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RESEARCH

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Role of great artery annulus ratio to predict transannular patch enlargement in repair of tetralogy of Fallot

Satyajit Samal*, Rakesh Sharma, Harpreet Singh Minhas, Girish G, Saket Agarwal, Sayyed Ehtesham Hussain Naqvi and Muhammad Abid Geelani

Abstract

Background: Traditionally, the pulmonary valve annulus (PVA) *z*-score is used to predict the requirement of transannular patch enlargement (TAPE) of right ventricular outflow tract (RVOT) and main pulmonary artery (MPA) in repair of tetralogy of Fallot (TOF). PVA *z*-score is highly variable and many other parameters are being reported to be accurate in predicting need of TAPE. In this study, we analyze the role of great artery annulus ratio (pulmonary valve annulus to aortic valve annulus ratio, PVA/AVA) to be used as a predictor for TAPE.

Methods: We analyzed 90 patients of TOF retrospectively who underwent repair between January 2021 and December 2021. The patients were divided as TAPE group who required TAPE of RVOT and MPA and non-TAPE group who did not have TAPE. Their baseline parameters, PVA *Z*-score, and cut-off great artery annulus ratio were compared.

Results: Total 44 (48.9%) patients had transannular patch (TAPE) repair and 46 (51.1%) patients had non-transannular patch repair. The great artery annulus ratio and PVA *z*-score was lower in case of TAPE group with statistical significance. Receiver operating characteristic curve analysis showed great artery annulus ratio as more accurate predictor of TAPE.

Conclusion: Great artery annulus ratio can be used as a simple and accurate predictor for transannular patch enlargement along with PVA *z*-score during repair of TOF.

Keywords: Tetralogy of Fallot, Great artery annulus ratio, Pulmonary valve *z*-score, Transannular patch enlargement

Background

Tetralogy of Fallot (TOF) remains the most common congenital heart defect with an incidence of 34 per 10,000 live births and 30-year survival ranges from 68.5 to 90.5% with current treatment strategies [1]. The first successful surgical correction of tetralogy of Fallot (TOF) was reported in 1954. It comprises of closure of ventricular septal defect (VSD) and relieving the right ventricular tract obstruction (RVOTO) which may require sacrificing the pulmonary valve annulus and augmenting RVOT with transannular patch (TAP) with acceptance of significant pulmonary insufficiency causing progressively right and left ventricular dysfunction which adversely affects long-term outcomes [2–4]. Therefore, some surgeons prefer to avoid putting TAP at the cost of accepting higher right ventricular (RV) pressure. Contrariwise, imprudent preservation of pulmonary valve annulus also results adverse long-term outcomes [5, 6]. Therefore, preoperative assessment for need of TAP has significant importance in predicting postoperative long-term outcomes.

Commonly, the *z*-score of the pulmonary valve annulus (PVA) has been used to predict the need for TAP in corrective surgery for TOF [7, 8]. The *z*-score indicates

*Correspondence: drsatyajitctvs@gmail.com

Department of Cardiothoracic and Vascular Surgery (CTVS), G.B. Pant Institute of Post Graduate Medical Education and research (GIPMER), New Delhi, India

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number of standard deviations the case is from the mean, calculated from published nomograms and its calculation is affected by height, body weight, body surface area, and reference population group [9]. Inappropriate *z*-score use may lead to unacceptable postoperative PVA pressure gradients due to preservation of significantly undersized PVA [10, 11].

Many other parameters also have been proposed as predictors for the need of transannular patch (TAP) repair but no definite conclusion has been drawn. In this study, we retrospectively investigated the role of pulmonary valve annulus size to aortic valve annulus size (PVA/AVA ratio) in predicting the need of transannular right ventricular outflow patch. The PVA/AVA ratio indicates the relative growth of pulmonary artery and annulus which can be readily measured from 2D echocardiography, cardiac tomography, and cardiac angiography.

Methods

For this study, medical records of total 90 patients who underwent surgery were analyzed retrospectively, between January 2021 to December 2021 by single surgeon at G.B. Pant institute of postgraduate medical education and research (GIPMER), New Delhi. Patients were excluded from the study prior to analysis if they had other associated cardiac abnormalities, associated syndromes, age > 14 years, absent pulmonary valve, coronary artery crossing right ventricle outflow tract (RVOT), outlet extension of ventricular septal defect (VSD), and any previous palliative procedure.

The preoperative 2D echocardiography, computed tomography angiography (CTA), and cardiac catheterization studies were analyzed. All surgeries were done through median sternotomy under general anesthesia and endotracheal intubation. Cardiopulmonary bypass was established by aorto-bicaval cannulation and del Nido cardioplegia solution was used for myocardial protection. The hypertrophied muscle bundles at right ventricular outlet tract (RVOT) were excised through longitudinal incision over RVOT and the VSD was closed with dacron patch through right atrial-pulmonary artery approach. Hegar dilators of different sizes were used to assess adequacy of size of pulmonary valve annulus, main pulmonary artery, and branched pulmonary arteries according to the minimum acceptable pulmonary valve ring diameter chart (employed by Kirklin in 1975, 1976) and the need of transannular RVOT patch was determined. Glutaraldehyde-treated autologous pericardium was used for RVOT patch. After complete repair and cardiopulmonary bypass weaned off, the ratio of right ventricle systolic pressure to left ventricular systolic pressure (PRV/PLV) $\leq$ 0.7 was accepted as optimal. If PRV/PLV was > 0.7, bypass was resumed and transannular patch repair was performed. After surgery, all patients were managed in ICU with optimal inotropic support and duration of postoperative mechanical ventilation, length of ICU stay, and mortality were analyzed. Postoperative 2D echocardiography was analyzed for severity of pulmonary regurgitation (PR) before discharge and at 3 months in follow-up.

The data were analyzed using IBM SPSS 20.0 software and comparison between the two groups were performed by *t* test and chi-square test. Sensitivity and specificity was calculated using receiver operating characteristic curve (ROC). *p* values < 0.05 were considered statistically significant (Fig. 1).

Results

Out of total 90 patients included in the study, 44 (48.9%) patients had transannular patch (TAP) repair and 46 (51.1%) patients had non-transannular patch repair (non-TAP) of RVOT. The overall median age, weight, and body surface are (BSA) were similar in both groups and statistically non-significant (Table 1). The intraoperative right ventricular systolic pressure to left ventricular systolic pressure ratio (PRV/PLV) was higher in TAP group with 0.68 $\pm$ 0.10 as compared to 0.59 $\pm$ 0.19 in the non-TAP group, which was statistically significant ($p = 0.042$) and the overall PRV/PLV ratio was 0.65 $\pm$ 0.15. The pulmonary valve annulus (PVA) *Z*-score was significantly higher in non-TAP group (− 0.9 $\pm$ 1.1 in non-TAP group versus (− 3.2 $\pm$ 1.2 in TAP group) with *p* value of 0.021. The great artery annulus ratio (PVA/AVA ratio) was significantly higher (0.71 $\pm$ 0.11) in non-TAP group as compared to the TAP group (0.54 $\pm$ 0.12) with *p* value of 0.017. Cardiopulmonary bypass (CPB) time during surgery was 160 $\pm$ 10 min in patients who had TAP repair of RVOT and 140 $\pm$ 15 min in non-TAP group. Postoperative mechanical ventilation time in ICU was significantly higher in TAP group (23.8 $\pm$ 4.1 h) as compared to the non-TAP group (18.1 $\pm$ 5.0 h) with *p* value of 0.039. Follow-up analysis of patients after 3 months of discharge, showed significantly higher moderate to severe pulmonary regurgitation (PR) in TAP group (90.4%) than non-TAP group (17.3%) (*p* value 0.003). The PVA *Z*-score cut-off value in this study was − 1.89 for requirement of TAP (AUC 0.716, CI = 0.699 to 0.788) with sensitivity of 73.5% and specificity of 79.2%. When the cut-off value *Z*-score of − 2 was applied, the sensitivity was 70% and specificity was 81.7%. The PVA/AVA (great artery annulus) ratio cut-off value for TAP repair was 0.581 (AUC 0.896, CI = 0.822 to 0.946) with sensitivity 82.5% and specificity of 87.8%. The AUC of great artery annulus ratio was significantly larger than that of *Z*-score (*p* value 0.022).

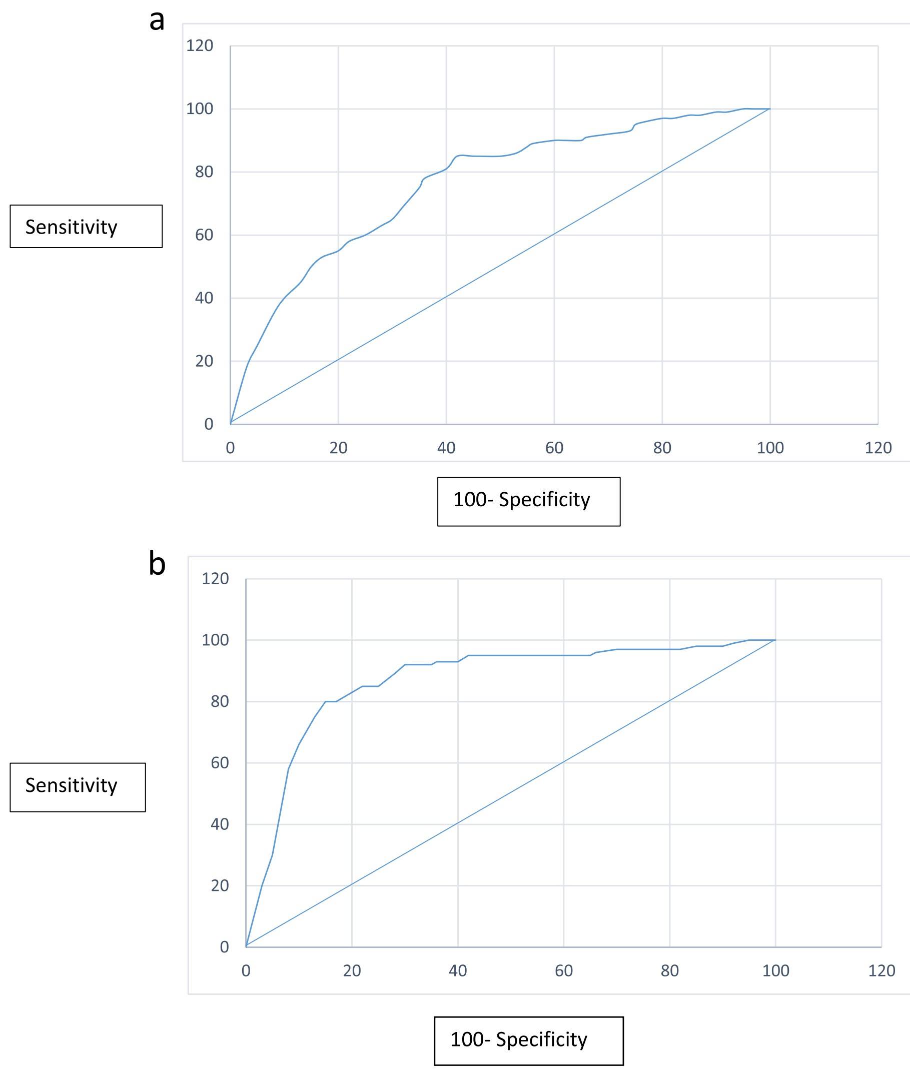

Fig. 1 a, b Receiver operating characteristic (ROC) and area under curve (AUC) for pulmonary valve annulus *z*-score and great artery annulus ratio (PVA/AVA), respectively. Sensitivity and specificity were calculated at different cut-off values. The AUC for great artery annulus ratio was higher than that of PVA *z*-score

Discussion

Traditionally, the technique of repair of TOF was closure of ventricular septal defect through ventriculotomy and relieving right ventricular outflow tract (RVOT) obstruction through transannular patch (TAP) enlargement [12]. Studies have shown early and late adverse effects of TAP enlargement such as RV dilation, functional tricuspid regurgitation, arrhythmias, and RV failure due to severe pulmonary regurgitation (PR) though it is considerably tolerated and many patients require pulmonary valve implantation in later life [13, 14]. So, preoperative anticipation of TAP is important in planning the timing for surgery for young infants. It also helps in preoperative counselling regarding the long-term adverse outcomes of TAP enlargement and need of pulmonary valve implantation later in life.

Pulmonary valve annulus (PVA) *z*-score is routinely used as predictor of TAP enlargement during repair of TOF, which is dependent on accurate calculation of body weight, height, body surface area (BSA), and population race. Although several echocardiographic parameters have been used for prediction of TAP enlargement, no consensus has been drawn. Choi et al have shown the correlation of pulmonary valve morphology and tissue characteristics in prediction of TAP enlargement [15]. Stewart et al. found the reference PVA *z*-score was − 4.0, whereas Awori et al. demonstrated it to be − 1.3 and the same was − 2.46 in findings by Choi KH et al.

Table 1 Comparison of baseline parameters between the patients underwent transannular patch enlargement (TAP group) and who did not (non-TAP group)

Parameters	TAP group (44 patients)	Non-TAP group (46 patients)	Total (90)	*p* value
Weight (kg)	7.9 ± 3.5	8.3 ± 2.8	7.9 ± 3.6	0.542
Age (months)	11.5 ± 6.1	14.2 ± 4.6	13.6 ± 7.2	0.513
Body surface area (BSA) (m^2)	0.39 ± 0.15	0.40 ± 0.12	0.40 ± 0. 9	0.615
Pulmonary valve annulus *z*-score	− 3.2 ± 1.2	− 0.9 ± 1.1	− 2.1 ± 1.3	**0.021**
Great artery annulus ratio (PVA/AVA)	0.54 ± 0.12	0.70 ± 0.11	0.62 ± 0.11	**0.017**
Cardiopulmonary bypass time (min)	160 ± 10	140 ± 15	152 ± 15	0.712
PRV/PLV ratio	0.68 ± 0.10	0.59 ± 0.19	0.68 ± 0.15	**0. 042**
Duration on ventilator (h)	23.8 ± 4.1	18.1 ± 5.0	21 ± 4.2	**0.039**
Re-intervention	01	0	1	0.662
Deaths	01	0	1	0.662
Mod-severe PR (3 months post-surgery)	41 (90.4 %)	08 (17.3%)	49	**0.003**

respectively [8, 10, 16]. In our study, the *z*-score was − 1.89, which shows the study to study variability of *z*-score as its calculation is complex and dependent on several other variables.

The great artery annulus ratio (PVA/AVA ratio) in predicting the need of TAP enlargement in repair of TOF is based on the normal embryological development when the truncus arteriosus is divided by spiral conal septum into two equal left and right ventricular outflow tract resulting in almost same size of both pulmonary and aortic annulus. In TOF, the conal septum is anteriorly deviated leading to formation of smaller pulmonary annulus and correspondingly larger aortic annulus [17]. So, it can be speculated, in the spectrum of deviation of conal septum, a certain ratio of pulmonary annulus to aortic annulus can act as a reference cut-off point in anticipating TAP enlargement. Based on this concept, several findings have been published by several authors. Kasturi et al. showed pulmonary annulus index (PAI, ratio between observed and expected pulmonary annulus) has been equally effective as the pulmonary annulus *z*-score in anticipating TAP [17]. Zhao et al. showed pulmonary annulus area index (PAAI, the pulmonary to aortic valve cross-sectional area ratio) could be a useful and accessible predictor of TAP [18]. In our study, comparison between pulmonary annulus *z*-score and the great artery annulus ratio showed significant difference. The cut-off value for great artery annulus index was 0.581 (AUC 0.896, CI = 0.822 to 0.946). The receiver operating characteristics curve demonstrates that the great artery annulus ratio was more accurate than pulmonary annulus *z*-score for prediction of TAP, as the AUC, sensitivity, and specificity of great artery annulus index was significantly greater than those of *z*-score (*p* value 0.017 for AUC). Similar findings were obtained by Choi KH et al. with cut-off great artery annulus ratio of 0.559 [16] and Lyu Z et al. with cut-off great artery annulus ratio of 0.55 [19].

As limitations of our study, firstly it was retrospective and needs prospective study for further verification of results. Because of different techniques adopted by different surgeons, large-scale studies at multiple centers are required to validate the implication of great artery annulus ratio and determining the threshold value for predicting requirement of TAP enlargement.

Conclusions

Great artery annulus ratio (PVA/AVA ratio) can serve as a useful and accurate predictor for transannular patch during repair of TOF, along with the PVA *z*-score. The advantage of this ratio is being calculated easily and readily, and it is patient-specific which avoids the wide variability as that of *z*-score. Nevertheless, the final decision is based on the adequate sizing of pulmonary valve and main pulmonary artery intraoperatively.

Abbreviations

AVA: Aortic valve annulus; AUC: Area under curve; CPB: Cardiopulmonary bypass; CTA: Computed tomography angiography; CI: Confidence interval; GIPMER: GB Pant Institute of Post Graduate Medical Education and Research; ICU: Intensive care unit; IBM SPSS: International Business Machines Corporation Statistical Package for Social Sciences; PAI: Pulmonary Artery Index; PAAI: Pulmonary Artery Area Index; PR: Pulmonary regurgitation; PRV/PLV: Systolic pressure of RV/systolic pressure of left ventricle; PS: Pulmonary stenosis; PV: Pulmonary valve; PVA: Pulmonary valve annulus; RV: Right ventricle; RVOT: Right ventricle outflow tract; RVOTO: Right ventricle outflow tract obstruction; TAP: Transannular patch; TAPE: Transannular patch enlargement; TOF: Tetralogy of Fallot.

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Authors' contributions
Dr. Satyajit Samal—conception and design of the work, data acquisition, analysis, and interpretation. Dr. Rakesh Sharma—data acquisition, analysis, and interpretation. Dr. Harpreet Singh Minhas—revision of the manuscript and intellectual input. Dr. Girish G—data acquisition, analysis, and interpretation. Dr. Saket Agarwal—revision of the work critically for important intellectual content. Dr. Sayyed Ehtesham Hussain Naqvi—drafting the work. Dr. Muhammad Abid Geelani—final approval to be published. All authors read and approved the final manuscript.

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Declarations

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Not applicable.

Consent for publication
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Competing interests
The authors declare that they have no competing interests.

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