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Primary Pulmonary Vein Stenosis: Outcomes, Risk Factors, and Severity Score in a Multicentric Study

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Background. **Primary pulmonary vein stenosis (PPVS) still carries a poor prognosis, and prognostic factors remain controversial. The aim of this study was to determine outcomes and prognostic factors after PPVS repair in the current era.**

Methods. **Thirty patients with PPVS and a normal pulmonary vein (PV) connection operated on in 10 European/North American centers (2000–2012) were included retrospectively. A specific PVS severity score was developed based on the assessment of each PV. Studied end points were death, PV reoperation, and restenosis. A univariate and multivariate risk analysis was performed.**

Results. **The mean number of affected PVs per patient was 2.7 ± 1.1. Sutureless repair was used in 21 patients (70%), endovenectomy was used in 5 patients, and patch venoplasty was used in 4 patients. Overall PV restenosis, reoperation, and mortality occurred in 50%, 40%, and 30% of patients respectively. Freedom from mortality, reoperation, and restenosis at 8 years of follow-up was 70% ± 8%, 62% ± 8%, and 47% ± 9%, respectively. Restenosis and mortality rates after sutureless repair versus non-sutureless repair were 57% (n = 12 of 21) versus 33% (n = 3 of 9) ($p = 0.42$) for restenosis and 38% (n = 8 of 21) versus 11% (n = 1 of 9) ($p = 0.21$) for mortality. Patients selected for a sutureless technique were younger and smaller and had more severe disease before operation. A postoperative high PVS score and pulmonary hypertension 1 month after the operation were independent risk factors for restenosis (hazard ratio [HR], 1.34; $p = 0.002$ and HR, 6.81; $p = 0.02$, respectively), reoperation (HR, 1.24; $p = 0.01$ and HR, 7.60; $p = 0.02$), and mortality (HR, 1.39; $p = 0.01$ and HR, 39.5; $p = 0.008$).**

Conclusions. **Primary PVS still has a guarded prognosis in the current era despite adoption of the sutureless technique. Postoperative pulmonary hypertension and severity of disease evaluated by a new severity score are independent prognostic factors regardless of surgical technique.**

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Primary (or native or congenital) pulmonary vein stenosis (PPVS) is a rare and fascinating, yet frustrating and challenging, disease from a medical and surgical standpoint. Reported recurrence, reoperation, and mortality rates after treatment of PPVS remain high. Freedom from reoperation or death at 3 to 5 years after operation for PPVS hovers around 50% to 60% in studies focusing on patients with PPVS [1–5] and in studies mixing patients with primary and acquired PVS [6–13]. The concept of a sutureless technique for PVS repair, avoiding suturing of the veins themselves, was introduced almost 20 years ago [14–16]. The outcomes of this technique, which were reported in limited series, are still unclear; they were presented as real progress in some early reports of mixed patients with primary and acquired PVS [17, 18] and appeared disappointing in more recent studies [1–4, 6, 9], especially in the series focusing on patients with PPVS. Similarly, independent risk factors for poor outcomes also remain controversial in the absence of large multicentric studies. Trying to better understand both risk factors and optimal management is of major importance to improve the management of this challenging disease. The aim of the current study was to determine outcomes and patient-related, disease-related, and procedure-related prognostic factors after PPVS repair in the current era.

Patients and Methods

Pediatric and adult patients with PPVS and a normal pulmonary vein (PV) connection who underwent at least 1 PV operation between January 1, 2000 and December 31, 2012 were included retrospectively. Ten European or North American institutions were enrolled in this study. We did not include (1) patients with acquired PVS (including PVS after ablation procedures and PVS after fibrosing mediastinitis), (2) patients with PVS and an abnormal PV connection (total anomalous pulmonary venous return), (3) and patients with PPVS who were not treated or who were treated by a percutaneous procedure or pneumonectomy as an initial procedure. Review of medical records was approved by each hospital's local committee on clinical investigation. Individual patients were not identified, and the need for patient consent was waived. Data regarding patients and anatomical characteristics, therapeutic procedures, and outcomes were collected according to a common and uniform database to ensure consistency in the data collection. Hospital records were reviewed in each center, and follow-up data were obtained by contacting the treating cardiologists. Studied end points were (1) PVS-related death, (2) persistence or recurrence of moderate (echographic mean gradient, 5–7 mm Hg) or severe (echographic mean gradient >7 mm Hg) stenosis of at least 1 vein, and (3) PV reintervention or PVS-related death. Severe pulmonary hypertension was defined in this study as pulmonary artery pressure greater than three-quarters systemic pressure.

Table 1. Specific Severity Score for Pulmonary Vein Stenosis

Each pulmonary vein is graded from 0–4	
0	No stenosis
1	Mild stenosis—focal
1.5	Mild stenosis—diffuse
2	Moderate stenosis—focal
2.5	Moderate stenosis—diffuse
3	Severe stenosis—focal
3.5	Severe stenosis—diffuse
4	Atresia/occlusion
PVS severity score = sum of these scores + 2 if there is bilateral disease (possible range, 0–18).	

PVS = pulmonary vein stenosis.

Severity Score

A specific PVS severity score was developed based on the assessment of each PV (Table 1). The assessment of each vein was based on echocardiography before each procedure in all cases, strengthened by angiography, computed tomography, and magnetic resonance imaging in 75%, 25%, and 13% of cases, respectively. This score is based on (1) the degree of the stenosis evaluated by the echographic pressure gradient measure at the venoatrial junction, (2) the focal/diffuse aspect of the stenosis evaluated by the combined imaging modalities mentioned earlier, and (3) the unilateral/bilateral feature of the disease. The absence of stenosis was defined by the absence of PV narrowing, biphasic blood flow, and a mean echographic gradient <2 mm Hg. Mild, moderate, and severe stenosis was defined by a mean echographic gradient of 2 to 4 mm Hg, 5 to 7 mm Hg, and >7 mm Hg, respectively. The stenosis was described as "focal" when it affected a very short length of the PV and associated with upstream dilatation of the PV. The stenosis was "diffuse" when it affected a significant length of the PV with no upstream dilatation of the PV. The PV was defined as atretic or occluded when no flow was demonstrated through it. The assignment of numbers for each PV (range, 0–4) into the score (range, 0–18) is described in Table 1. All imaging reports were completed by an experienced cardiologist in each center independent of the outcome of the PV procedure. PVS scores were then established by a single observer, independent of the outcome of the PV procedure.

Data Analysis

Data analysis was performed with IBM SPSS Statistics, version 20 software (SPSS Inc, Chicago, IL). Data are expressed as median with range or mean ± standard deviation. The comparison of percentages was achieved with the χ^2 test or the Fisher exact test for qualitative variables, and comparison of means and medians was performed using the Student *t* test or the Mann-Whitney *U* test. Actuarial freedom curves from PVS-related mortality, PV recurrence, and PV reoperation/PVS-related mortality were analyzed according to Kaplan-Meier

estimates, with 95% confidence intervals (CIs). Only the initial surgical procedures were included in the analysis, because the 4 reinterventions for PVS recurrence included 2 pneumonectomies and 2 percutaneous procedures.

A univariate analysis of time-related end points was achieved with the log-rank test, and the univariate Cox model was used for continuous variables. Multivariate analysis was performed using multiple logistic regression. Variables that were found to be associated with the 3 studied end points, were marginally significant ($p < 0.15$) in the univariate analysis, or had clinical relevance were included into the logistic models. Calibration of the logistic model was assessed using the Hosmer-Lemeshow goodness-of-fit test to evaluate the discrepancy between observed and expected values. Hazard ratios (HRs) were expressed with 95% CIs. All the tests were 2-sided.

Analysis of variance was used to compare PVS scores before and after the repair. Predictive accuracy for the obtained PVS score value was assessed by calculating the area under the receiver operating characteristic curve, and model calibrations and fit were assessed with Hosmer-Lemeshow goodness-of-fit statistics. For all tests, a p value less than 0.05 was considered significant.

Results

Patient Characteristics, PVS Anatomy, and Surgical Procedures

Thirty patients with PPVS underwent 34 PV procedures. The 30 initial procedures were sutureless in 21 patients (70%) and nonsutureless in 9 patients (30%). Demographic and anatomical characteristics of the patients are presented in Table 2. The mean preoperative severity score was 8.8 ± 4.1 (range, 1–16). A PVS score of greater than 4 had the best predictive accuracy (area under the curve, 0.65) for postoperative mortality. Patients who were selected for a sutureless repair were significantly younger ($p = 0.001$) and smaller ($p = 0.02$) than those who had a nonsutureless repair (Table 2). They also tended to have a lower birthweight (2.2 kg versus 2.8 kg; $p = 0.05$), be more premature (24% versus 0%; $p = 0.28$), and have more severe disease (preoperative severity score was >4 in 91% of patients selected for sutureless repair versus

Table 2. Demographic and Anatomical Characteristics

Variable	All Primary PVS, n (%) N = 30	Sutureless, n (%) n = 21	Nonsutureless, n (%) n = 9	Comparison of Sutureless Versus Nonsutureless, p Value
Male sex	6 (20%)	3 (14%)	3 (33%)	0.33
Age at procedure (mo)	Median, 9.5 (1-308) Mean:43 ± 78	Mean, 24 ± 47	Mean, 87 ± 115	0.001[a]
Weight at procedure (kg)	Median, 6.8 (2-67) Mean, 12 ± 14	Mean, 9 ± 9	Mean,19 ± 21	0.02[a]
Prematurity (<35 wk)	5 (17%)	5 (24%)	0 (0%)	0.28
Mean birthweight (kg)	2.4 ± 0.9	2.2 ± 0.9	2.8 ± 0.3	0.05
Genetic syndrome	8 (27%)	6 (29%)	2 (22%)	1
Associated lesions	19 (63%)	14 (67%)	5 (55%)	0.12
Atrial septal defect		4	1	
Ventricular septal defect		5	1	
Cor triatriatum		0	3	
Atrioventricular septal defect		1	0	
Scimitar syndrome		1	0	
Other		3	0	
Severe pulmonary hypertension	14 of 22 (63%)	12 of 17 (71%)	2 of 5 (40%)	0.31
Preoperative number of obstructed PVs				
1	4 (13%)	1 (5%)	3 (33%)	
2	9 (30%)	8 (38%)	1 (11%)	0.59
3	7 (23%)	5 (24%)	2 (22%)	
4	10 (33%)	7 (33%)	3 (33%)	
Mean	2.7 ± 1.1	2.9 ± 1.1	2.5 ± 1.2	0.33
Bilateral disease	17 (57%)	12 (57%)	5 (56%)	1
Diffuse stenosis (no upstream PV dilatation)	16 (53%)	13 (62%)	3 (33%)	0.23
Preoperative severity score				
Score >4	25 (83%)	19 (91%)	6 (67%)	0.14
Mean (range)	8.8 ± 4.1 (1–16)	9.3 ± 4.1 (1–16)	7.4 ± 4.1 (2–12)	0.75

[a] $p < 0.05$.

PVs = pulmonary veins; PVS = pulmonary vein stenosis.

67% in other patients; $p = 0.14$) (Table 2). Surgical procedures are presented in Table 3. Median follow-up was 37 months (range, 3–171 months).

Recurrence, Reoperation, and Mortality

A global overview of the outcomes is presented in Figure 1 and Table 4. Overall PV-related mortality, PV reoperation/mortality and PV restenosis occurred in 30% (n = 9 of 30), 40% (n = 12 of 30), and 50% (n = 15 of 30), respectively. PV-related mortality, reoperation, and restenosis rates after sutureless procedures compared with nonsutureless procedures were 38% (n = 8 of 21) versus 11% (n = 1 of 9) ($p = 0.21$) for mortality, 48% (n = 10 of 21) versus 22% (n = 2 of 9) ($p = 0.24$) for reoperation, and 57% (n = 12 of 21) versus 33% (n = 3 of 9) ($p = 0.42$) for restenosis. Kaplan-Meier actuarial curves for the 3 end points are presented in Figures 2 and 3. Freedom from mortality, reoperation, and restenosis at 8 years of follow-up was 70% ± 8%, 62% ± 8%, and 47% ± 9%, respectively (Fig 2). Restenosis occurred in the first postoperative year in the vast majority of cases, with a median delay of 2.8 months (range, 1 month–4 years). Cumulative reoperation-free survival at 4 years was higher in patients with a preoperative PVS score ≤4 (100% vs 54% ± 9%; $p = 0.05$) and in patients with no persistence or recurrence of pulmonary hypertension 1 month after operation (76% ± 10% vs 14% ± 13%; $p = 0.001$) (Figs 3A, 3C). Cumulative reoperation-free survival was not significantly different between sutureless and nonsutureless procedures (Fig 3B).

Results of the univariate analysis are shown in Table 5. Factors significantly associated with PV restenosis, reoperation, and mortality are bilateral disease, high postoperative severity score at 1 month after operation, and persistence or recurrence of severe pulmonary hypertension at 1 month after operation ($p < 0.05$). A preoperative severity score greater than 4, preoperative pulmonary hypertension, and a diffuse aspect of the PV with no upstream vessel dilatation tended to be associated with poorer outcomes ($p < 0.15$). The type of procedure was not significantly associated with outcomes. Multivariate analysis showed that a postoperative high severity score at 1 month after operation and persistence or recurrence of severe pulmonary hypertension at 1 month after operation were independent risk factors for PV restenosis (HR, 1.34; 95% CI, 1.11–1.61; $p = 0.002$ and HR, 6.81; 95% CI, 1.30–35.5; $p = 0.02$ respectively), PV reoperation (HR, 1.24; 95% CI, 1.05–1.46; $p = 0.01$ and HR, 7.60; 95% CI, 1.41–40.97; $p = 0.02$), and PVS-related mortality (HR, 1.39; 95% CI, 1.07–1.80; $p = 0.01$ and HR, 39.5; 95% CI, 2.6–607.8; $p = 0.008$.

Comment

To date and to our knowledge, this study is the largest series focusing on this specific population of patients undergoing a surgical procedure for primary PVS with a normal PV connection. This study shows that PPVS still has a poor prognosis in the current era. Restenosis, PV reoperation, and mortality remain high despite the introduction of the sutureless technique 20 years ago [14–16]. We report a new specific preoperative PVS severity score that might be used to predict the outcomes of patients with PPVS and a normal PV connection. The postoperative severity score and the persistence or recurrence of severe pulmonary hypertension at 1 month after operation were found to be independent risk factors for poor outcomes.

Recurrence, Reoperation, and Mortality

Reported recurrence, reoperation, and mortality rates after operation for PPVS remain high in the literature focusing on PPVS. Toronto's group reported a mortality

Table 3. Characteristics of the Initial Surgical Procedure

Variable	Initial Sutureless Procedures, n (%) n = 21	Initial Nonsutureless Procedures, n (%) n = 9	Comparison of Sutureless Versus Nonsutureless Procedures, *p* Value
Type of operation	Sutureless repair	Nonsutureless repair	
	Incision type: 13 (62%)	Excision of fibrotic tissue (endovenectomy): 5 (55%)	
	Resection type: 7 (33%)	PV plasty: 2 (22%)	
	Incision + resection: 2 (9%)	Endovenectomy + PV plasty: 2 (22%)	
Laterality of the procedure			0.45
Left side only	9 (43%)	3 (33%)	
Right side only	4 (19%)	1 (11%)	
Both sides	8 (22%)	5 (55%)	
Circulatory arrest	6 (27%)	3 (25%)	1

In the resection-type sutureless technique, the PV pathologic tissue was totally resected along with part of the left atrial wall. When an endovenectomy was performed, stenosed veins were divided through the scarring and the fibrous tissue back to a larger-caliber vein proximal to the stenosis, and the surgeon excised fibrous tissue in the area to further open the stenosis. PV plasty was performed in 4 patients using a patch of autologous pericardium (n = 2) or appendage tissue (n = 2).

PV = pulmonary vein.

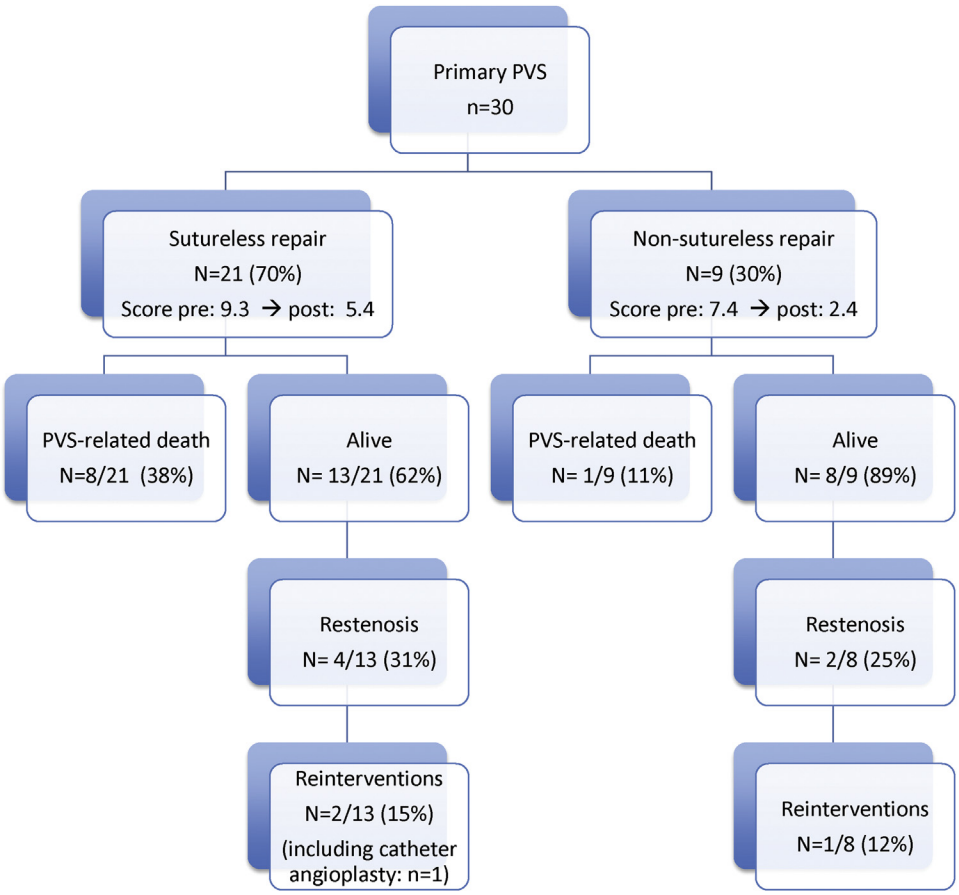

Fig 1. Global overview of outcomes of patients with native pulmonary vein stenosis (PVS).

rate of 47% (11 of 23) at a mean follow-up of 40.2 ± 42.2 months [2], which was confirmed by more recent PPVS studies [1, 3, 4]. Our multicentric series focusing on patients operated on in the current era (after 2000) confirms such disappointing results, with actuarial freedom from mortality, reoperation, and restenosis of 70% ± 8%, 62% ± 8%, and 47% ± 9%, respectively, at 8 years of follow-up. Restenosis occurred in the first postoperative year in the vast majority of cases, with a median delay of 2.8 months. This confirms the findings from Song and colleagues [1] who showed that restenosis occurred frequently (80%) and rapidly.

Influence of Patient-Related and Disease-Related Factors

Interestingly, patient-related factors—such as low weight and young age at operation, prematurity, genetic anomalies (including heterotaxy syndrome), and single-ventricle anatomy—do not seem to increase the risk of poor outcomes in patients with PPVS, confirming the results of previous series [1–5].

Table 4. Overall Outcomes

Outcome	Primary PVS, n (%) N = 30	Sutureless, n (%) n = 21	Nonsutureless, n (%) n = 9	Comparison of Sutureless Versus Nonsutureless Procedure, *p* Value
Severity score at last follow-up	4.5 ± 4.9 (0–15.5)	5.4 ± 5.1 (0–14)	2.4 ± 53.8 (0–15.5)	0.079
Percentage of score improvement	Mean, –45% ± 60% Range, –100%; +133%	Mean, –37% ± 66% Range, –100%; +125%	Mean, –62% ± 41% Range, –100%; +133%	0.19
RV/LV pressure ratio >75% at last follow-up	7 (32%)	6 (35%)	1 (20%)	1
Recurrence/persistence of PVS	15 (50%)	12 (57%)	3 (33%)	0.42
PV reoperation or PVS-related mortality	12 (40%)	10 (48%)	2 (22%)	0.24
PVS-related Mortality	9 (30%)	8 (38%)	1 (11%)	0.21

LV = left ventricular; PVS = pulmonary vein stenosis; RV = right ventricular.

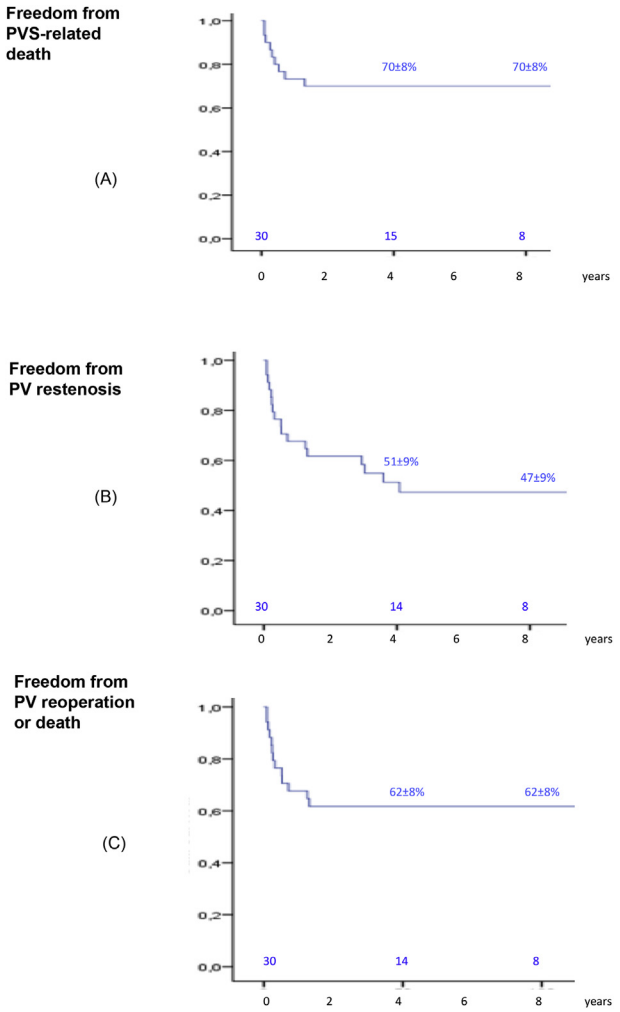

Fig 2. Kaplan-Meier actuarial curves for (A) PVS-related death; (B) PV restenosis; and (C) PV reoperation. (PV = pulmonary vein; PVS = pulmonary vein stenosis.)

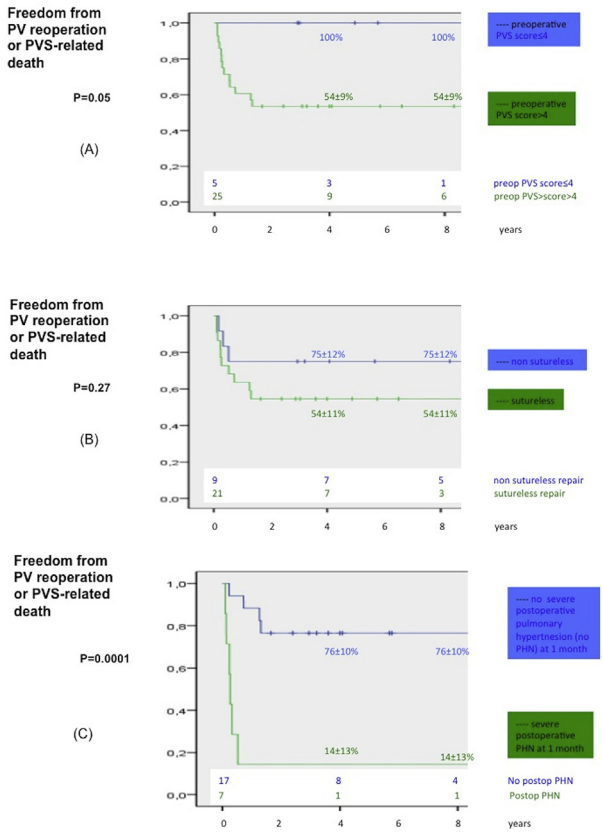

Fig 3. Kaplan-Meier actuarial curves for PV reoperation or PVS-related death: (A) stratified on preoperative PVS score; (B) stratified on the type of repair; (C) stratified on postoperative pulmonary hypertension. (PHN = pulmonary hypertension; PV = pulmonary vein; PVS = pulmonary vein stenosis.)

Rather, the preoperative intrinsic severity of PPVS appears to be the most decisive factor determining final outcomes, as shown in the recent literature [1–5] and in our series. Indeed, many anatomical and hemodynamic factors reflecting the severity of the disease at the time of or 1 month after the procedure (bilateral disease, diffuse stenosis with no upstream PV dilatation, preoperative and postoperative severity score, and preoperative and postoperative pulmonary hypertension) tended to be or were significantly associated with a higher risk of death, restenosis, or reoperation in the univariate analysis. The postoperative severity score and pulmonary hypertension at 1 month after operation were found to be independent risk factors in the multivariate analysis. A greater number of stenotic PVs has been shown to be associated with an increased risk of death in many series, especially when there is bilateral involvement [1, 3, 5]. Shi and associates [4] demonstrated that PVs with moderate stenosis, compared with those with mild stenosis, developed restenosis, irrespective of the surgical strategy. The only 3 independent predictors of mortality demonstrated so far in multivariate analysis in the literature (a high preoperative PVS score [2], the involvement of more than 3 PVs, and the progression to uninvolved PVs [1]) strengthened the major importance of the intrinsic anatomical severity of the disease.

The impact of the specific PVS score that we describe in the present study emphasizes the major role played by the severity of the disease on outcomes. By taking into account the degree of stenosis of each vein (based on echocardiographic data enriched with other imaging), but also the focal/diffuse aspect of each PV and the unilateral/bilateral aspect of the disease, this new score might represent a more comprehensive and integrated method for grading severity in these patients, compared with other scores or predictive models [2, 19]. It may provide useful prognostic information to guide decision-making in clinical practice but needs to be validated prospectively in a larger number of patients.

Influence of the Surgical Technique

In the present study, the sutureless technique was not significantly associated with better outcomes compared with nonsutureless techniques. This is in concordance

Table 5. Results of the Univariate Analysis (Cox Models)

Variable	PV Restenosis (HR; 95% CI; *p* Value)	PV Reoperation (HR; 95% CI; *p* Value)	PV-Related Mortality (HR; 95% CI; *p* Value)
Weight	0.98; 0.94–1.02; 0.42	0.94;0.85–1.03; 0.16	0.93; 0.82–1.05; 0.23
Prematurity	1.07; 0.14–8.44; 0.95	1.74;0.38–8.00; 0.48	1.30; 0.16–10.63; 0.81
Preoperative pulmonary hypertension	1.83; 1.11–5.50; 0.28	**4.50; 1.01–20.96; 0.05**[a]	**5.35; 1.07–43.68; 0.12**[a]
Preoperative severity score >4	**4.83; 1.02–36.52; 0.13**[a]	29.73; 0.10–8,467.36; 0.24	28.16; 0.02–35,033.9; 0.36
Diffuse stenosis (no upstream PV dilatation)	**2.50; 1.02–7.12; 0.09**[a]	**3.26; 1.04–11.88; 0.07**[a]	**3.6; 1.05–17.39;0.11**[a]
Sutureless procedure	1.65; 0.58–4.72; 0.35	2.04; 0.56–7.42; 0.28	3.94; 0.49–31.52; 0.20
Bilateral disease	**4.29; 1.25–14.75; 0.02**[b]	2.03; 0.42–9.80; 0.38	4.47; 0.53–37.35; 0.17
Postoperative severity score at 1 mo	**1.32; 1.17 – 1.50; <0.001**[b]	**1.29; 1.13–1.46; <0.001**[b]	**1.33; 1.14–1.55; <0.001**[b]
Postoperative pulmonary hypertension at 1 mo	**5.39; 1.72–16.95; 0.004**[b]	**9.05; 2.37–34.58; 0.001**[b]	**17.31; 3.23–92.86; 0.001**[b]

[a] Trend to statistical significance: $p < 0.15$; 95% CI not including 1. [b] Significant: $p < 0.05$; 95% CI not including 1.

Pulmonary hypertension: defined as pulmonary artery pressure >3/4 systemic pressure

CI = confidence interval; HR = hazard ratio; PV = pulmonary vein.

with the literature, which shows that the sutureless technique provides lesser outcomes for repair of PPVS [1, 2, 4] compared with acquired PVS after total anomalous pulmonary venous return [15, 20]. Nevertheless, we have to recognize that patients who were selected for a sutureless repair in this series were significantly younger and smaller and also tended to have a lower birthweight and more severe disease (preoperative severity score >4), suggesting a probable selection bias in the choice of operation, with the more challenging patients more likely undergoing a sutureless approach.

Overall, these findings emphasize the preponderant role played by the intrinsic severity of the PVS disease over the role played by the surgical technique on outcomes. This could be explained by the fact that more severe stenosis at the time of operation triggers a complex biological and hemodynamic process that increases the risk of PVS recurrence (as noted in human studies [5, 8, 21] and animal models [22–24]), even if the initial surgical repair was effective in relieving the initial stenotic disease. The recurrence of postoperative pulmonary hypertension, which was a strong independent risk factor for recurrence in our series and which is often unrelated to the quality of the surgical repair, could be a marker of the complex biological process triggered by the severity of the initial disease. This can explain why patients with 1 stenosed PV but without pulmonary hypertension can lead a normal life, whereas patients with postoperative pulmonary hypertension despite complete relief of their PVS have worse outcomes.

Limitations

This retrospective nonrandomized study is limited by the small number of patients and the inherent risk of selection bias. The multicentric nature of this study led to a significant heterogeneity in the decision-making processes regarding imaging and interventions. The institution-dependent and operator-dependent aspect of these PV operations could not be taken into account in the risk analysis because of the large number of participating surgeons and the variability of the number of patients enrolled per institution. The decision to include the "bilateral disease" criterion into the PVS score still needs to be validated in a prospective study. Histologic specimen examination and genetic studies would have been of major interest to further investigate the mechanisms at work in this complex disease. Finally, the PVS-related morbidity and neurodevelopmentally related outcomes and quality of life of patients were not investigated.

Conclusions

Primary PVS still has a guarded prognosis in the current era despite the adoption of the sutureless technique. Postoperative pulmonary hypertension and severity of disease evaluated by a new severity score are independent risk factors for poor outcomes regardless of surgical technique.

Audio Discussion: Audio of the discussion that followed the presentation of this paper at the STS Annual Meeting can be accessed in the online version of this article [http://dx.doi.org/10.1016/j.athoracsur.2017.03.022] on http://www.annalsthoracicsurgery.org.

References

1. Song MK, Bae EJ, Jeong SI, et al. Clinical characteristics and prognostic factors of primary pulmonary vein stenosis or atresia in children. Ann Thorac Surg 2013;95:229–34.
2. Viola N, Alghamdi AA, Perrin DG, Wilson GJ, Coles JG, Caldarone CA. Primary pulmonary vein stenosis: the impact of sutureless repair on survival. J Thorac Cardiovasc Surg 2011;142:344–50.
3. Charlagorla P, Becerra D, Patel PM, Hoyer M, Darragh RK. Congenital pulmonary vein stenosis: encouraging mid-term outcome. Pediatr Cardiol 2016;37:125–30.
4. Shi G, Zhu Z, Chen H, Zhang H, Zheng J, Liu J. Surgical repair for primary pulmonary vein stenosis: Single-institution, midterm follow-up. J Thorac Cardiovasc Surg 2015;150:181–8.
5. Holt DB, Moller JH, Larson S, Johnson MC. Primary pulmonary vein stenosis. Am J Cardiol 2007;99:568–72.
6. Kanter KR, Kirshbom PM, Kogon BE. Surgical repair of pulmonary venous stenosis: a word of caution. Ann Thorac Surg 2014;98:1687–91.
7. Latson LA, Prieto LR. Congenital and acquired pulmonary vein stenosis. Circulation 2007;115:103–8.

8. Seale AN, Webber SA, Uemura H, et al. Pulmonary vein stenosis: the UK, Ireland and Sweden collaborative study. Heart 2009;95:1944–9.
9. Quinonez LG, Gauvreau K, Borisuk M, et al. Outcomes of surgery for young children with multivessel pulmonary vein stenosis. J Thorac Cardiovasc Surg 2015;150:911–7.
10. Shuhaiber J, Rehman M, Jenkins K, Fynn-Thompson F, Bacha E. The role of surgical therapy for pulmonary vein atresia in childhood. Pediatr Cardiol 2011;32:639–45.
11. Balasubramanian S, Rehman M, Gauvreau K, Jenkins KJ. Bilateral disease and early age at presentation are associated with shorter survival in patients with congenital heart disease and intraluminal pulmonary vein stenosis. Congenit Heart Dis 2012;7:378–86.
12. Drossner DM, Kim DW, Maher KO, Mahle WT. Pulmonary vein stenosis: prematurity and associated conditions. Pediatrics 2008;122:e656–61.
13. Breinholt JP, Hawkins JA, Minich LA, et al. Pulmonary vein stenosis with normal connection: associated cardiac abnormalities and variable outcome. Ann Thorac Surg 1999;68:164–8.
14. Lacour-Gayet F, Rey C, Planche C. Pulmonary vein stenosis. Description of a sutureless surgical procedure using the pericardium in situ. [Article in French] Arch Mal Coeur Vaiss 1996;89:633–6.
15. Najm HK, Caldarone CA, Smallhorn J, Coles JG. A sutureless technique for the relief of pulmonary vein stenosis with the use of in situ pericardium. J Thorac Cardiovasc Surg 1998;115:468–70.
16. Lacour-Gayet F. Surgery for pulmonary venous obstruction after repair of total anomalous pulmonary venous return. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu 2006:45–50.
17. Devaney EJ, Chang AC, Ohye RG, Bove EL. Management of congenital and acquired pulmonary vein stenosis. Ann Thorac Surg 2006;81:992–5.
18. Azakie A, Lavrsen MJ, Johnson NC, Sapru A. Early outcomes of primary sutureless repair of the pulmonary veins. Ann Thorac Surg 2011;92:666–71.
19. Lo Rito M, Gazzaz T, Wilder TJ, et al. Pulmonary vein stenosis: severity and location predict survival after surgical repair. J Thorac Cardiovasc Surg 2016;151:657–66.
20. Yun TJ, Coles JG, Konstantinov IE, et al. Conventional and sutureless techniques for management of the pulmonary veins: evolution of indications from postrepair pulmonary vein stenosis to primary pulmonary vein anomalies. J Thorac Cardiovasc Surg 2005;129:167–74.
21. Caldarone CA, Najm HK, Kadletz M, et al. Relentless pulmonary vein stenosis after repair of total anomalous pulmonary venous drainage. Ann Thorac Surg 1998;66:1514–20.
22. Kato H, Fu YY, Zhu J, et al. Pulmonary vein stenosis and the pathophysiology of "upstream" pulmonary veins. J Thorac Cardiovasc Surg 2014;148:245–53.
23. Zhu J, Ide H, Fu YY, et al. Losartan ameliorates "upstream" pulmonary vein vasculopathy in a piglet model of pulmonary vein stenosis. J Thorac Cardiovasc Surg 2014;148:2550–7.
24. Endo M, Yamaki S, Hata M, Saiki Y, Tabayashi K. Pulmonary vascular changes induced by unilateral pulmonary venous obstruction. Pediatr Cardiol 2002;23:420–5.