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Comparison of different pulmonary valve reconstruction techniques during transannular repair of tetralogy of fallot

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Abstract

Background: Transannular patch, which results in pulmonary insufficiency (PI), is usually required during repair of tetralogy of fallot (TOF). In this study, we compared three types of pulmonary valve reconstruction techniques during transannular repair of TOF.

Methods: Between February 2014 and January 2018, 50 patients with TOF underwent primary repair with transannular patch. These patients were divided into three groups. In Group 1, ($n = 15$), a single gluteraldehyde-treated autologous pericardial patch (standard method) was reconstructed as monocusp. In Group 2, ($n = 16$) Nunn's bileaflet pulmonary valve reconstruction technique was used with pericardial patch. In Group 3, ($n = 19$), Nunn's bileaflet technique was performed with expanded polytetrafluoroethylene membrane. The outcomes of the patients and early and midterm competency of the pulmonary valves were analyzed.

Results: These techniques were significantly effective in early postoperative period. Freedom from moderate to severe PI were 73.3%; 100% and 89.4%, respectively. Mortality, duration of intensive care unit and hospital stay were similar between the groups. The mean follow-up period was 17.5 ± 13.0 (3–57) months. Freedom from moderate to severe PI decreased to 40%; 81.2% and 73.7%, respectively at the end of the follow-up period. Presence of moderate to severe PI was significantly higher in Group 1 ($p = .018$ between Groups 1 and 2, $p = .048$ between Groups 1 and 3).

Conclusion: All three pulmonary valve reconstruction techniques provided competent pulmonary valves. Nunn's bileaflet technique had better outcome at midterm. It has a potential to delay right ventricular dysfunction at long-term.

KEYWORDS

cardiac valve annuloplasty, congenital heart defects, pulmonary regurgitation, pulmonary valve, pulmonary valve stenosis, tetralogy of fallot

1 | INTRODUCTION

Tetralogy of fallot (TOF) is the most common cyanotic congenital heart defect.[1] There is a wide variety of clinical and morphological spectrum, which affects surgical approaches. Although pulmonary valve sparing strategy gained acceptance over the last decades, transannular patch (TAP) repair is still required in more than 50% of the cases according to the Society of Thoracic Surgeons (STS) database.[2] TAP repair alone, inevitably causes severe pulmonary insufficiency which may lead to right ventricle systolic and diastolic dysfunction, septal motion abnormality, electrical dyssynchrony, dysrhythmias, eventual left ventricle dysfunction, and sudden cardiac

death.[3–5] Although techniques of right ventricular outflow tract (RVOT) reconstruction have gained increased popularity recently, they are far from being used in common practice since there is a big concern about the fate of the pulmonary valve functions in the mid to long term.[6,7] Nevertheless there is no consensus about which technique of pulmonary valve reconstruction has better results.

In this study, we aimed to present the early and midterm results of three different techniques of pulmonary valve reconstruction during primary repair of TOF with TAP.

2 | MATERIALS AND METHODS

Between February 2014 and January 2018, a total of 161 patients with TOF underwent total repair. Fifty of them (31%) needed TAP to relieve RVOT obstruction. Pulmonary valve reconstruction was performed during operations for all those patients and three different techniques were used. Transthoracic echocardiography (TTE) and cardiac catheterization were performed before operations. Eleven patients had pulmonary balloon angioplasty and five had systemic to pulmonary shunt operation as a palliative intervention before total repair. Angiographically estimated Mc Goon index greater than 1.6 was used to decide total repair. TAP implantation was decided during the operations, when the patients had pulmonary valve annulus *Z*-value of ≤−2.

Approval for the study was obtained from the university ethics committee. Written concent was taken from all patients's families. TTE examinations were done in early postoperative period, before discharge and at the last outpatient clinic visit.

All operations were performed with median sternotomy and cardiopulmonary bypass (CPB) under moderate hypothermia. Aortic and bicaval cannulation were done. Previous shunts were ligated if present. The heart was arrested with intermittant antegrade tepid blood cardioplegia. Ventricular septal defect was closed with interrupted sutures with teflon pledgets via right atriotomy using a dacron patch. The patients were divided into three groups according to the pulmonary valve reconstruction techniques.

In the first group (Group 1, $n = 15$), a gluteraldehyde treated autologous pericardial patch was used for creation of a monocusp valve (standard method).[6] The length of the patch was equal to the length of the incision from the apex of RVOT to pulmonary annulus. The width of the free edge of the monocusp was equal to the circumference of the native annulus. The superior margin of the monocusp was positioned at the level of the commissures and was attached to the both sides of the pulmonary valve incision and the inferior margin was attached to the apex of the RVOT incision at three points. Monocusp was covered with a second pericardial patch which was sutured together with the remnants of the pericardial monocusp to close the transannular incision. In the second group (Group 2, $n = 16$) Nunn's bileaflet valve technique was used with gluteraldehyde treated autologous pericardial patch, which was prepared as the same fashion, but its free margin was at least 1.5 times larger than the standard technique.[8] Mid point of the free margin was sutured to the posterior wall of the pulmonary annulus first. Both ends were sutured to the both sides of the pulmonary trunk incision. Apex of the patch was sutured to the apex of the right ventriculotomy incision (Figure 1). TAP was sutured over the created bileaflet valve to secure the remnants of the valve and to close the transannular incision. In the third group (Group 3, $n = 19$), Nunn's bileaflet valve technique was used with 0.1-mm expanded polytetrafluoroethylene (e-PTFE) membrane (Figure 2).

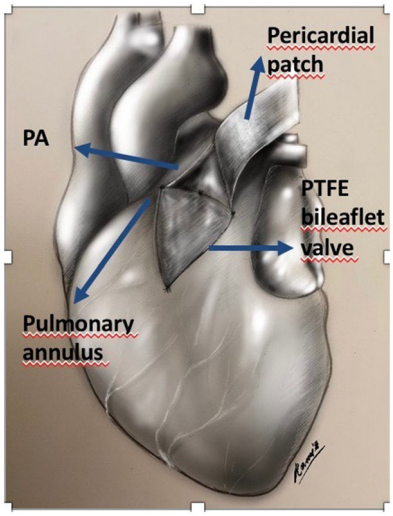

FIGURE 1 Nunn's bileaflet valve technique. Mid point of the free margin is sutured to the posterior wall of the pulmonary annulus. Both ends are sutured to the both sides of the pulmonary trunk incision. Apex of the patch is sutured to the apex of the right ventriculotomy incision. Transannular patch is sutured over the created bileaflet valve to secure the remnants of the valve and to close the transannular incision. PA, pulmonary artery; PTFE, polytetrafluoroethylene

Nunn's bileaflet valve technique creates two outflows for the right ventricle and outflow orifices should be large enough to prevent obstruction. Valve reconstructions were made with three or four single sutures and usually lasted no more than 5 min. A small fenestration of 2–3 mm in size in atrial septum was left. After weaning from CPB, right ventricular (RV)/left ventricular (LV) pressure ratio

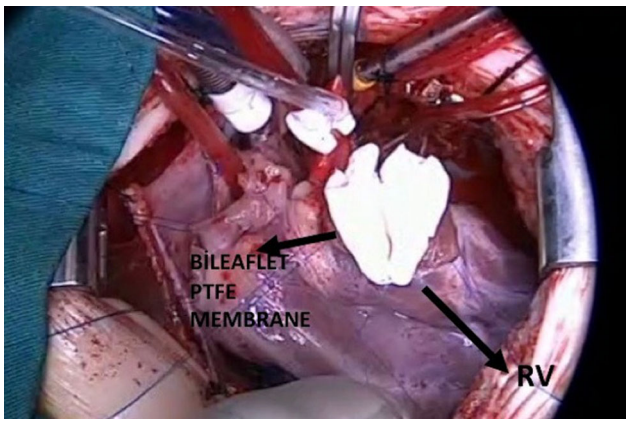

FIGURE 2 Intraoperative image of bileaflet PTFE membrane. PTFE, polytetrafluoroethylene; RV, right ventricular

was measured. If RV/LV pressure ratio was greater than 0.75, revision of the repair was considered. All patients had a dose of 5 mg/kg acetyl salicylic acid treatment for 3 months.

2.1 | Statistical analysis

Statistical analysis was performed using SPSS software version. The conformity of variables to normal distribution was analyzed by visual (histogram and probability graphs) and analytical methods (Kolmogorovz–Simirnov/Shapiro–Wilk tests). Descriptive analyzes were performed using the frequency tables for categorical variables using mean and standard deviations for normally distributed variables. For the variables not normally distributed, the median and minimal - maximum values were given. For the comparison of intergroup variables, Kruskal–Wallis test and Mc Nemar test was used. Fisher Freman–Halton test, Pearson χ^2 test was used for categorical variables. p Values <.05 were considered as statistically significant.

3 | RESULTS

The mean age of the patients was 16.2 ± 11.9 (range from 7 months to 6 years) months (Table 1). (M/F: 28/22). There was no significant difference in CPB and cross clamp times between the groups. Mean CPB times were 103.7 ± 19.5, 111.8 ± 29, and 97.1 ± 35, respectively (p = .11). Mean cross clamp times were 71 ± 16.4, 74.1 ± 15.6, and 68.5 ± 12.4 respectively (p = .70). Total mortality was 6% (three patients). One patient in Group 1 needed ECMO support due to low cardiac output and could not wean from ECMO because of multiorgan failure (MOF) and gastrointestinal bleeding. Other two patients in Groups 1 and 2 died of sepsis and MOF. No statistical difference was present in terms of mortality and morbidity between the groups. Postoperative complications are presented in Table 2. The median duration of intensive care unit stay (ICU) was 3 (2–90) days. The median time of ventilation was 1 (1-20) days. Nine patients (18%) needed long duration of mechanical ventilation (> 7 days). Of these, 4 patients (8%) needed tracheostomy. The median duration of hospital stay was 10 (5-108) days. The degree of pulmonary insufficiency was evaluated with TTE and was quantified as none, mild, moderate and severe (Figure 3). All three pulmonary valve reconstruction techniques were mostly effective in the early postoperative period. Freedom from moderate to severe pulmonary valve insufficiency were 73.3%; 100% and 89.4% respectively.

All patients were followed up for mean 17.5 ± 13.0 (ranged 3 to 57) months. In group 1, mean follow-up time was statistically longer than the other groups (p: 0,01).

No late mortality was observed. All patients had normal growth and development without symptoms. Freedom from moderate to severe pulmonary valve insufficiency decreased to 40%; 81.2% and 73.7% respectively at the end of the follow-up period (Figure 4). Presence of moderate to severe pulmonary insufficiency (PI) was significantly higher in group 1 (p: 0,018 between group 1 and 2, p: 0,048 between group 1 and grup 3). Pulmonary valve competency significantly worsened in group 1 than the others (p: 0.050) (Table 3). The postoperative RVOT gradients were between 0 and 30 mmHg. Peripheral pulmonary artery stenosis was observed in 2 patients in group 1 and group 2 and pulmonary balloon valvuloplasty was performed successfully during follow-up period. None of the patients in the series required reintervention for residual or recurrent RVOT obstrucion.

4 | DISCUSSION

The prevailing method of TOF repair is, if possible, the protection of the pulmonary annulus and valve. In the presence of severe hypoplasia of pulmonary annulus, the integrity of the pulmonary annulus is impaired during repair and a transanular patch is inevitable. TAP leads to PI which is usually well-tolerated.[9] But the absence of pulmonary valve and pulmonary valve regurgitation after TAP repair are associated with postoperative right ventricle (RV) dysfuncion and RV

TABLE 1 Clinical data between groups

Clinical data	Group 1 (n = 15)	Group 2 (n = 16)	Group 3 (n = 19)	p Value
Age (months)	13.3 ± 6.8	19.1 ± 18.7	15.9 ± 6.8	.29
CC time (min)	71 ± 16.4	74.1 ± 15.6	68.5 ± 12.4	.70
CPB time (min)	103.7 ± 19.5	111.8 ± 29	97.1 ± 35	.11
ICU stay days	9.7 (3/2–58)	9.2 (2.5/2–90)	6.9 (2/2–55)	.32
Hospital stay mean, range	17 ± 14.1	18.6 (9.5/5–108)	15.7 (10/6–96)	.83
Mechanical ventilation time (median/min–max)	1/1–15	1/1–20	1/1–12	.81
Follow-up (month)	26.7 ± 17.2 (6–57)*	17.0 ± 10.1 (3–30)	10.6 ± 5.3 (3–22)	.01*

Abbreviations: CC, cross clamp; CPB, cardiopulmonary bypass time; ICU, intensive care unit.
*p < .05.

TABLE 2 Postoperative complications

Postoperative data	Group 1 (*n* = 15) (%)	Group 2 (*n* = 16) (%)	Group 3 (*n* = 19) (%)	*p* Value
Mortality *n* (%)	2 (13.3)	1 (6.3)	0	.27
ECMO *n* (%)	1 (6.7)	0	0	.30
Prolonged ventilation (>7 days)	4 (26.7)	2 (12.5)	3 (15.8)	.56
Tracheostomy	2 (13.3)	1 (6.3)	1 (5.3)	.66
Minor neurological event	1 (6.7)	1 (6.3)	0	.53
Sepsis	1 (6.7)	1 (6.3)	0	.53

Abbreviation: ECMO, extracorporeal membrane oxygenation.

dilatation[10,11] and some of the patients will eventually experience decreased exercise capacity and RV dysfunction.[12] This situation may cause the need for pulmonary valve replacement.

To prevent pulmonary valve insufficiency during TAP repair, pulmonary valve reconstruction techniques with various methods may be used, although they are not generally accepted because of the lack of proven advantages in the mid-long term follow-up. However, most of the authors agree that monocusp pulmonar valves are effective in early postoperative period. Turrentine et al[6]; stated that monucusp valves reduces early postoperative and midterm PI. It is also shown that pulmonary monocusp creation may shortens intensive care unit (ICU) stay and reduces postoperative mortality and morbidity.[6,8,13,14] Some authors support that leaving mild residual RVOT obstruction helps to protect the right ventricle by limiting pulmonary regurgitation.[15] In a study of 171 operated TOF patients mild residual PS independently reduced the risk of pulmonary valve replacement as compared with patients without PS and moderate-to-severe PS.[16]

In our recent report[17] a total of 64 TOF patients underwent total correction and pulmonary valve-sparing techniques were performed in 29 patients (Group 2), while TAP was applied in the remaining 35 patients (Group 1). Pericardial monocusp valve was constructed in 15 patients in Group 1. Total postoperative morbidity rate was significantly higher in Group 1 (51.4% vs. 6.8%) ($p = .0001$). Morbidity rate was significantly lower in patients with pulmonary monocusp insertion than patients in the same group without a monocusp ($p = .0176$). Twelve (80%) of the patients in Group 1 who had monocusp insertion were followed up. Only two of these patients had free pulmonary regurgitation (16.6%). The rest of them had mild ($n = 6$) or mild-moderate pulmonary regurgitation ($n = 4$). After this study, we started routine use of pulmonary valve reconstruction in TOF patients who need TAP during repair.

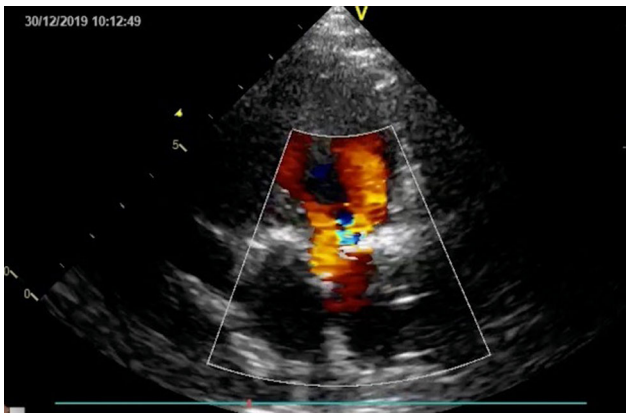

FIGURE 3 Postoperative transthoracic echocardiography image of mild regurgitation of the reconstructed bileaflet pulmonary valve

In this report, we compared three types of pulmonary monocusp creation techniques to delineate the most effective one in early and midterm period. All three techniques were effective in early postoperative period. There was no significant difference in postoperative complications and ICU or hospital stay between the groups. Patients who underwent pulmonary valve reconstruction with Nunn technique had better results in the midterm follow-up.

As described by Nunn, attaching the free central portion of the patch to the posterior of the pulmonary artery with a single suture enables a bileaflet formation of the valve.[8] In Brown's study, hand-sewn valves constructed from 0.1-mm PTFE have not shown structural deterioration or calcification.[13] The valves fashioned as monocusps have lost their competence (88%) in almost all cases. The valves fashioned as bicuspid valves using the same 0.1-mm PTFE membrane have retained their competence (93%) in most cases, and there has not been a deterioration in their function in the period of mean follow-up time for 4.9 ± 3.1 years. Gil-Juarena et al.[18] treated 21 patients of TOF with 0.1 mm PTFE monocusp valve using posterior fixation and right after the operation, pulmonary regurgitation was mild in 19 cases and moderate in two. Posterior fixation of the valve enables leaflet motion and coaptation without prolapse.[8] Also, it serves as an anchor point to optimize the closure mechanism.[8,18] Quintessenza et al.[19] created PTFE bicuspid pulmonary valves (a surgically prepared 0.6 mm PTFE bicuspid valve with opposing attached leaflets that are shaped like a bishop's hat) in 41 patients and stated that it is a durable and effective technique and appropriate oversizing of the patch minimizes outflow tract obstruction while maximizing competence.

Monocusp repair can be done with autogenous pericardium, bovine or porcine pericardium or e-PTFE patch. Autogenous

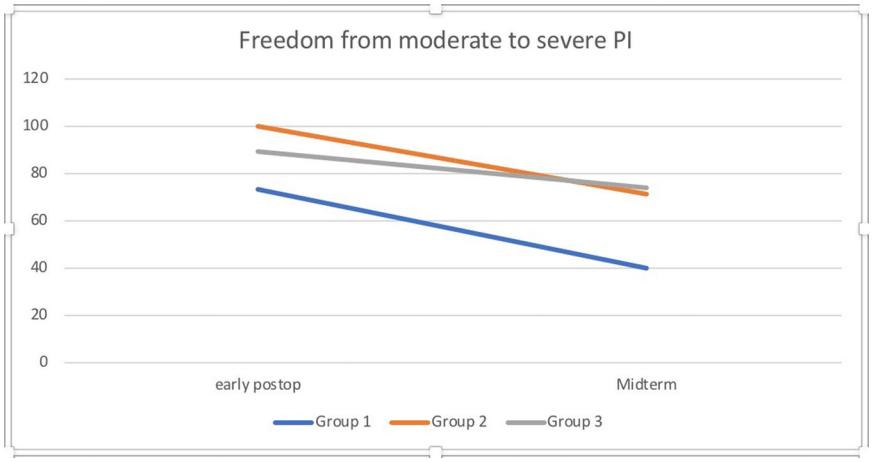

FIGURE 4 Freedom from moderate to severe PI in early and midterm postoperative period. PI, pulmonary insufficiency

pericardial and heterograft pericardial materials are claimed to be degenerated in the early period and valve functions are impaired.[20] 0.1 mm PTFE membrane is a synthetic, inert material and it is suggested that this material can maintain its function for a very long time.[13] 0.1 mm thick ePTFE has micropores that are 1 μm in diameter that might prevent cellular infiltation, calcification, and maintains flexibility. It has good biocompatibility and its surface exerts antithrombogenic effects by electrically repelling platelets.[21,22] The histopathological analysis of explanted ePTFE valved patches or conduits showed that the surface of vascular grafts was covered in thin fibrous collagenous tissue predominantly comprising fibroblasts, even with partial endothelialization, whereas the valvular leaflet remained free of any attached matter.[23] Sasikumar et al.[14] reported that the factors which effect PI progression are, fibrocollagenous incorporation of the monocusp valve, lack of proper frame for the valve, residual stenotic lesions in pulmonary vasculature, size of branch pulmonary arteries, and mobility of the monocusp. A study in Japan assessed the outcomes of ePTFE valved patches and conduits in 469 and 325 patients, respectively, based on clinical data collected from 52 institutions.[21] The follow-up rate was 100% over a period of 43.62 ± 26.4 (range, 1.1–120) months. No patch or conduit-related deaths were reported, and 10-year rates of freedom from reoperation were 92.3 and 95.4% in patients with patches and conduits, respectively. No evidence of thrombus or pannus formation was found in any of the patients.

We agree with the idea of trying to preserve the integrity of pulmonary annulus and competency of the valve in all patients with TOF during repair but it is not always possible. In our practice 31% of patients need TAP. This ratio is around 50% according to STS database.[2] Our study shows that all types of pulmonary valve reconstruction techniques were effective, but Nunn bileaflet technique with e-PTFE is our current choice because of the midterm advantages. The implantation technique of monocusp valves is simple and not time consuming. Our study is important as it is one of the few reports that compares different reconstruction techniques of hand-sewn valves with different materials.

Limitations of the study are its retrospective nature and limited number of the cases.

TABLE 3 Pulmonary valve functions

	Data	Group 1 (n = 15) (%)	Group 2 (n = 16) (%)	Group 3 (n = 19) (%)	p Value
Early postop	No PI	1 (6.7)	3 (18.8)	9 (47.4)*	.02*
	Mild PI	10 (66.7)	13 (81.3)	8 (42.1)	.054
	Moderate PI	1 (6.7)	0	1 (5.3)	.59
	Severe PI	3 (20)	0	1 (5.3)	.1
Midterm	PI (−)	1 (6.7)	3 (18.8)	9 (47.4)*	.02*
	Mild PI	5 (33.3)	10 (62.5)	5 (26.3)	.08
	Moderate PI	5 (33.3)	2 (12.5)	3 (15.8)	.31
	Severe PI	4 (26.7)	1 (6.3)	2 (10.5)	.24
p Value		.050*	N/A	.135	

Abbreviation: PI, pulmonary insufficiency.
*p < .05.

5 | CONCLUSION

In patients with TOF, who need TAP during total repair, pulmonary monocusp reconstruction may be easily performed and the results are promising. This technique has a potential to delay right ventricular dysfunction at long-term. Studies with large number of patients and long-term results are needed to reveal the efficacy of pulmonary valve reconstruction techniques.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

AUTHOR CONTRIBUTIONS

Concept or design: Bahar Temur and Ersin Erek. Data analysis or interpretation: Selim Aydın, Dilek Suzan, Bahar Temur, and Barış Kırat. Drafting article: Bahar Temur and Ersin Erek. Critical revision of article: Bahar Temur, İbrahim Halil Demir, and Ersin Erek. Approval of article: Bahar Temur and Ersin Erek. Statistics: Bahar Temur. Data collection: Selim Aydın, Dilek Suzan, Barış Kırat, and İbrahim Halil Demir.

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