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Original Article

Pulmonary Valve Annulus Z-Score as a Predictor of Transannular Patch Insertion in Tetralogy of Fallot Repair: A Cross-sectional Study at National Cardiovascular Center Harapan Kita

Pribadi Wiranda Busro[1,2], Ahmad Adityawarman[2], Suprayitno Wardoyo[2], Olfi Lelya[3], Oktavia Lilyasari[3]

Abstract

Background: The use of a Transannular Patch (TAP) in the surgical repair of Tetralogy of Fallot (TOF) can improve Right Ventricular Outflow Tract (RVOT) flow but may increase the risk of long-term pulmonary insufficiency. Therefore, the decision to use TAP is critical. The Pulmonary Valve Annulus (PVA) diameter z-score is commonly used to predict TAP insertion; however, no z-score threshold has been established in Indonesia. This study sought to investigate whether the preoperative z-score of PVA diameter predicts the use of TAP during TOF repair surgery.

Methods: This cross-sectional study utilized data from 101 TOF patients who underwent TOF repair at National Cardiovascular Center Harapan Kita between January 2023 and December 2024. Patients were divided into two groups based on TAP usage (Yes: n = 65; No: n = 36). Preoperative PVA diameter was obtained from cardiac Multislice Computed Tomography (MSCT). Multivariate logistic regression was performed, and Receiver Operating Characteristic (ROC) curve analyses were conducted to determine the optimal cutoff thresholds.

Results: Multivariate analysis showed the z-score of PVA minimal diameter was significantly associated with TAP usage (Odds Ratio [OR] 0.450, 95% Confidence Interval [CI] 0.297 to 0.683, P < 0.001). A preoperative minimum PVA diameter z-score cut-off of -1.6 yielded a sensitivity of 75.4% and a specificity of 61.1%.

Conclusions: The z-score of the PVA diameter may serve as a useful predictor in planning an appropriate surgical strategy in ToF repair, particularly regarding the decision to use a TAP.

[1]Department of Pediatric and Congenital Heart Surgery, National Cardiovascular Center Harapan Kita, Universitas Indonesia, Jakarta, Indonesia
[2]Division of Thoracic, Cardiac, and Vascular Surgery, Department of Surgery, Faculty of Medicine, Universitas Indonesia, Jakarta, Indonesia
[3]Pediatric Cardiology and Congenital Heart Disease Division, Department of Cardiology and Vascular Medicine, Faculty of Medicine Universitas Indonesia

Correspondence:
Pribadi Wiranda Busro,

Department of Pediatric and Congenital Heart Surgery, National Cardiovascular Center Harapan Kita/Division of Thoracic, Cardiac, and Vascular Surgery, Department of Surgery, Faculty of Medicine, Universitas Indonesia, Jakarta, Indonesia

Email: pribadibusro@gmail.com

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Introduction

Among cyanotic congenital heart defects, Tetralogy of Fallot (TOF) is the most frequently encountered, representing 3–5% of all congenital heart diseases, with an estimated incidence of 0.28–0.34 per 1,000 live births.[1] Surgical correction of TOF has been routinely performed with success since 1955. The repair strategy includes closing the ventricular septal defect and alleviating Right Ventricular Outflow Tract (RVOT) obstruction, which may require infundibular muscle resection, pulmonary valvotomy or valvectomy, and, in most cases, enlargement of the outflow tract by placement of either a subvalvular or Transannular Patch (TAP).[2] Surgical total correction of TOF in children often leads to positive prognoses, with long-term survival reported at nearly 90%.[3]

TAP remains a commonly used technique in primary TOF repair. Data from the Society of Thoracic Surgeons (STS) Database show that TAP is used in approximately 45% of cases, whereas studies in Asian populations report a wider range of 25% to 74.6%, depending on anatomical factors and surgical strategy.[4–6] The use of TAP provides effective enlargement of the RVOT in cases of pulmonary annular hypoplasia; however, this comes at the expense of pulmonary valve competency, increasing the likelihood of progressive PR, right ventricular dilatation, arrhythmogenic events, and sudden cardiac death.[7-8] Accordingly, accurate prediction of TAP requirements is of great importance for optimizing surgical planning and, when feasible, pursuing a valve-sparing approach.[9]

Up to now, the prediction of TAP requirement has largely been determined by the Pulmonary Valve Annulus (PVA) z-score.[10] However, there is currently no definitive consensus regarding the cutoff value. A PVA z-score greater than -3 suggests that a TAP may be avoidable, whereas other literature recommends applying a TAP when the z-score is less than -2 to avoid residual RVOT obstruction, which may be more detrimental to the patient's outcome.[11-12]

Previous studies used echocardiography to measure the preoperative PVA diameter.[8-9] However, echocardiography has inherent limitations in accurately characterizing the three-dimensional geometry of the PVA. Multislice Computed Tomography (MSCT) enables more precise measurements and facilitates superior three-dimensional assessment through enhanced visualization of the annular plane and its geometry.[13] Despite these advantages, data on MSCT-derived PVA z-score for guiding TAP utilization remain limited. Therefore, this study aimed to evaluate the ability of the PVA diameter z-score, measured by MSCT, to assist in decision-making regarding TAP use during primary surgical repair of ToF.

Methods

Study Design and Setting

We conducted a cross-sectional study at the National Cardiovascular Center Harapan Kita in Jakarta. The subjects were patients who underwent surgical repair of ToF between January 2023 and December 2024. The study was approved by the Committee on Institutional Review Board/Health Research Ethics of National Cardiovascular Center Harapan Kita Hospital, under approval number DP.04.03/KEP164/EC102/2025.

Study Population

This study included all patients diagnosed with TOF who underwent primary total correction before the age of less than 18 years and had complete preoperative cardiac MSCT data.

Patients were excluded if they had a history of palliative procedures, such as systemic-to-pulmonary artery shunts (modified Blalock–Taussig–Thomas shunt, central shunt, or patent ductus arteriosus stenting) or RVOT stenting, prior to definitive TOF repair. Patients with other complex congenital anomalies (e.g., TOF with atrioventricular septal defect, pulmonary atresia, absent pulmonary valve, anomalous pulmonary venous drainage, or coronary artery anomalies) and those with incomplete data were also excluded.

Data Collection and Measurements

The diameter of the PVA was measured retrospectively from preoperative cardiac MSCT recordings. Imaging was generally performed within 6 months prior to surgery to minimize the potential influence of somatic growth on PVA measurements. To ensure accurate PVA measurement, Multiplanar Reformation (MPR) was performed at the annular level to obtain the most ideal circular image, then the minimum and maximum diameters were measured. The obtained minimum and maximum diameters were then substituted into the z-score formula.13 Body Surface Area (BSA) was measured using the Haycock formula. The decision to use a TAP was made intraoperatively by the surgeon, based on the anatomical condition of the RVOT and the pulmonary annulus. TAP was also inserted when significant RVOT stenosis persisted after attempts to preserve PVA, as indicated by a right ventricular systolic pressure greater than 75% of the systemic systolic pressure.

Statistical Analysis

Patients were divided into two groups based on whether a TAP was used intraoperatively: the TAP group and the non-TAP group. Continuous variables are presented as mean ± standard deviation or median (interquartile range), while categorical variables are presented as frequencies and percentages. Comparisons between groups for continuous variables were performed using the independent t-test or the Mann-Whitney test. Associations between categorical variables were analyzed using the Chi-square or Fisher's exact test. Variables with a p-value < 0.25 in univariate analysis were entered into a multivariate logistic regression model. A p-value < 0.05 was considered statistically significant. Receiver Operating Characteristic (ROC) curve analysis was used to determine the optimal cutoff value of the PVA diameter z-score for predicting TAP utilization. All analyses were performed using SPSS version 27.0.

Results

Patient Characteristics

Among the 101 patients with TOF, 65 (64.4%) underwent surgical repair with TAP, whereas 36 (35.6%) underwent repair without TAP. There were no significant differences in baseline characteristics, including age, sex, weight, height, BSA, and McGoon ratio between the two groups (p > 0.05) (Table 1). The mean interval between MSCT examination and surgery was 89.8 ± 55.0 days (median 82 days; range 3–235 days).

Comparison of PVA Z-Score

Preoperative PVA diameter measurements were obtained from MSCT images and independently assessed by two observers, followed by an Intraclass Correlation Coefficient (ICC) analysis. Excellent agreement was observed for the maximum PVA diameter (ICC = 0.939; 95% Confidence Interval (CI): 0.881-0.969; p < 0.001); Cronbach's alpha = 0.971) and good agreement for the minimum PVA diameter (ICC = 0.898; 95% CI: 0.808-0.947;

Table 1. Patient demographics and PVA z-score between groups.

	TAP (N = 65)	Non TAP (N = 36)	P-value
Gender			0.138
Male	44 (69.8%)	19 (30.2%)	
Female	21 (55.3%)	17 (44.7%)	
Weight (kg)	10.6 (5.5-32)	11.85 (6.6-39)	0.099
Height (cm)	85 (61-140)	93 (67-162)	0.087
BSA (m^2)	0.51 (0.33-1.06)	0.56 (0.35-1.31)	0.079
Age (months)	34 (8-141)	49 (7-162)	0.161
McGoon ratio	2.19 ± 0.41	2.22 ± 0.44	0.725
PVA Z-score			
Maximum diameter	-2.57 ± 1.09	-1.61 ± 1.25	< 0.001
Minimum diameter	-2.25 ± 1.08	-1.61 ± 1.23	< 0.001

BSA: Body Surface Area; PVA: Pulmonary Valve Annulus.

Table 2. The logistic regression analysis for risk factors of TAP use in ToF repair operations.

Variables	Multivariate		
	P-values	OR	CI (95%)
Age	0.365	1.02	0.98-1.05
BSA	0.625	0.564	0.06-5.62
PVA z-score			
Maximum diameter	0.3	0.739	0.417-1.310
Minimum diameter	< 0.001	0.450	0.297-0.683

BSA: Body Surface Area; PVA: Pulmonary Valve Annulus.

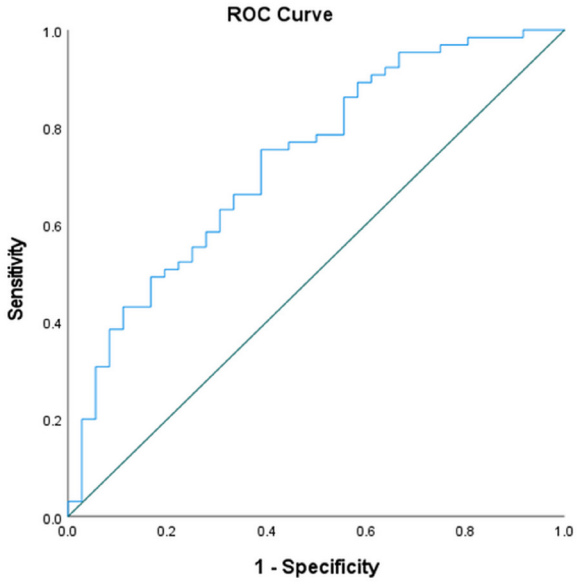


Figure 1. ROC curve analysis of the z-scores of PVA minimum diameter in predicting TAP use.

$p < 0.001$; Cronbach's alpha = 0.945). Mean PVA diameter z-score in the TAP group was lower (-2.57 ± 1.09 for maximum diameter and -2.25 ± 1.08 for minimum diameter) when compared with the non-TAP group (-1.61 ± 1.25 for maximum diameter and -1.21 ± 1.23 for minimum diameter), with a significant difference based on the t-test results ($p < 0.001$ for both maximum and minimum diameter).

Multivariable analysis using binary logistic regression was performed for risk factors with p-values < 0.25. The result showed that the z-score of the PVA minimum diameter was consistently associated with the use of a TAP (Odds Ratio [OR] = 0.450; 95% CI: 0.297-0.683; $p < 0.001$) (Table 2).

ROC analysis was performed on the z-score of the PVA minimum diameter parameter to predict the use of TAP (Figure 1) and revealed an Area Under the Curve (AUC) of 0.732 (95% CI 0.63-0.83; $p < 0.001$), indicating fair discriminative performance. A cutoff of -1.6 will provide a sensitivity of 75.4% and a specificity of 61.1%, a positive predictive value of 77.8%, and a negative predictive value of 57.9%.

Discussion

TOF is one of the most common cyanotic congenital heart defects and carries a poor prognosis if timely surgical intervention is not performed. Total corrective repair remains the standard therapy, with TAP repair often required to relieve pulmonary annular stenosis. However, TAP is associated with less favorable long-term outcomes due to significant PR, which can impair right ventricular function and survival. Earlier research has established that the use of TAP is associated with an increased risk of long-term Pulmonary Regurgitation (PR).[2,14-15] Consequently, contemporary surgical strategies emphasize valve-sparing approaches to preserve pulmonary valve function, minimize PR, and improve long-term quality of life.[1,7–9]

The PVA size is a critical determinant in selecting the appropriate RVOT reconstruction strategy. Patients with a markedly small PVA typically require TAP, whereas those with a sufficiently large PVA are suitable candidates for valve-sparing repair.[10] In patients with borderline PVA sizes, however, the choice of RVOT reconstruction often depends on the surgeon's experience and institutional practices, leading to variability in clinical decision-making. A recent meta-analysis has demonstrated that a pulmonary annulus z-score cutoff around –2.59 predicts the need for TAP, while Li et al reported a lower cutoff value of -1.4.[8,10]

Other factors that may play an important role in ToF repair surgical strategy are prior palliative interventions and the timing of definitive repair. Procedures such as modified Blalock-Taussig-Thomas shunt or RVOT stenting are sometimes performed to improve pulmonary blood flow and stabilize patients before total correction, particularly in late presenters or those with unfavorable anatomy.[16-17] However, staged repair following palliation may be associated with higher morbidity and reintervention rates, although long-term

survival appears comparable to primary repair. In addition, delayed presentation may lead to more severe RVOT obstruction and pulmonary annular hypoplasia, potentially increasing the likelihood of TAP utilization during repair.[16] In the present study, patients with prior palliative procedures were excluded to maintain a homogeneous population undergoing primary repair.

Limited access to early diagnosis and specialized cardiac centers often results in later presentation compared with high-income settings, where repair is typically performed during infancy. Data from the International Quality Improvement Collaborative showed that more than half of ToF repairs in low- and middle-income countries were performed after the age of one year.[18] Delayed diagnosis and the absence of preoperative palliation may reduce the likelihood of pulmonary valve-sparing repair. Operative decisions are therefore frequently made intraoperatively based on anatomical assessment, including PVA size and z-score, the degree of valvular dysplasia, and the ability to relieve RVOT obstruction without annular disruption.[1] Our findings support this perspective, suggesting that objective preoperative parameters, such as the PVA z-score, may help standardize surgical planning and assist decision-making in centers where clinical presentations and resource settings vary.

Variability in TAP cutoff values likely reflects the use of inconsistent z-score datasets, which may overestimate annular size and result in inappropriate valve-sparing. The traditionally accepted cutoff value is -2, as reported by Awori et al., since lower thresholds are generally avoided to reduce the risk of residual RVOT obstruction, which may be more detrimental than TAP-related PR.[12]

We demonstrated that the optimal cutoff value of the z-score of PVA minimum diameter for predicting the use of a TAP was -1.6. This value provided a favorable balance between sensitivity (75,4%) and specificity (61,1%). Our study used pulmonary annulus diameter measurements based on cardiac MSCT and computed tomography-derived reference values from Soszyn et al., which explain the differences in cutoff values compared with previous echocardiography-based studies. MSCT provides greater measurement accuracy due to its higher spatial resolution, and three-dimensional assessment of the pulmonary valve allows better visualization of the annular plane and its configuration.[13]

These findings suggest that preoperative assessment of the z-score of PVA diameter, obtained with cardiac MSCT, can help surgeons individualize RVOT reconstruction strategies. A higher PVA minimum diameter z-score may allow for a safer valve-sparing or pulmonary valve preservation approach, which will produce superior mid- and long-term outcomes.[9,19] The moderate AUC indicated that annular size was not a single perfect predictor, although this variable made a significant contribution in predicting the TAP insertion. Other clinical factors may need to be considered to enhance diagnostic accuracy. For instance, morphological abnormalities of the pulmonary valve may also influence a surgeon's decision to perform a TAP procedure. Unfortunately, incomplete intraoperative data on pulmonary valve morphology in our study precluded its analysis despite its clinical relevance.

A further limitation of this study is its single-center retrospective design. In addition, PVA z-scores were calculated using the formula proposed by Soszyn et al., which is based on a non-Indonesian population and may limit comparability with other studies. Although this study focused on predictors of TAP utilization, postoperative PR remains an important determinant of long-term outcomes after TOF repair. Further studies are warranted to evaluate its predictors, including the role of preoperative PVA z-score.

Conclusion

A lower PVA diameter z-score was significantly associated with the use of a TAP in TOF repair. Preoperative assessment of this parameter may assist in surgical decision-making, potentially reducing the need for TAP and its long-term consequences. Therefore, we recommend an optimal z-score cutoff of -1.6 for the preoperative minimum PVA diameter measured by MSCT to predict the need for TAP insertion.

List of Abbreviations

AUC	Area Under the Curve
BSA	Body Surface Area
CI	Confidence Interval
ICC	Intraclass Correlation Coefficient
MPR	Multiplanar Reformation
MSCT	Multislice Computed Tomography
OR	Odds Ratio
PR	Pulmonary Regurgitation
PVA	Pulmonary Valve Annulus
ROC	Receiver Operating Characteristic
RVOT	Right Ventricular Outflow Tract
STS	Society of Thoracic Surgeons

TOF Tetralogy of Fallot
TAP Transannular Patch

Ethical Clearance

The study was approved by the Committee on Institutional Review Board/Health Research Ethics of National Cardiovascular Center Harapan Kita Hospital, under approval number DP.04.03/KEP164/EC102/2025.

Publication Approval

All authors consent to the publication of this manuscript.

Authors' Contributions

Pribadi W. Busro (PWB), Ahmad Adityawarman (AA), Suprayitno Wardoyo (SW), and Oktavia Lilyasari (OL) were involved in concept/design and drafted the paper. PWB, AA, SW, and OL defined the analysis method and were involved in data analysis and interpretation. AA collected the data. OL and Olfi Lelya (OLY) contributed to the assessment of cardiac MSCT imaging. PWB, SW, and OL performed critical revision. All authors approved the final version of the manuscript and take responsibility for the work as a whole.

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Conflict of Interest

The authors declare that they have no proprietary, financial, professional, or any other conflict of interest.

Availability of Data and Materials

The datasets generated and/or analyzed during this study are not publicly available due to patient confidentiality but are available from the corresponding author upon reasonable request.

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