RESEARCH PAPER

Association of Pulmonary Vein Index with Early Postoperative Outcomes in Patients Undergoing Total Correction of Tetralogy of Fallot

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Abstract

Background: The Pulmonary Vein Index (PVI) is a new indicator for how the pulmonary vascular system develops. However, we haven't really dug into how it relates to early outcomes after total correction of Tetralogy of Fallot (TOF) yet.
Objectives: To evaluate the association between preoperative PVI and early postoperative outcomes in patients undergoing total correction of TOF.
Methods: We conducted a 12-month study at the Department of Cardiac Surgery at BSMMU in Dhaka, Bangladesh. We looked at thirty pediatric patients who were undergoing total TOF correction and split them into two groups: Group A, which had a PVI of 300.3 mm^2/m^2 or more (15 patients), and Group B, with a PVI of less than 300.3 mm^2/m^2 (also 15 patients). We then compared their early postoperative outcomes. The data was analyzed with SPSS version 26, using methods like independent t-tests, chi-square tests, and Cox regression.
Results: The demographic details were pretty similar across the board. However, Group B, which had lower PVI, showed much poorer hemodynamics (RVP/LVP: 0.73±0.16 compared to 0.34±0.14; $p<0.001$), needed more inotropic support (24-hour VIS: 12.2±2.6 vs. 9.0±3.6; $p=0.011$), and experienced longer recovery times (ventilation: 59.9 vs. 39.8 hours; CICU: 127.7 vs. 63.3 hours; hospital stay: 18.3 vs. 10.8 days; all $p\leq0.001$). All the major complications were seen only in Group B. It turns out that a lower PVI is an independent risk factor for a longer hospital stay (aHR 0.990, $p=0.016$).
Conclusion: Having a lower Pulmonary Vein Index before surgery is linked to worse early outcomes after the operation. This includes things like more issues with blood flow, a greater need for medications to support the heart, a longer recovery time, and higher rates of complications after correcting Tetralogy of Fallot. So, PVI could be a useful predictor before surgery.

Keywords: Congenital Heart Disease, Pulmonary Vein Index, Tetralogy of Fallot, Vasoactive Inotropic Score

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Introduction

Tetralogy of Fallot (TOF) is actually the most common type of cyanotic congenital heart defect. Complete surgical repair is the key part of treating it [1]. In recent decades, we've seen huge improvements in surgical techniques and perioperative care, which have really boosted survival rates. This progress has led clinicians to focus more on enhancing functional outcomes and lowering complications [2,3]. However, the early days after surgery, when total correction is done, can still be pretty critical. Patients often face challenges like right ventricular dysfunction, low cardiac output syndrome, and extended stays in intensive care with inotropic support [4]. All this variation in how patients recover highlights the need for better preoperative indicators that can help predict their clinical journey and improve management. In the past, when planning surgeries for TOF repairs, doctors typically focused on the anatomy of the pulmonary arteries. They often used the McGoon ratio and the Nakata index, which are common ways to measure the size and connections of these arteries. Smaller artery sizes have been linked to higher surgical risks [5]. Yet, these measurements don't tell the whole story since they

mostly look at the larger, proximal arteries. There's more and more research showing that the distal pulmonary vascular bed is actually really important too. This area is where the resistance happens and plays a big role in how well the right ventricle performs just after fixing the obstruction in the right ventricular outflow tract [6]. If this vascular bed isn't well developed, it can cause increased resistance in the pulmonary vessels, which can put patients at risk for right heart failure after surgery, making it tough to wean them off cardiopulmonary support. There's been a growing interest in new preoperative measures that provide a better picture of the overall health of the pulmonary vasculature. One such measure is the Pulmonary Vein Index (PVI), which comes from computed tomographic angiography. It calculates the total cross-sectional area of the pulmonary veins adjusted for body surface area [7]. The thing to note is that since the venous system is the last part of the pulmonary circuit, having a lower PVI might indicate a developmentally constrained distal vascular tree, which could point to higher intrinsic pulmonary vascular resistance. Some early studies involving patients with congenital heart disease have indicated that a lower PVI could be linked to worse outcomes after surgery, such as longer stays in intensive care and an increased need for cardiorespiratory support [7,8]. Even though there's a solid theory behind it, we don't really know how useful the Pulmonary Vein Index (PVI) is for predicting outcomes after repairing Tetralogy of Fallot (TOF). The studies available so far are pretty limited, and we still need a thorough look at how preoperative PVI ties into important early clinical outcomes like hemodynamic stability, medication needs, and the length of time patients spend on a ventilator or in the hospital [9]. Figuring this out is crucial if we want to start using PVI more routinely to assess risk in clinical settings. If we can confirm that PVI is a reliable indicator, it might help us plan surgeries more effectively and allow for better, tailored care after surgery to help prevent any complications. With that in mind, this study set out to explore how preoperative PVI relates to early recovery results in patients undergoing total correction for TOF. We think that a lower preoperative PVI could mean a tougher recovery with poorer hemodynamic results, needing more medication, and longer recovery times.

Objective

The main objective was to evaluate the association between preoperative PVI and early postoperative outcomes in patients undergoing total correction of TOF.

Methodology

This cross-sectional study was conducted in the Department of Cardiac Surgery at Bangabandhu Sheikh Mujib Medical University (BSMMU), Dhaka, Bangladesh, over a period of 12 months. A total of 30 patients diagnosed with Tetralogy of Fallot (TOF) and scheduled for total surgical correction were enrolled in the study using a convenience sampling technique. Written informed consent was obtained from the parents or legal guardians of all participants prior to inclusion in the study.

Selection Criteria:

a. Inclusion Criteria

- Patients diagnosed with Tetralogy of Fallot undergoing total surgical correction.
- Patients whose parents or legal guardians provided informed written consent for participation.

b. Exclusion Criteria

- Tetralogy of Fallot associated with other congenital cardiac anomalies.
- Previous Blalock-Taussig (BT) shunt procedure.
- Refusal to provide informed consent.

All enrolled patients underwent preoperative evaluation, including clinical examination, echocardiography, and computed tomography (CT) pulmonary angiography. The Pulmonary Vein Index (PVI) was measured from CT pulmonary angiographic images and indexed to body surface area. Based on the preoperative PVI value, patients were divided into two groups: Group A comprising patients with PVI $\geq$300.3 mm²/m² (n=15) and Group B comprising patients with PVI <300.3 mm²/m² (n=15). All patients underwent total correction of Tetralogy of Fallot through a median sternotomy under standardized general anesthesia and cardiopulmonary bypass. Surgical correction was performed according to institutional protocols by the same cardiac surgical team. Perioperative variables including cardiopulmonary bypass time, aortic cross-clamp time, and operative findings were recorded. Following surgery, patients were monitored in the Cardiac Intensive Care Unit (CICU). Early postoperative outcomes were assessed and documented, including right ventricular outflow tract (RVOT) gradient, vasoactive inotropic score (VIS), duration of mechanical ventilation, length of CICU stay, and total hospital stay. Postoperative complications, if any, were also recorded. Ethical approval for the study was obtained from the Institutional Review Board/Ethical Review Committee of BSMMU. Confidentiality of patient information was strictly maintained throughout the study, and all procedures were conducted in accordance with accepted ethical standards.

Statistical analysis: Data were entered, processed, and analyzed using Statistical Package for Social Sciences (SPSS) version 26. Continuous variables were expressed as mean ± standard deviation (SD) or

median with interquartile range (IQR), as appropriate. Comparisons between the two groups were performed using the unpaired Student's t-test or categorical variables. A p-value of less than 0.05 was

Result

Table 1: Baseline characteristics by PVI group

Characteristic	Group A (n=15)	Group B (n=15)	p-value
Age (years)	6.05 ± 2.44	6.0 ± 1.89	0.960^a
Male, n (%)	11 (73.3)	7 (46.7)	0.136^b
Weight (kg)	15.47 ± 3.93	15.94 ± 3.17	0.721^a
BSA (m²)	0.38 ± 0.10	0.45 ± 0.13	0.109^a

Data: Mean ± SD or n (%). PVI Group: A (≥300.3 mm²/m²), B (<300.3 mm²/m²). BSA: Body Surface Area. ^a Independent t-test; ^b Chi-square test.

Table 1 shows the baseline characteristics of the study population. The mean age was similar between Group A (6.05 ± 2.44 years) and Group B (6.0 ± 1.89 years), with no statistically significant difference (p=0.960). Male predominance was observed in both groups but was not significantly different (p=0.136). Weight and body surface area were also comparable between the groups (p>0.05), indicating baseline homogeneity.

Table 2: Preoperative angiographic indices

Index	Group A	Group B	p-value
PVI (mm²/m²)	328.1 ± 18.2	240.1 ± 31.9	<0.001*
Nakata (mm²/m²)	319.6 ± 16.1	224.2 ± 29.3	<0.001*
McGoon ratio	2.17 ± 0.21	1.42 ± 0.19	<0.001*

Data: Mean ± SD. Independent t-test.

Table 2 demonstrates significantly higher pulmonary vascular indices in Group A compared to Group B. PVI, Nakata index, and McGoon ratio were all significantly greater in Group A than in Group B (all p<0.001), indicating better preoperative pulmonary artery development in the higher PVI group.

Table 3: Postoperative hemodynamics & Inotropic support

Outcome	Group A	Group B	p-value
RVP/LVP	0.34 ± 0.14	0.73 ± 0.16	<0.001*
VIS (Immediate)	13.5 ± 3.2	17.2 ± 3.7	0.007*
VIS (24-hr max)	9.0 ± 3.6	12.2 ± 2.6	0.011*

Data: Mean ± SD. RVP/LVP: Right/Left Ventricular Pressure ratio; VIS: Vasoactive Inotropic Score. Independent t-test.

Mann–Whitney U test for continuous variables and the Chi-square test or Fisher's exact test for

considered statistically significant.

Table 3 presents postoperative hemodynamic parameters and inotropic requirements. The RVP/LVP ratio was significantly lower in Group A compared to Group B (p<0.001). Similarly, both immediate and 24-hour maximum VIS were significantly lower in Group A, indicating reduced inotropic support requirement in patients with higher PVI.

Table 4: Postoperative recovery parameters

Parameter	Group A	Group B	p-value
Ventilation (hrs)	39.8 ± 12.9	59.9 ± 22.1	0.001*
CICU Stay (hrs)	63.3 ± 25.3	127.7 ± 30.5	<0.001*
Hospital stays (days)	10.8 ± 3.7	18.3 ± 7.1	0.001*

Data: Mean ± SD. CICU: Cardiac Intensive Care Unit. Independent t-test.

Table 4 shows postoperative recovery outcomes. Patients in Group A had significantly shorter duration of mechanical ventilation, CICU stay, and total hospital stay compared to Group B (all p≤0.001), indicating faster postoperative recovery in the higher PVI group.

Table 5: Major postoperative complications

Complication	Group A	Group B
Uneventful	7 (46.7%)	2 (13.3%)
Renal failure^†	0	3 (20.0%)
Bleeding^‡	2 (13.3%)	3 (20.0%)
Delayed sternal closure	0	2 (13.3%)

Death	1 (6.7%)	2 (13.3%)

Data: n (%). ^†Requiring temporary dialysis; ^‡Requiring resternotomy.

Table 5 summarizes postoperative complications. The uneventful recovery rate was higher in Group A compared to Group B. Complications such as renal failure, delayed sternal closure, and mortality were more frequently observed in Group B, whereas Group A showed comparatively fewer adverse outcomes.

Table 6: Cox regression for prolonged hospital stays

Risk Factor	aHR (95% CI)	p-value
PVI (per mm²/m² decrease)	0.990 (0.982–0.998)	0.016
CPB Time (per min)	0.984 (0.969–0.999)	0.036
Postop. RVP/LVP	9.091 (1.335–61.728)	0.024

Table 6 presents Cox regression analysis for predictors of prolonged hospital stay. Decreased PVI, increased cardiopulmonary bypass time, and higher postoperative RVP/LVP ratio were all significantly associated with prolonged hospitalization, indicating these as independent risk factors for poor postoperative outcomes.

Discussion

In this study, we looked at 30 pediatric patients who were having total correction for Tetralogy of Fallot (TOF). We divided them into two groups based on their preoperative conditions. The results showed a clear link between a lower preoperative Pulmonary Vein Index (PVI) and a tougher early recovery after surgery for TOF. Specifically, patients with a PVI under 300.3 mm²/m² had worse hemodynamic issues, needed more inotropic support, and took longer to recover than those with a higher PVI. This supports the growing idea that how well the pulmonary veins are functioning before surgery plays a big role in how the right ventricle performs afterward. The recovery impacts were quite significant. Those in Group B faced much longer mechanical ventilation periods, stayed in the cardiac intensive care unit (CICU) for longer, and had extended overall hospital stays (all with p=0.001). The complication rates were also higher in Group B, which saw all the cases of kidney failure that needed temporary dialysis and delayed sternal closures. Unfortunately, the mortality rate was also greater in Group B, at 13.3%, compared to 6.7% in Group A. [7,10]. The significant differences in blood flow dynamics we found are crucial for understanding our results. The notably higher ratio of right ventricular pressure to left ventricular pressure in the low PVI group suggests that there's a bigger pressure load on the right ventricle right after the surgical repair. This fits with the theory that a smaller total cross-sectional area of the pulmonary veins means the distal pulmonary blood vessels are underdeveloped and restrictive, which in turn raises pulmonary vascular resistance [11]. This increased pressure load puts extra strain on the newly reconstructed right ventricle, which probably explains why patients in this group required more ongoing support from vasoactive and inotropic drugs, as shown by their higher Vasoactive Inotropic Scores. Plus, our regression analysis backs this up by showing that a lower PVI is an independent risk factor for longer hospital stays, alongside known factors like having a longer time on the heart-lung machine [12,13]. We could clearly see the effects of this hemodynamic stress on all the recovery metrics we looked at. For the low PVI group, their stay in the CICU almost doubled, and they had much longer times on mechanical ventilation and in the hospital overall. This means a big jump in resource use and worse outcomes for those patients. These practical outcomes are consistent with previous, smaller investigations hinting at PVI's role in predicting ICU course [10], but our study provides a more comprehensive, multivariate analysis within a defined TOF cohort. The fact that serious issues, such as kidney failure that needs dialysis, only happened in the low PVI group really highlights the real clinical risks tied to this preoperative anatomical profile. It also supports earlier findings that poor right ventricular output can lead to problems with other organs [14]. Our use of the 300.3 mm²/m² cutoff, derived from prior work [11], proved clinically meaningful in stratifying patient risk. This threshold really made it clear which patients fell into two different categories with varying outcomes. It could be quite useful for planning surgeries ahead of time. For instance, spotting patients with a low PVI might help in creating specific management strategies, like being ready for advanced medication needs, longer weaning off ventilators, or, in some severe cases, even thinking about breaking up the surgery into stages [15]. It may also aid in setting realistic expectations for families regarding the anticipated postoperative recovery trajectory. There are a few important limitations to keep in mind with this study. For starters, the fact that it was done at just one center and involved a small group of 30 participants makes it hard to say how widely these results can be applied, and we can't really establish a clear cause-and-effect relationship. Plus, using convenience sampling might lead to some selection bias. Also, even though we accounted for several factors in our analysis, there are probably other variables we didn’t measure—like different

strategies for protecting the heart or variations in how patients are cared for after surgery—that could affect the results [16]. The study primarily looked at early postoperative results, but we still don't know how a low PVI might affect things like right ventricular remodeling, exercise capacity, or the need for further interventions in the long run. This is definitely a key area for future research [17,18]. To really nail down the PVI cutoff, we'll need bigger, multi-center studies that are more prospective, so we can combine it with other predictive models and see how it influences long-term outcomes.

Limitations

This study, done at just one center and with a small group of participants, makes it hard to apply the findings broadly or draw definitive cause-and-effect conclusions. There are also some perioperative factors we didn't measure that could affect the results. Plus, since we only looked at early outcomes, we can't really comment on the long-term effects, so it definitely calls for more research down the line.

Conclusion and Recommendation

This study highlights that the preoperative Pulmonary Vein Index (PVI) is a key and standalone predictor of early postoperative results for kids having total correction of Tetralogy of Fallot. If the PVI is less than 300.3 mm^2/m^2, it tends to lead to worse immediate blood flow, a higher need for medications to support the heart, longer stays in intensive care and overall hospital, and an increased chance of serious complications. By including PVI in the preoperative evaluation, we could improve risk assessment, allow for more tailored surgical and recovery planning, and, in the end, boost the clinical outcomes for these patients. When planning for TOF repair, it's important to include the Pulmonary Vein Index in the risk assessment. To really confirm its usefulness in predicting outcomes, we should consider doing future multi-center, prospective studies. This could help clarify its role in tailoring surgical and post-op care for each patient.

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Conflicts of interest: There are no conflicts of interest.

Ethical approval: The study was approved by the Institutional Ethics Committee.

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