

## Is the patch repair of partial anomalous pulmonary venous drainage equivalent to the Warden procedure?

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### ABSTRACT

**Introduction:** Partial anomalous pulmonary venous return (PAPVR) is a congenital heart defect frequently associated with a sinus venosus atrial septal defect (ASD). Surgical repair varies depending on the anatomical position of the anomalous pulmonary veins. This study aims to compare the outcomes of three surgical techniques - single patch, two-patch technique, and Warden procedure- used in the repair of PAPVR with sinus venosus ASD.

**Methods:** A retrospective study was conducted, analyzing the outcomes of 87 patients who underwent surgical repair for PAPVR between January 2011 and August 2024. Patients were divided into three groups based on the surgical technique used: 44 underwent the Warden procedure, 33 were treated with the single-patch technique, and 10 received the two-patch technique.

**Results:** No mortality was observed across all techniques. The median age at operation was 5.4 years (1.4–10.4 years), and the median hospital stay was 3.0 days (IQR 3.0–4.0). Logistic regression analysis revealed a higher likelihood of immediate postoperative complications with the Warden technique (OR: 5.00, 95% CI [1.30–19.25],  $p = 0.0193$ ). No patients required a pacemaker implantation. Four patients who had a single (2) and double patch (2) technique needed a reintervention on the systemic or pulmonary venous pathway, while no patient who had a Warden procedure needed a reintervention of the venous pathways.

**Conclusion:** Despite a higher risk of early complications, the Warden procedure seems to preserve patients from reinterventions on the systemic or pulmonary venous pathway.

**Keywords:** partial anomalous pulmonary venous return, warden procedure, congenital heart surgery, sinus venosus ASD, pediatric cardiac surgery, reintervention

### INTRODUCTION

Partial anomalous pulmonary venous return (PAPVR) is a rare congenital heart defect, occurring in 0.4–0.7% of the population.<sup>1</sup> It involves one or more pulmonary veins

draining abnormally into the right atrium (RA), either directly or via systemic veins.<sup>2</sup> PAPVR often coexists with sinus venosus atrial septal defects (ASDs), most commonly involving the right upper pulmonary vein draining into the superior vena cava (SVC).<sup>3</sup>



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This study evaluates the outcomes and postoperative complications of three surgical techniques—single-patch, two-patch, and Warden procedures—for right-sided PAPVR repair in pediatric patients at our institution over the past 15 years.

## PATIENTS AND METHODS

This study was approved by the Institutional Ethics Committee (Approval no: Pro00014533). A total of 87 PAPVR repairs performed between 2011 and 2024 were reviewed, comparing outcomes of single-patch, two-patch, and Warden techniques. Among the 87 patients, 44 underwent the Warden procedure, 33 underwent the single-patch technique, and 10 underwent the two-patch technique.

Patient characteristics such as age, weight, sex, and the presence of comorbidities, including chromosomal anomalies, prematurity, and non-cardiac risk factors (e.g., renal dysfunction, pulmonary disease) were collected. Associated cardiac anomalies and additional interventions were also documented, including secundum ASDs, patent ductus arteriosus (PDA), and the need for concurrent pulmonary artery patching or secondary ASD closure. These data are summarized in Table 1.

### Definitions and variables

Reintervention was defined as any surgical or catheter-based procedure required after hospital discharge following the initial repair. In-hospital reinterventions (e.g., for pneumothorax, pericardial effusion, or temporary pacing) were excluded, as they reflect immediate postoperative care rather than long-term surgical durability. The SVC gradient was categorized by Doppler flow evaluation as mild ( $<3$  mmHg), moderate (3–5 mmHg), or severe ( $>5$  mmHg), determined by institutional cardiologists. Pulmonary vein velocity was categorized as normal or elevated. Preoperative and postoperative conduction blocks were assessed using ECG recordings, with any complete or incomplete conduction block classified as a conduction abnormality.

**Surgical Approaches:** All cases were approached via median full sternotomy under cardiopulmonary bypass.

**Single-Patch Technique:** An intra-caval baffle redirects anomalous pulmonary veins to the LA through the sinus venosus ASD.

**Two-Patch Technique:** One patch redirects the veins, while another enlarges the SVC.

**Warden Procedure:** The SVC is transected above the anomalous connection and reattached to the right atrial appendage, while a patch redirects the pulmonary veins to the LA.

### Statistical analysis

Categorical variables were expressed as frequencies and percentages, while continuous variables were expressed as medians and interquartile ranges (IQR). Chi-square, Fisher's exact tests, T-tests, or Mann-Whitney U-tests were used as appropriate. Logistic regression analysis was conducted to estimate odds ratios (OR) and 95% confidence intervals (CI). All p-values  $<0.05$  were considered statistically significant. Analysis was performed using RStudio version 4.3.1.<sup>4</sup>

## RESULTS

### 1. Demographic and clinical characteristics:

Table 1 summarizes the demographics and baseline characteristics of the 87 patients included in the study. Among them, 51 (59%) were female, and 36 (41%) were male. The median age at the time of operation was approximately 65 months (95% CI [31, 127]). The median weight was 18 kilograms (95% CI [12, 41]). Eight patients (9%) had a known chromosomal abnormality, and 26% ( $n = 23$ ) had a preoperative risk factor associated with a non-cardiac diagnosis such as renal dysfunction, pulmonary disease, prematurity, hypothyroidism, or significant developmental delay.

### 2. Surgical techniques and operative metrics

Among the techniques, 44 patients underwent the Warden procedure, 33 underwent the single-patch technique, and 10 underwent the two-patch technique. Cardiopulmonary bypass and cross-clamp times differed significantly across groups ( $p < 0.01$ ). Median CPB times were 88, 71, and 91 minutes; cross-clamp times were 47, 38, and 43 minutes for Warden, single-patch, and two-patch groups, respectively. Core temperatures also varied ( $p = 0.03$ ); values are shown in Table 1. Extubation in the operating room was achieved for 63% ( $n = 55$ ) of patients, and only one patient (1%) required postoperative mechanical circulatory support. This Warden patient required venoarterial ECMO for right ventricular failure immediately postoperatively; support was weaned after 3 days. The average length of hospital stay following surgical repair was 3 days (95% CI [3, 4]).

**Table 1.** Descriptive analysis of surgical techniques in PAPVR repair

Perioperative Variable	Overall Median (IQR); n (%) N = 87	Two-Patch Median (IQR); n (%) N = 10	Single-patch Median (IQR); n (%) N = 33	Warden Median (IQR); n (%) N = 44	p-value
Gender					
Male	36 (41%)	8 (80%)	13 (39%)	15 (34%)	<b>0.03</b>
Female	51 (59%)	2 (20%)	20 (61%)	29 (66%)	
Age at operation (months)	64.5 (931.1–125.1)	49.2 (30.9, 99.1)	49.0 (27.5, 85.7)	99.3 (45.7, 173.2)	0.06
Weight at operation (kg)	18 (12, 41)	17 (13, 18)	16 (11, 30)	24 (15, 50)	0.13
Prematurity	12 (14%)	1 (10%)	4 (12%)	7 (16%)	0.91
Chromosomal Abnormalities	8 (9%)	1 (10%)	0 (0%)	7 (16%)	NA
Pre-Op non-cardiac risk factors	23 (26%)	2 (20%)	5 (15%)	16 (36%)	0.11
ASD Type					
Superior Sinus Venosus	67 (77%)	9 (90%)	26 (79%)	32 (73%)	not applicable
Inferior Sinus Venosus	5 (6%)	1 (10%)	4 (12%)	0 (0%)	
Secundum	5 (6%)	0 (0%)	2 (6%)	3 (7%)	
Intact	10 (11%)	0 (0%)	1 (3%)	9 (20%)	
Preoperative Moderate/Severe Dilation RV Dilation	57 (66%)	10 (100%)	21 (64%)	26 (59%)	not applicable
Preoperative Qp/Qs (ratio)	2.50 (2.00, 2.98)	2.55 (2.13, 3.00)	2.45 (1.95, 2.95)	2.45 (2.00, 2.80)	0.66
Anomalous Pulmonary Vein Drainage Site					not applicable
SVC	46 (53%)	7 (70%)	7 (21%)	32 (73%)	
SVC-RA Junction	25 (29%)	3 (30%)	12 (36%)	10 (23%)	
RA (including IVC-RA junction)	12 (14%)	0 (0%)	12 (36%)	0 (0%)	
Others (IVC, Coronary Sinus, Innominate Vein)	4 (5%)	0 (0%)	2 (6%)	2 (4%)	
Additional Operational Procedure					<b>0.01</b>
None	47 (54%)	1 (10%)	16 (48%)	30 (68%)	
Additional secundum ASD/ PFO Closure	35 (40%)	8 (80%)	16 (48%)	11 (25%)	
Others	5 (6%)	1 (10%)	1 (4%)	3 (7%)	
CPB Time (min)	84 (71, 102)	88 (83, 99)	71 (62, 84)	91 (75, 123)	<b>&lt;0.01</b>
Cross Clamp Time (min)	41 (33, 49)	47 (44, 52)	38 (32, 43)	43 (34, 55)	<b>&lt;0.01</b>
Lowest Core Temp -Rectal (°C)	32 (30, 33)	33 (32, 34)	32 (31, 32)	31 (30, 32)	<b>0.03</b>
Length of Hospital Stay (days)	3.00 (3.00, 4.00)	3.00 (3.00, 3.00)	3.00 (2.73, 4.00)	4.00 (2.93, 4.18)	0.41
Length of Follow-Up (days)	417 (14, 1,453)	854 (478, 999)	399 (13, 1,656)	260 (20, 1,112)	0.84

ASD = atrial septal defect; PFO = patent foramen ovale; RA = right atrium; SVC = superior vena cava; IVC = inferior vena cava; RV = right ventricle; Qp/Qs = pulmonary-to-systemic flow ratio, CPB = cardiopulmonary bypass

### 3. PAPVR pathoanatomic characteristics

The most common PAPVR pattern involved the right upper and middle pulmonary veins draining into the SVC, seen in 55% (n = 48) of patients. Among these, the choice between

Warden (53%) and patch techniques (58%) was balanced. However, when drainage was exclusively to the SVC (n = 32), the Warden procedure was used significantly more often (73%,  $p < 0.001$ ).

The second most frequent pattern was drainage at the SVC–right atrial (RA) junction (29%, *n* = 25), with 23% receiving Warden and 35% patch repairs; no significant preference was observed.

In patients with drainage directly into the RA or (inferior vena cava–right atrial) IVC-RA junction (14%, *n* = 12), all underwent patch repair. Less common drainage sites (5%, *n* = 4) included the IVC, coronary sinus, or innominate vein.

The Warden procedure was associated with longer cardiopulmonary bypass (median 91 vs. 71 minutes, *p* < 0.01) and cross-clamp times (43 vs. 38 minutes, *p* < 0.01), and slightly lower core body temperatures (*p* = 0.03).

The most common accompanying ASD type in PAPVR patients was superior sinus venosus, identified in 77% (*n* = 67) of cases. Additional procedures were performed in 46% of patients, primarily secundum ASD or PFO closures. Rare procedures included Maze, tricuspid repair, (Right Pulmonary Artery) RPA plasty, PDA ligation, and (Right Coronary Artery) RCA button transfer with PA reconstruction (1 case each; see Table 1).

At the most recent follow-up, 86% of patients had no measurable SVC gradient (<3 mmHg), while 7% had mild (3–5 mmHg) and 7% moderate (>5 mmHg) gradients. All patients demonstrated normal pulmonary vein velocities.

4. Postoperative outcomes

**Immediate Complications:** Postoperative complications occurred in 15 patients (17%), with the Warden technique showing a significantly higher rate (27%, OR: 5.00, *p* < 0.05) compared to the single-patch and two-patch techniques (7%). Despite this, reintervention rates did not differ significantly between surgical techniques (OR: 0.23).

**Conduction Blocks:** Preoperative conduction blocks were present in 24 patients (28%). Among these, resolution was achieved in 42% of patients in the Warden group

compared to 66% in the single-patch or two-patch groups. Postoperative conduction blocks developed in 19 patients (30%) who did not have preexisting blocks, with a higher incidence in the Warden group (37%) compared to the single-patch or two-patch groups (23%). No patients required a pacemaker implantation.

For patients without preoperative conduction blocks, 37% (*n* = 12) of those undergoing the Warden procedure developed postoperative conduction blocks compared to 23% (*n* = 12) in the single-patch or two-patch groups. In contrast, among patients with preoperative conduction blocks, resolution was achieved in 42% (*n* = 5) of the Warden group and 66% (*n* = 8) of the single-patch or two-patch group.

**Reinterventions:** No reoperations were required in the cohort. However, five patients (6%) underwent catheter-based reinterventions. Four of these occurred in patients repaired with the single-patch or two-patch techniques and included balloon angioplasty of the SVC, right pulmonary venous baffle, SVC stent placement, and balloon valvuloplasty of the right upper pulmonary vein. Logistic regression analysis did not identify a difference in reintervention rates between surgical techniques (OR: 0.23, 95% CI [0.02–2.12], *p* = 0.19) (Table 2). Notably, no patient in the Warden group required reintervention on the venous pathways.

DISCUSSION

Challenges and considerations in PAPVR surgical management

The surgical management of PAPVR poses unique challenges due to variability in anatomy. While it may not be considered one of the most technically demanding cardiac surgeries, the complexity lies in achieving a repair that is not only effective but also free of long-term complications.

Table 2. Logistic regression analysis for immediate complication and reintervention				
	PAPVR Repair Method			
	Overall	Warden	Single Patch and Two Patch	p-value
Reintervention	5 (6%)	1 (2%)	4 (9%)	0.20
Immediate Complications	15 (17%)	12 (27%)	3 (7%)	0.02
		OR	(95% CI) 2.5 % 97.5 %	p-value
Immediate Complication		5.00	1.30, 19.25	0.0193
Reintervention		0.23	0.02, 2.12	0.19

OR = odds ratio; CI = confidence interval

The choice of surgical technique—single-patch, two-patch, or Warden—depends on the location of the anomalous veins and the flow dynamics. For example, the Warden procedure is preferred for veins farther from the sinus venosus defect, as it minimizes the risk of obstruction. However, it requires significant technical expertise, especially in cases with a short right atrial appendage, where stretch anastomosis or patch augmentation may be necessary.<sup>5</sup> Ultimately, surgical decisions rely on the surgeon's expertise and judgment.

The Warden technique is also frequently used in anatomically complex cases of PAPRV, particularly in younger, smaller patients with additional defects.<sup>6</sup> However, this increased complexity can lead to longer cardiopulmonary bypass and cross-clamp times, as well as a higher risk of anastomotic stenosis at the cavo-atrial junction. Some claimed that prophylactic measures, such as augmentation of the anastomosis, are essential to reduce these risks and ensure optimal outcomes.<sup>7</sup> We do not share this point of view and do not add patches to these anastomoses. In a broader context, our approach aligns with multiple published reports that emphasize individualized surgical strategies based on pulmonary venous anatomy and drainage site. Studies by Mathis et al. and Binsalamah et al. highlight how the choice of repair should be anatomically guided, particularly when balancing technical feasibility and long-term flow characteristics.<sup>6-8</sup> Furthermore, Alsoufi et al. observed that outcomes are optimized when repair techniques are adapted to the drainage location and associated cardiac anatomy.<sup>9</sup> These studies reinforce that no single technique is universally superior, but that tailored approaches lead to comparable results in terms of mortality and reintervention.

### Postoperative outcomes and complications

Rhythm abnormalities, such as junctional rhythms, were observed in 9% ( $n = 8$ ) of our patients, with 5 requiring temporary pacing. However, no patients required permanent pacemaker implantation, consistent with prior studies.<sup>7,8</sup> These findings suggest that transient rhythm disturbances are common but rarely lead to long-term complications, irrespective of the repair technique. While the observed rhythm abnormalities were self-limited, caution is still warranted near the atrioventricular node and His bundle region — particularly around the triangle of Koch — during suture placement, as inadvertent injury to conduction tissue remains a theoretical risk.

Reintervention rates were low in our cohort, with four cases primarily related to obstruction in the single-patch

or two-patch group. No reintervention occurred in the Warden group. Literature reports similarly low reoperation rates across techniques (related to SVC or pulmonary vein obstructions, anastomotic strictures, and arrhythmias caused by damage to the SA node or its blood supply), with no clear superiority in terms of reintervention-free survival.<sup>5-7</sup> Although the Warden procedure is traditionally described in pediatric populations, its application in older children and adults has also been reported in the literature. In our cohort, the decision to perform a Warden repair in selected older patients was based on anatomic considerations—such as high insertion of the anomalous pulmonary veins into the superior vena cava and concerns for sinus node preservation. This approach has been supported by prior reports, including institutional series demonstrating favorable outcomes in adolescent and adult patients undergoing the Warden procedure.<sup>7,9,10</sup>

The Warden technique in our study showed a significantly higher likelihood of immediate postoperative complications (OR: 5.00,  $p = 0.0193$ ), most of them benign, such as arrhythmias, sinus node dysfunction, and respiratory complications. Interestingly, studies such as Zubritskiy's reported fewer sinus node dysfunction cases with the Warden technique compared to two-patch repairs, highlighting variability in complication rates and the need for individualized surgical strategies.<sup>10,11</sup>

Our findings underline the complexity of PAPVR repair and the need for meticulous surgical planning to minimize complications and optimize outcomes. This study is limited by its retrospective nature and sample size, underscoring the need for prospective, multicenter trials to further refine technique selection and long-term management strategies.

### CONCLUSION

Despite a higher rate of early postoperative complications, the Warden procedure showed favorable long-term outcomes, with no reinterventions on systemic or pulmonary venous pathways. This suggests that in selected patients, it provides reliable and durable reconstruction. As all three techniques had low morbidity, surgical choice should be individualized based on anatomy and institutional experience.

At our institution, we shifted to a preference for the Warden procedure, reflecting a lower threshold for its selection. Ultimately, all techniques yield comparably low morbidity and mortality rates, highlighting the critical importance of individualized surgical planning.

## Ethical approval

This study has been approved by the Children's National Medical Center Institutional Review Board (approval date 25.11.2020, number Pro00014533). The institution provides departmental allowance for retrospective research, under which this study was conducted.

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## Author contribution

The authors declare contribution to the paper as follows: Study conception and design: AT, CY; data collection: ZBE, MO, MD; analysis and interpretation of results: AT, YdU, CY; draft manuscript preparation: AT, ZBE, MO. All authors reviewed the results and approved the final version of the article.

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## Conflict of interest

The authors declare that there is no conflict of interest.

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