedging of a 5 or 6 French catheter would distend a pulmonary vein sufficiently to trigger these reflexes and produce an artifactually low PVWP.

In some cases complicated by nonconfluent pulmonary arteries or unilateral pulmonary artery stenosis/atresia, the pulmonary blood blow of each lung might often be supplied severally by major pulmonary collateral arteries. In such patients, mean pressure obtained in one pulmonary venous wedge position is not always reflective of the PVWP of other pulmonary lobes, as our case shows (Fig. 4). However, this method is very useful in the assessment of pulmonary blood distribution in the lungs, is compared with qualitative analysis by radioisotope pulmonary perfusion scanning.

We feel therefore that provided the limitations of this means of measurement are

clearly recognized, pulmonary venous wedge pressure recording can prove a valuable aid in the hemodynamic assessment of some cases of congenital heart disease. To our knowledge, this is the first original report concerning the qualitative evaluation of diminished pulmonary blood flow from the surgical viewpoint, using the PVWP measurement method.

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