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Tetralogy of Fallot Correction in Low Z-scores: Expanding the Use of the Valve-sparing Approach

Sabrina Anne G. Gonzales, M.D.; Richard S. Nicolas, M.D. and Gisel T. Catalan, M.D., F.P.C.S.

Division of Thoracic and Cardiovascular Surgery, Department of Surgery, Philippine General Hospital, University of the Philippines Manila

Objective: Sparing the pulmonary valve (PV) complex in tetralogy of Fallot (TOF) repair prevents pulmonary regurgitation and consequently, the need for valve replacement. Traditional criteria for employing a valve-sparing strategy include a PV z-score of > -2. This retrospective cohort study aimed to establish differences in outcomes between patients with low and high z-scores who underwent a pulmonary valve-sparing technique of TOF correction.

Methods: From 2002 to 2012, 59 patients were subjected to a PV-sparing TOF repair. Of these, 25 patients had low z-scores ? -3 (Group 1), while 34 patients had high z-scores > -3 (Group 2). A retrospective review of patient outcomes and follow-up two-dimensional transthoracic echocardiograms in the immediate and intermediate postoperative periods was conducted.

Results: There was no significant difference in baseline patient characteristics except in PV z-scores. Average z-scores were -4.85 for Group 1 and -1.45 for Group 2 (P-value 0.00). No significant difference in immediate postoperative outcomes was noted between groups, specifically in terms of arrhythmias, conversions, early reoperations, morbidity and mortality. There were three deaths (5%) in the series. For intermediate outcomes, Group 1 had a higher degree of residual stenosis than Group 2; however, this did not translate to an increase in late reoperation rates. In both groups, there was note of a significant decrease in residual obstruction through time (P-value 0.00).

Conclusion: A pulmonary valve-sparing TOF repair can be successfully utilized even in patients with low pulmonary valve z-scores, with similarly acceptable outcomes as in those with larger pulmonary valve annuli.

Key words: Tetralogy of Fallot, pulmonary valve, reoperation

In recent years, discussions regarding the surgical management of Tetralogy of Fallot (TOF) have concentrated on determining optimal strategies for relieving the associated right ventricular outflow tract (RVOT) obstruction. While the conventional technique of total TOF correction results in significantly lower residual stenosis, a number of recent studies have revealed that this technique is also associated with the late occurrence of pulmonary regurgitation (PR). This can lead to deleterious consequences, specifically reduced exercise tolerance and ventricular failure. The trend has now evolved towards preservation of the pulmonary annulus during the total repair of TOF. Sparing the pulmonary valve (PV) complex minimizes PR and obviates the need for prosthetic valve replacement in the long run.

Traditional criteria for employing a pulmonary valve-sparing (PVS) technique for TOF correction include a z-score of ≥ -2 with newer studies showing that this can be successfully applied in patients with z-scores of up to -4. The potential for using this technique in smaller pulmonary annuli is becoming more attractive to proponents of the valve-sparing approach. This study aimed to determine any difference in early and medium-term outcomes between patients with low and high z-scores who were subjected to the PVS technique of TOF correction and to determine whether patients with small pulmonary valve annuli actually benefit from a valve-sparing approach.

Methods

The authors report on their 10-year experience on 59 patients who underwent a pulmonary valve-sparing technique for total correction of TOF, and the outcomes in the early and intermediate postoperative periods.

All pediatric patients (ages 0 to 18 years) who underwent a pulmonary valve-sparing strategy of TOF repair from the years 2002 to 2012 were included in the study. Excluded were TOF patients with absent pulmonary valve, pulmonary atresia and atrioventricular canal defects. Also excluded were TOF patients who underwent total correction using the transannular patching technique for TOF repair. Demographic, operative and postoperative clinical data were retrieved from hospital records and from the computerized registry of the Department of Surgery. Follow-up data were extracted from the computerized database of the Section of Pediatric Cardiology of the Department of Pediatrics.

Patients were divided into two groups, based on their preoperative pulmonary valve z-scores. The z-scores were derived from a published normogram[1]. Patients with small pulmonary valve annuli having z-scores ≤ -3 were included in Group 1 and those with larger pulmonary valve annuli having z-scores > -3 were included in Group 2.

The PVS technique conducted was similar in all patients. After median sternotomy and initiation of cardiopulmonary bypass using moderate hypothermia, the aorta was clamped and cold blood cardioplegia given at 20-minute intervals. The right atrium was opened parallel to the atrioventricular groove and the right ventricle (RV) inspected for obstructing infundibular muscles, which were then resected. The main pulmonary artery was likewise opened and the PV anatomy was assessed for stenosis. Pulmonary valvuloplasty was then carried out as necessary. The RVOT was visualized for obstructing muscles that were also removed through the PV until the apex was visualized. If further resection was needed then an RVOT incision was made for better exposure and enlargement of the area through a polytetrafluoroethylene (PTFE) patch was done. The ventricular septal defect was closed through the right atrium. The main pulmonary artery was closed using pericardium and the ventriculotomy using PTFE. The patient was then re-warmed and the aortic cross-clamp removed followed by weaning from cardiopulmonary bypass. The outflow tract was deemed to be unobstructed if the RV systolic pressure was less than 2/3 the systemic pressure after the procedure. If the ratio was more than this value, the authors then proceeded with a transannular patch (TAP) using autologous pericardium as a monocusp.

The immediate postoperative course was reviewed, as well as electrocardiogram results. Serial postoperative two-dimensional echocardiogram (2D-echo) was conducted with monitoring of RVOT pressure gradients, degree of residual stenosis and presence of valvular regurgitation. Outcomes examined were: intubation times, mean ICU stay, mean postoperative hospital stay, arrhythmia, operative morbidity, conversion to TAP, early and late reoperation and mortality.

Data collection forms were accomplished and data encoding was performed using Microsoft Excel. Frequencies and rates were computed. Parameters between patients in the low z-score and high z-score groups were compared. Statistical analysis was conducted using SPSS version 16. Continuous variables were analyzed using independent t-test, categorical variables were analyzed using Fisher's exact test, and serial 2D echocardiographic values were analyzed using repeated measures ANOVA.

Results

Between the years 2002 and 2012, a total of 79 pediatric patients underwent total correction of TOF. Sixty-four patients (81%) were subjected to a PVS strategy of TOF repair; the rest (19%) were subjected to a TAP technique. Data were available for retrieval in 59 of these 64 patients and follow-up data were obtained in 39 (66%) of these 59 patients.

Of the 59 patients who underwent the annular-sparing repair, 34 (57.6%) were males and 25 (42.4%) were females. Mean age at operation was 6.59 + 3.69 years and average weight was 19.08 ± 9.05 kg. Eight patients (15.25%) had co-morbidities preoperatively and 14 patients had an associated patent ductus arteriosus (PDA), all of which were either coiled preoperatively or ligated during the operation. Eleven patients (18.64%) underwent cardiac interventions before the repair, seven of which were palliative modified Blalock-Taussig shunts.

Of the 59 patients, 25 patients (42%) had z-scores ≤ -3 (up to -7) and were included in Group 1, while 34 patients (58%) had z-scores between -3 to 0 and were included in Group 2. There was no significant difference in the patient profiles (Table 1) between the two groups, except in terms of the pulmonary annulus sizes and the PV z-scores. Patients in Group 1 have an average PV z-score of -4.85 + 1.18 (mean pulmonary annulus of 7.58 mm), which was significantly different (P=0.00) with those in Group 2, with a mean PV z-score of -1.45 + 1.11 (mean pulmonary annulus of 12.26 mm).

With regard to immediate postoperative outcomes, there was no significant difference between the two groups. Intubation times and mean ICU stay were 1.25 days and 4.79 days for Group 1 and 1.65 days and 5.59 days for Group 2 (P-value 0.513 and 0.408), respectively. Average postoperative length of stay was 8.96 days for Group 1 and 10.06 days for Group 2 (P-value 0.504).

Four patients (16.67%) in Group 1 and ten patients (29.41%) in Group 2 developed rhythm disturbances in the early postoperative period (P-value 0.356). One patient in Group 2 developed complete heart block requiring implantation of a permanent pacemaker. Seven patients (28%) in Group 1 and 11 patients (32.35%) in Group 2 developed morbidities in the early postoperative period (P-value 0.781). The most common morbidity acquired is health care-associated sepsis (50%) followed by pleural effusion (33%).

Ten patients, 5 from Group 1 (20%) and another 5 from Group 2 (14.71%), underwent early reoperation (P-value 0.729). One patient (2.94%) from Group 2 had to be converted to a TAP technique of repair (P-value 0.503). Three patients (5%) necessitated further operative intervention at a later time (P-value 0.569), all for residual stenosis. There were also 3 deaths (5%), 2 from the Group 1 for myocardial failure and pulmonary edema, and 1 from Group 2 for postoperative hemorrhage (P-value 0.569). Patient outcomes are listed in Table 2.

In terms of intermediate outcomes, the authors focused on the degree of residual RVOT obstruction, based on pressure gradients across the pulmonary valve (PG PV) in the early (within 30 days, with an average of

Table 1. Profiles of TOF patients undergoing pulmonary valve-sparing repair.

	Total n=59	Group 1 n=25	Group 2 n=34	P-value
Age at OR (in yrs)	6.59 ± 3.69	6.75 ± 3.72	6.48 ± 3.72	0.78
Sex				0.44
Male	34 (57.63%)	16 (64%)	18 (52.94%)	
Female	25 (42.37%)	9 (36%)	16 (47.06%)	
Weight (in kg)	19.08 ± 9.05	20.29 ± 10.87	18.18 ± 7.48	0.38
Body Surface Area	0.74 ± 0.24	0.79 ± 0.26	0.71 ± 0.22	0.21
McGoon's score	1.74 ± 0.4	1.78 ± 0.47	1.7 ± 0.32	0.52
Co-morbidities	8 (13.56%)	3 (12%)	5 (14.71%)	
Associated PDA	14 (23.73%)	2 (8%)	12 (35.29%)	
Previous OR	11 (18.64%)	4 (16%)	7 (20.59%)	
PV annulus	10.28 ± 2.98	7.58 ± 1.44	12.26 ± 2.14	0.00
PV z-score	-2.89 ± 2.03	-4.85 ± 1.18	-1.45 ± 1.11	0.00

Continuous Variables are presented in Mean ± Standard Deviation, Compared using Independent T-Test.
Categorical Variables are presented in Count (Percentages%), Compared using Chi-Square Fisher's Exact Test.
PDA-patent ductus arteriosus; PV-pulmonary valve.

6.65 days) and medium-term (beyond 30 days, with an average of 20.77 months) postoperative periods. Patients who underwent a PVS technique had an average preoperative PG PV of 66.31, which was improved by surgery to 32.39 in the early postoperative period. The value decreased further by an average of 4.47 in the intermediate postoperative period. There was a statistically significant decrease in the PG PV values in all patients through time. Comparing the two groups, PG PV is higher in Group 1 than Group 2 (P-value 0.053). These values are shown in Table 3 and Figure 1. The authors likewise reviewed the incidence of clinically significant PR (moderate to severe PR). None of the patients developed significant PR up until discharge, but 3 patients (7.69%) eventually developed PR in the medium-term period (Table 4).

Table 2. Outcomes of TOF patients.

	Total n=59	Group 1 n=25	Group 2 n=34	P-value
Intubation times	1.48 ± 2.25	1.25 ± 2.01	1.65 ± 2.42	0.51
Mean ICU stay	5.26 ± 3.58	4.79 ± 2.3	5.59 ± 4.26	0.41
Mean postoperative hospital stay	9.59 ± 6.17	8.96 ± 6.61	10.06 ± 5.89	0.50
Arrhythmia	14 (24.14%)	4 (16.67%)	10 (29.41%)	0.36
RBBB	5	1	4	
1° AV block	1	0	1	
2° AV block	1	0	1	
Intraventricular block	2	1	1	
Complete heart block	1	0	1	
Junctional rhythm	1	0	1	
SVT	2	1	1	
PVC	1	1	0	
Morbidity	18 (30.51%)	7 (28%)	11 (32.35%)	0.78
Nosocomial sepsis	9	2	7	
Pleural effusion	6	4	2	
Stroke	1	1	0	
Mediastinitis	1	0	1	
Postop hemorrhage	1	0	1	
Conversion to TAP	1 (1.7%)	0 (0%)	1 (2.94%)	0.50
Early reoperation	10 (16.95%)	5 (20%)	5 (14.71%)	0.73
Minor		4	1	
Major		1	4	
Late reoperation	3 (5.08%)	2 (8%)	1 (2.94%)	0.57
Mortality	3 (5.08%)	2 (8%)	1 (2.94%)	0.57
Hemorrhagic shock		0	1	
Myocardial failure		1	0	
Pulmonary edema		1	0	

Continuous Variables are presented in Mean ± Standard Deviation, Compared using Independent T-Test.
Categorical Variables are presented in Count (Percentages%), Compared using Chi-Square Fisher's Exact Test
ICU-intensive care unit; RBBB-right bundle branch block; AV-atrioventricular; SVT-supraventricular tachycardia; PVC-premature ventricular contraction; TAP-transannular patching.

Table 3. Pressure gradients across the pulmonary valve (PG PV) in TOF patients through time.

	Total	Group 1	Group 2	P-value
Preoperative				
PG PV	66.31 ± 26.61	69.23 ± 32.07	64.1 ± 21.88	Within subjects 0.00
Early				
PG PV	33.92 ± 19.46	38.09 ± 21.8	30.79 ± 17.19	Between subjects 0.05
Intermediate				
PG PV	29.45 ± 22.36	36.24 ± 27.63	23.63 ± 14.95	

Continuous Variables are presented in Mean ± Standard Deviation, Analyzed using Repeated Measures ANOVA.

Table 4. Development of Significant Pulmonary Regurgitation (PR) in TOF patients through time.

	Total	Group 1	Group 2	P-value
Early PR	0 (0%)	0 (0%)	0 (0%)	-
Intermediate PR	3/39 (7.69%)	2/18 (11.11%)	1/21 (4.76%)	0.60

Continuous Variables are presented in Mean ± Standard Deviation, Compared using Independent T-Test.

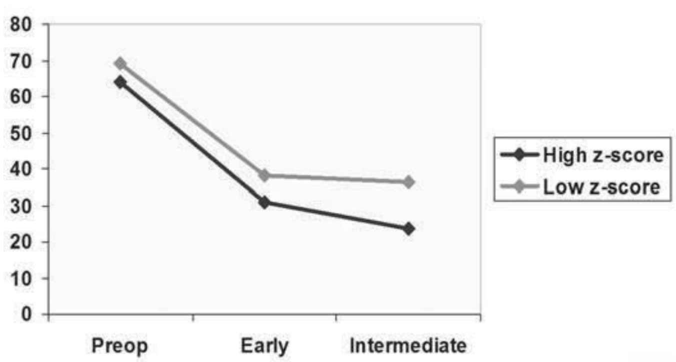

Figure 1. Decrease in right ventricular outflow tract obstruction (based on PV pressure gradients) in the early and medium-term postoperative periods in the low z-score (Group 1) and high z-score (Group 2) groups.

Discussion

The two major points of interest postoperatively with regard to the surgical correction of Tetralogy of Fallot remain to be the degree of residual RVOT obstruction and the development of late PR. The majority of TOF repair involves transecting the pulmonary annulus and augmenting the pulmonary outflow with a prosthetic TAP. This has been shown to produce significant relief in RVOT obstruction with minimal residual stenosis. However, follow-up studies on these patients have shown that the TAP technique is associated with a higher incidence of significant PR occurring in up to 80% of patients[2-4]. Chronic RV volume overload associated with the resultant PR has been shown to produce progressive RV dilatation, diastolic dysfunction and arrhythmias[4,5]. The deterioration in right ventricular function, although previously known to be well tolerated clinically[3,5], is now believed to contribute to decreased exercise capacity, poor functional status, and late left ventricular failure[4,6]. Furthermore, the late effects of PR result in a 7 to 15% risk of reoperation, specifically pulmonary valve replacement[2,7]. Newer researches suggest pulmonary valve replacement before the RV becomes dilated, in order to significantly decrease right ventricular end diastolic volume[13].

Thus, with a better understanding of the detrimental effects of significant PR in TOF patients, there has been a move toward a PVS strategy for TOF correction. Research shows a lower incidence of PR, both in the immediate and late postoperative periods, by as much as 50%[2]. Preservation of the pulmonary annulus during total TOF repair could therefore prevent the development of subsequent heart failure and eventual need for valve replacement[8].

In order to address these concerns regarding PR, the authors have utilized the PVS strategy on most of their patients (81%) undergoing TOF correction. A local preliminary study showed no significant difference in the early, intermediate and late outcomes of patients undergoing a PVS and a TAP technique for TOF correction. Their experience on the use of a valve-sparing strategy has revealed acceptable results, comparable to earlier studies demonstrating minimal risk for complications. They had a morbidity rate of 30.5% (n=18), half of which were due to nosocomial infection, and a total mortality rate of 5% (n=3), both of which fall within international standards[2,7,10,11]. The main advantage of utilizing a valve-sparing technique for TOF correction is the decreased incidence of clinically significant PR ranging from 3% to 36% in the immediate to the late postoperative period[2,8,10,11]. In this series, the incidence of PR is low at 7.89% in the medium-term period.

The major setback with the use of the PVS technique remains to be the risk for residual stenosis. This is the most common cause for late re-intervention, with studies showing a 6-12.5% rate of reoperation for residual obstruction[2,11]. In this series, 3 patients (5%) required further intervention for residual pulmonic stenosis. One patient from Group 1 had to undergo a repeat infundibulectomy and RVOT reconstruction after one year while another underwent an RV to PA conduit 3 years after. Meanwhile, one patient from Group 2 will undergo re-operation for residual pulmonic stenosis and a large VSD leak.

Although the valve-sparing technique is associated with a higher degree of residual RVOT obstruction[5], studies have shown a consistent decrease in trans-valvar pressure gradients through time[2,8,9]. Similarly, this current study has shown a progressive decrease in the pressure gradients across the pulmonary valve through time (P-value 0.000), until the medium-term period.

The pulmonary valve z-score is a preoperative measure that determines whether a patient is a good candidate for a PVS approach of TOF correction. Standard criteria include patients with a z-score of ≥-2[4,7,10] as lesser PV z-scores correlate with higher postoperative RV:LV pressure ratios as reported by Kirklin[14]. Awori[15] in 2013 determined that the minimum acceptable z-score is -1.3 in order to produce acceptable residual stenosis. More recent studies, however, have shown that successful repairs can be done even in patients with z-scores of up to -3[11] and even up to -4[2,5], with acceptable postoperative pressures and reoperation rates[14]. According to a study by Boni[11], the risk for residual obstruction increases when the z-score is ≤ -3. A landmark study by Stewart, et al.[16] in 2005 demonstrated several positive prognostic factors for an annulus-sparing TOF repair which include a tricuspid pulmonary valve, PV z-score of ≥ -4, and a postoperative RV:LV pressure ratio below 0.7.

Extending the guidelines to include patients with preoperative z-scores of up to -7 has demonstrated that patients with small PV annuli may be subjected to a valve-sparing strategy with comparable results in the early postoperative period. No significant difference was noted in all immediate postoperative parameters, specifically in terms of intubation times, ICU stay, conduction abnormalities, morbidities, reoperations and mortalities. Surprisingly, the only conversion in the series is one patient from Group 2 who was noted to have an elevated RV/LV pressure post-repair. As expected, there is a higher degree of residual RVOT obstruction noted in patients with smaller pulmonary valve annuli in the medium-term period (P-value 0.05) with an average difference in PG PV of 12.6 mmHg between the two groups. However, this did not translate to any significant increase in late re-intervention rates in these patients (P-value0.57).

The existing consensus, therefore, is to spare the pulmonary valve complex during the surgical repair of TOF whenever possible. The authors suggest that preoperative PV annulus z-scores be used as a guide and not necessarily the primary determinant of whether or not a PVS technique is indicated. They also believe that longer follow-up is essential in order to determine whether there will be any difference in late outcomes between patients with low and high z-scores who underwent a PVS strategy for TOF correction, specifically in terms of long-term pulmonary valve and ventricular function. Furthermore, they recommend determination of other preoperative and intraoperative markers of success in patients undergoing a PVS approach, and possibly extending its use to include patients with more dysmorphic pulmonary valves. Finally, knowing the potential benefits of this kind of TOF correction in contrast with the TAP technique, they recommend extending the annular-sparing technique to most TOF patients presenting for repair, including those with low z-scores.

Conclusion

A pulmonary valve-sparing approach of TOF correction can be successfully utilized even in patients with small pulmonary valve annuli, with similarly acceptable outcomes in the early and medium-term postoperative period. Although a higher degree of residual stenosis is noted in the medium-term period, this did not result to an increase in late re-intervention rates. A progressive decrease in residual RVOT obstruction through time is associated with the use of the pulmonary valve-sparing technique.

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