Pulmonary Segmental Artery Ratio

An Alternative to the Pulmonary Artery Index in Patients With Tetralogy of Fallot

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SUMMARY

The objective of this study was to determine a reliable, alternative ratio to the pulmonary artery (PA) index, which will help to estimate the adequacy of postoperative pulmonary blood flow in patients with tetralogy of Fallot.

We propose the pulmonary segmental artery ratio (PSAR), which is an angiographic measure for the quantitative standardization of the total number of pulmonary segmental arteries in a patient. The expected value of the PSAR is 1 and it is constant after the 16th week of intrauterine life. Retrospective analysis of the PSAR and PA index calculations in patients with tetralogy of Fallot was conducted. Sixty-one patients were assigned to a moderate or low risk group according to their PSAR; the low risk group included 31 patients whose PSAR was between 0.75-1 (group 1) while the moderate risk group included 30 patients whose PSAR was between 0.50-0.75 (group 2). High risk patients whose PSAR was less than 0.50 were excluded from the study. Postoperative peak right ventricular pressure, the pulmonary artery to systemic pressure ratio, and peripheral arterial oxygen saturation preoperatively after cardiopulmonary bypass were analyzed separately in groups 1 and 2. Postoperative peak right ventricular pressure was lower in group 1 than group 2, while the pulmonary artery to systemic pressure ratio and peripheral arterial oxygen saturation were higher in group 1 than group 2 ($P < 0.01$).

Based on the present findings, it is concluded that PSAR is not as reliable as the Nakata index. However, in cases in which the PSAR and PA index are not correlated, PSAR may be helpful for determining the adequacy of postoperative pulmonary blood flow and postoperative outcomes of patients with hypoplastic pulmonary arteries. (Int Heart J 2006; 47: 67-75)

Key words: Tetralogy of Fallot, Pulmonary segmental artery ratio, Aorta pulmonary collaterals

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THE bronchopulmonary segment is the basic topographical unit of the lung. In about the 16th week of intrauterine life, the pulmonary segmental arteries and preacinar structures of the bronchi are all present in the numbers and anatomical distribution that they will maintain throughout life.[1] However, at the microscopic level, important changes occur in the acinar structures. Although they continue to grow, the acinar structures have yet to develop, especially in the first year of postnatal life, and continue growing until 10 years of age.[2] Healthy lung segments should be incorporated into the unifocalized pulmonary circulation as early as possible after birth because of the tremendous potential for additional growth and development of the pulmonary circulation and parenchyma that exists in early infancy.[3] Thus, congenital heart surgeons today have become more aggressive about the type and timing of corrective surgery. At this point, an efficient pulmonary circulation will play a crucial role in better postoperative outcomes and more preferable functional status. An important physiologic component of a favorable outcome is the postrepair peak right ventricular pressure, which may depend greatly upon the pulmonary arterial and aorta-pulmonary collateral morphology as well as the type of repair procedure.[4] Thus, the ultimate goals are to decide whether to choose a single stage correction in early infancy or not and how to determine the timing and type of operation for these patients.

METHODS

This was a retrospective study. Sixty-one consecutive patients between the ages 1 and 3 with a diagnosis of ToF who underwent surgical repair from January 1996 to May 2004 were identified from our cardiac surgery database. Preoperative cardiac catheterization and operative data were collected by reviewing hospital records. We included patients with a prior systemic to pulmonary artery shunt, and excluded patients with all other associated cardiac anomalies, noncardiac anomalies, ventricular septal defect with pulmonary atresia, patients with a PSAR < 0.50, major aorta-pulmonary collaterals requiring unifocalization, and malformation syndromes.

Measurements: The cross-sectional areas of bilateral pulmonary arteries proximal to lobar branching were measured and the number of pulmonary segmental arteries distal to lobar branching were counted one by one from preoperative cardiac catheterizations. From these measurements, the Nakata index and pulmonary segmental artery ratio (PSAR) were calculated. In order to calculate the PSAR, the number of pulmonary segmental arteries distal to lobar branching were counted bilaterally and divided by 20, which is the expected number in healthy individuals. In this way, we calculated the total number of pulmonary segmental arteries in the patients in proportion to healthy individuals and obtained the ratio

for the patients. We then classified the patients according to their ratios into 3 different groups - a moderate risk group with a ratio between 0.50-0.75, a low risk group with a ratio between 0.75-1, and a high risk group whose PSAR was less than 0.50. The moderate and low risk groups were included in the study while the high risk patients were excluded. Operative factors that were assessed were the age, weight, and body surface area of the patient, the duration of aortic cross-clamping and cardiopulmonary bypass, the use of a transannular patch, and the ratio of mean right ventricular to left ventricular systolic pressure and peak right ventricular pressure at the end of the procedure. After decannulation, the postoperative peak right ventricular and systemic arterial pressures, heart rate, central venous pressure, and peripheral arterial oxygen saturation were analyzed. The postoperative use and doses of intravenous inotropic and vasodilator infusions, the occurrence of postoperative arrhythmias, and the presence of chest roentgenographic changes such as pulmonary athelectasis and effusions were recorded. The cases of patients who died were reviewed for cause of death and were noted.

Surgical technique: After median sternotomy, a pericardial patch was removed for subsequent use. The native pulmonary arteries (PA) were dissected and isolated up to their hilar region and if there was a prior systemic to pulmonary artery shunt, it was dissected and isolated as well. The aorta-pulmonary collaterals (if present) were approached as per their course delineated by the preoperative angiography to a sufficient length from their origin in order to ligate them safely. After CPB was established under cardioplegic arrest, the VSD was closed with a PTFE patch and hegar dilators were passed through the tricuspid valve (TV) into the PA to calibrate the right ventricular outflow tract (RVOT). If a dilator of adequate caliber could not be passed through the RVOT and PV, then the PA incision was extended across the annulus through the anterior commissure (in an attempt to preserve some PV function), for 5-10 mm onto the RV free wall. Transannular patching and reconstruction of the RVOT and hypoplastic pulmonary arteries were performed in 25 patients in group 1 and in 28 patients in group 2 using pericardial patches.

Data analysis: All data are presented as frequencies, medians with ranges, and means with standard deviations, as appropriate. The level of significance was a *P* value less than or equal to 0.05. Results are presented as the mean ± standard deviation and the significance of the differences between the mean values was analyzed by the Student t-test, with a level of significance of $P < 0.05$. The correlations between PSAR, pulmonary artery index (PA index), peak right ventricular pressure, ratio of pulmonary arterial pressure to the systemic pressure, and oxygen saturation were analyzed using Pearson's correlation. SPSS Version 10.0 software (SPSS Inc, Chicago, Illinois) with default settings was used.

RESULTS

As mentioned above, the patients were divided into 3 different groups according to their PSAR; 31 patients with a PSAR between 0.75-1 (group 1) and 30 patients with a PSAR between 0.50-0.75 (group 2). The mean PSAR of group 1 was 0.85 ± 0.07 and that of group 2 0.69 ± 0.07, which was significantly lower than the mean PSAR of group 1 ($P < 0.001$). Patients in the third group whose PSAR was < 0.50 were excluded from the study.

There were no significant differences in the mean ages (group 1, 1.7 ± 0.7 years, group 2, 2.2 ± 0.8 years), weights (group 1, 10.8 ± 1.9 kg, group 2, 13.0 ± 3.7 kg), heights (group 1, 70.8 ± 5.4 cm, group 2, 83.5 ± 6.3 cm) between the 2 groups. Mean body surface area was 0.52 ± 0.14 m^2 in group 1 and 0.56 ± 0.14 m^2 in group 2, and the difference was not statistically significant (Table I).

Postoperative peak right ventricular pressure (group 1, 31.0 ± 3.5 mmHg, group 2, 36.5 ± 3.0 mmHg; $P < 0.001$) and pulmonary artery pressure (group 1, 25.8 ± 3.7 mmHg, group 2, 33.7 ± 3.7 mmHg; $P < 0.001$) were significantly lower in group 1 than group 2. Systolic blood pressure was not different between the groups (89.0 ± 7.5 mmHg and 88.0 ± 6.6 mmHg, respectively). However, the ratio of pulmonary arterial pressure to systemic pressure was significantly lower in group 1 than in group 2 patients (29.1% ± 4.1% and 38.4% ± 4.4%, respec-

Table I. Basic Characteristic of Study Groups

	Group 1 (n = 31)	Group 2 (n = 30)	P
Age	1.7 ± 0.7	2.2 ± 0.8	0.194
Weight (kg)	10.8 ± 1.9	13.0 ± 3.7	0.202
Height (cm)	70.8 ± 5.4	83.5 ± 6.3	0.160
Body surface area (m^2)	0.52 ± 0.14	0.56 ± 0.14	0.286

Values are presented as mean ± standard deviation.

Table II. Pulmonary Segmental Artery Ratio, Peak Right Ventricular Pressure, Pulmonary Arterial Pressure, Systolic Blood Pressure, Ratio of Pulmonary Arterial Pressure to Systemic Blood Pressure, Oxygen Saturation, and PA Indexes of Group 1 and Group 2

	Group 1 (n = 31)	Group 2 (n = 30)	P
Pulmonary segmental artery ratio	0.85 ± 0.07	0.69 ± 0.07	< 0.001
Peak right ventricular pressure	31.0 ± 3.5	36.5 ± 3.0	< 0.001
Pulmonary arterial pressure	25.8 ± 3.7	33.7 ± 3.7	< 0.001
Systolic blood pressure	89.0 ± 7.5	88.0 ± 6.6	0.571
Pulmonary arterial pressure/systemic blood pressure	29.1% ± 4.1	38.4% ± 4.4	< 0.001
Oxygen saturation	96.5 ± 1.9	91.3 ± 1.5	< 0.001
PA index	285 ± 50	216 ± 31	< 0.001

Table III. Correlation Ccoefficients (r) Between PSAR and PA Index, Peak Right Ventricular Pressure, Ratio of Pulmonary Arterial Pressure to the Systemic Pressure and Oxygen Saturation and Pulmonary Segmental Artery Ratio

	r	*P*
PSAR- PA index	0.440	< 0.001
PSAR- Peak right ventricular pressure	-0.484	< 0.001
PSAR- Ratio of pulmonary arterial pressure to the systemic pressure	-0.666	< 0.001
PSAR- Oxygen saturation	0.579	< 0.001

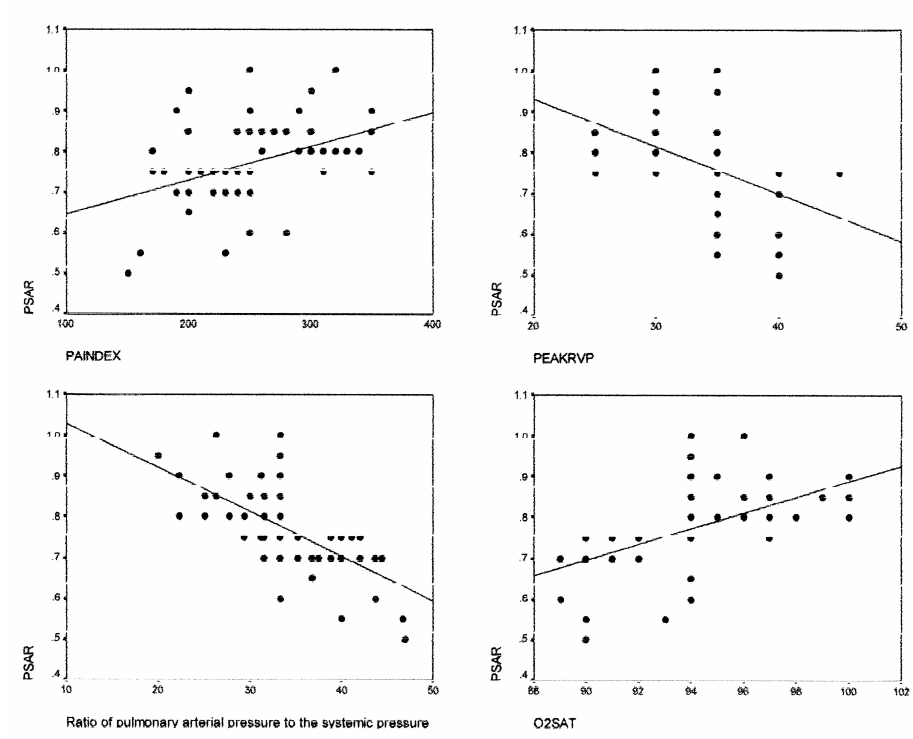


Figure 1. Scatter plots between PSAR and PA index, peak right ventricular pressure, ratio of pulmonary arterial pressure to the systemic pressure, and oxygen saturation. PSAR indicates pulmonary segmental artery ratio; PEAKRVP, peak right ventricular pressure; PA index, pulmonary artery index; and O2SAT, oxygen saturation.

tively; $P < 0.001$).

On the other hand, peripheral arterial oxygen saturation (group 1, 96.5% ± 1.9%, group 2, 91.3% ± 1.5%) and the PA index (group 1, 285 ± 50, group 2, 216 ± 31) were higher in group 1 than in group 2 ($P < 0.01$) (Table II).

The Pearson correlation coefficients and scatter plots between PSAR and

the PA index, peak right ventricular pressure, the ratio of pulmonary arterial pressure to systemic pressure, and oxygen saturation are presented in Table III and Figure 1.

DISCUSSION

Tetralogy of Fallot (ToF) is the most common cause of cyanotic congenital heart disease and is responsible for as many as 10% of all cases of congenital heart disease. It consists of a right ventricular outflow tract obstruction, a malalignment ventricular septal defect, an overriding aorta, and right ventricular hypertrophy. The mortality rates for untreated ToF are progressive with patient age; for example, the mortality rate is 25% at the age of 1, while it dramatically increases to 40% at the age of 3 and 70% at the age of 10.[2-7] Therefore, the type and timing of corrective surgery is important. Surgical treatment has greatly improved the prognosis because of the introduction of palliative shunts and corrective surgery.[8-10] In patients with ToF, the feasibility of complete operative repair is largely dependent on the underlying distribution and size of the pulmonary arteries.[11,12] The pulmonary segmental arteries and preacinar structure of the bronchi, which is called the bronchopulmonary segment, are the basic topographical units of the lung. Although there is still disagreement with respect to whether the number of normal pulmonary segments is 20, it is widely accepted that the total number of bronchopulmonary segments is 20 in healthy individuals.[1,2] In our study, we assumed the total number of pulmonary segmental arteries was 20 in healthy individuals, however, while we were forming the groups, wide ranges of percentage intervals were used in order to minimize statistical errors.

On the other hand, an important feature of the morphology of ToF is the frequent failure of the pulmonary arteries to distribute to all 20 pulmonary vascular segments.[13] Thus, although many studies have examined this topic, ToF patients have not yet been quantitatively standardized into groups according to the number of pulmonary vascular segments. For the first time, we defined the number of pulmonary segmental arteries in ToF patients as a ratio. Using this method, we were able to classify these patients into groups. The reason for doing this was to determine whether or not the total number of pulmonary segmental arteries in ToF patients affects the postoperative results. Thus, we used 2 groups, a low risk group whose total number of pulmonary segmental arteries was 15-20 and PSAR was 0.75-1 (group 1) and a moderate risk group whose total number of pulmonary segmental arteries was 10-15 and PSAR was 0.50-0.75 (group 2). Previous studies reported 74% of their ToF patients had a total of between 15 and 20 pulmonary segmental arteries, while 23% had between 10 and 15.[13,14] Thus, ToF patients who had more than 10 pulmonary segmental arteries, which account for

approximately 97%, were included in this study.

An efficient pulmonary circulation will play a crucial role in achieving a favorable postoperative outcome and more preferable functional status.[8-12] An important physiologic component of a favorable outcome is the postrepair peak right ventricular pressure, which may depend greatly upon the pulmonary arterial and aorta-pulmonary collateral morphology, as well as the type of repair performed.[4-8]

In the present study, low and moderate risk patients were included while high risk patients with a PSAR < 0.50 were excluded. Therefore, the postrepair peak right ventricular pressures were very similar in the 2 groups. However, although the pressures were similar, there were statistically important differences in this data between the 2 groups. On the other hand, we performed transannular repair in most of the patients, which is also an important determinant in the postrepair peak right ventricular pressure in Tof patients. We believe this may have been another reason why the postrepair peak right ventricular pressures were similar.

Angiography, which has been used for preoperative evaluation of the coronary arteries and peripheral pulmonary circulation, is the traditional criterion standard for the evaluation of pulmonary and coronary arterial morphology.[15] The morphology of systemic collateral arteries is best assessed with conventional angiography.[16] In our study conventional biplane cineangiography was used. It should be mentioned that the lobar branches of the pulmonary arteries can be seen better in 3-D images, although 2-D images in a certain view may be adequate to count the lobar branches of the pulmonary arteries by using different angles.[18] Due to recent advances in cardiac surgery and echocardiography, some surgeons presently believe that there is no need to perform angiography as a preoperative test. However, we are still using it at our center in order to evaluate pulmonary and coronary arterial morphology.

The McGoon ratio and the Nakata index, which are angiographic indexes, are used to determine if the branch pulmonary arteries are large enough to permit corrective surgery. Children with small ratios are poor candidates for complete repair because of the inability of the small pulmonary arteries to adequately handle the increased blood flow after complete repair.[6,12,13]

The present results indicate PSAR is a promising index that can be used to estimate the postoperative success in some cases. The findings of this study have showed that if the PSAR value is less than 0.75, then the PA index and oxygen saturation are lower compared to when the PSAR value is greater than 0.75. On the other hand, postoperative peak right ventricle pressure and pulmonary arterial pressure, and the ratio of this pulmonary artery pressure to systemic pressure, were higher in the group with the smaller PSAR values. It is well known the mor-

tality rates for untreated ToF progress with age, which makes it necessary to decide as soon as possible about performing surgery. Not only the timing, but also the type of corrective surgery is important. Thus, reliable ratios and indexes are needed to decide when and how to perform the surgery. The morphology and physiology of the pulmonary arteries are 2 main factors used to determine these ratios and indexes because the distribution, size of the pulmonary arteries, and efficiency of the pulmonary circulation are critical factors for successful surgery.[4,5,8,11,12)]

The McGoon ratio, which is the combined branch pulmonary arterial diameters divided by the descending aorta diameter, and the Nakata index, which is the combined cross-sectional area of the branch pulmonary arteries per square meter, are used to determine if the branch pulmonary arteries are large enough to permit corrective surgery.[12,17)] Like the Mcgoon and Nakata indexes, smaller PSAR values are related to poor postsurgical outcomes, although in some cases PSAR and the PA index may not always be correlated (Figure 2). In these cases, however, the PA index was normal when the PSAR ranged between 0.50 and 0.75 (moderate risk-group 2). Postoperative peak right ventricular pressure and pulmonary artery pressure in group 2 were 36.5 ± 3.0 mmHg and 33.7 ± 3.7 mmHg, respectively, both of which were significantly lower in group 1 than group 2, suggesting that although the PA index was within the normal in range in these cases, their postoperative outcomes were not as good as expected.

In conclusion, PSAR may not be as reliable as the Nakata index, although in some cases, especially if the PA index was within the normal range and PSAR was between 0.50 and 0.75, PSAR may be helpful for determining the adequacy

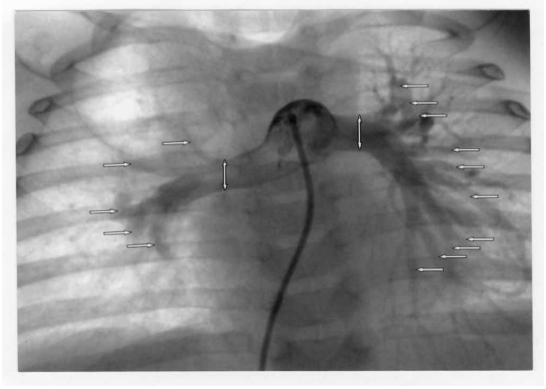


Figure 2. PA index was calculated as being 280 mm^2/BSA between vertical arrows and PSAR calculated by counting horizontal arrows was 0.75.

of postoperative pulmonary blood flow and postoperative outcomes of patients with hypoplastic right and left pulmonary arteries as well as making a decision concerning the type and timing of the surgery.

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