Pulmonary vein stenosis: Severity and location predict survival after surgical repair

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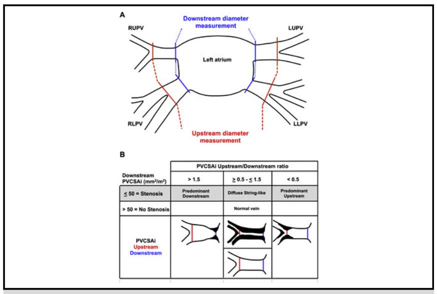
ABSTRACT

Objectives: Pulmonary vein characteristics that influence survival after repair of stenosis have not been defined. We sought to develop a predictive model relating postrepair survival to preoperative pulmonary vein characteristics on computed tomography and magnetic resonance imaging.

Methods: Patients who underwent pulmonary vein stenosis repair (1990-2012) with preoperative computed tomography and magnetic resonance imaging were reviewed. We measured pulmonary vein short and long cross-sectional diameters at the left atrial junction (downstream), vein bifurcation (upstream), and narrowest point, and calculated the total cross-sectional area indexed for body surface area. The relationship between pulmonary vein dimensions and survival was related via risk-adjusted parametric hazard analyses.

Results: Of 145 patients who underwent surgical repair, 31 had preoperative computed tomography and magnetic resonance imaging and were analyzed. Surgical repairs were sutureless (n = 30) or pericardial patch reconstruction (n = 1). Mean follow-up was 4.28 ± 4.2 years. In-hospital mortality was 9.7%; unadjusted survival was 75% ± 7%, 69% ± 8%, and 64% ± 7% at 1, 3, and 5 years, respectively. Median downstream total cross-sectional area indexed for body surface area was 163 mm^2/m^2, upstream total cross-sectional area indexed for body surface area was 263 mm^2/m^2, and total cross-sectional area indexed for body surface area at maximal stenosis, localized at the left atrial junction in approximately two thirds of patients, was 163 mm^2/m^2. Smaller upstream total cross-sectional area indexed for body surface area ($P = .030$) and greater number of stenotic pulmonary veins ($P = .0069$) were associated with increased early (<1 year) risk of death. Smaller downstream total cross-sectional area indexed for body surface area tended to be associated with a late risk of death ($P = .059$).

Conclusions: Smaller upstream or downstream total cross-sectional area indexed for body surface area negatively influenced survival. Early survival seemed especially poor for patients with a greater number of stenotic veins and upstream pulmonary vein involvement. The total cross-sectional area indexed for body surface area measurements can help to inform prognosis and stratify patients for enrollment in clinical trials of agents directed at pulmonary vein pathology. (J Thorac Cardiovasc Surg 2015;■:1-9)



Scheme of PV diameters, measurements, and stenosis classification.

Central Message

Survival for patients with PV stenosis can be predicted using the upstream/downstream dimensions and the number of involved veins.

Perspective

The current study introduces an innovative methodology to assess PV stenosis on the basis of CT/MRI. Severity of upstream narrowing and greater number of stenotic PVs are associated with early mortality, whereas the severity of downstream narrowing is associated with late attrition. The proposed methodology could aid in risk stratification for future clinical trials.

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Abbreviations and Acronyms

CT	= computed tomography
IQR	= interquartile range
LLPV	= left lower pulmonary vein
LUPV	= left upper pulmonary vein
MRI	= magnetic resonance imaging
PV	= pulmonary vein
PVCSAi	= pulmonary vein cross-sectional area indexed to body surface area
RLPV	= right lower pulmonary vein
RUPV	= right upper pulmonary vein
TCSA	= total pulmonary vein cross-sectional area
TCSAi	= total pulmonary vein cross-sectional area indexed to body surface area

Supplemental material is available online.

Pulmonary vein (PV) stenosis is common after repair of total anomalous pulmonary venous drainage, affecting 10% to 17% of the patients.[1-3] Less frequently (0.4%-0.6%), PV stenosis presents as a primary congenital disease.[4,5] In either form—postrepair or primary congenital disease—the overall outcomes remain poor. Furthermore, surgical intervention does not substantially improve outcomes and is associated with relatively high rates of mortality (46%-80%).[1,4-9] Available scoring systems created to predict postoperative survival are based mainly on echocardiogram measurements.[4,10,11] However, these scoring systems are limited by the inability to image the PVs "upstream" within the lung parenchyma. We hypothesized that the upstream PV dimensions, evaluable precisely with computed tomography (CT) and magnetic resonance imaging (MRI), are important determinants of postrepair survival. As such, we used CT and MRI to evaluate the relationship between PV characteristics and survival after surgical repair.

MATERIALS AND METHODS

We retrospectively reviewed patients who underwent PV stenosis repair at the Hospital for Sick Children (Toronto, Ontario, Canada) from 1990 to 2012 and who had a preoperative CT or MRI. Among 145 patients treated for PV stenosis, 110 were excluded because they did not have a preoperative CT/MRI and 4 were excluded secondary to associated right lung hypoplasia in scimitar syndrome. Of the remaining 31 patients, 16 had a preoperative MRI, 10 had a preoperative CT, and 5 had both MRI and CT imaging before surgery. These 31 patients formed the study population for the subsequent analysis. The Research Ethics Board approved the study and waived the requirement for patient consent.

Data Acquisition and Follow-up

Patient admission, diagnostic, and surgical data were obtained from medical records, echocardiogram, and surgical reports. Details of PV morphology and physiology were abstracted from CT/MRI reports and operative notes. Follow-up was obtained through review of medical records up to December 2014, with a mean duration of 4.28 years (range, 0.14-12.8 years).

Imaging Review

Preoperative PV dimensions were assessed through retrospective analysis of CT/MRI performed by 2 pediatric cardiac radiologists (TG, S-JY) using previously published methods.[12-16] The data sets were analyzed using off-line workstations both for angiographic ("Leonardo," Siemens Medical Solution, Forchleim, Germany or "Advantage Windows 3.0," GE Medical System, Milwaukee, Wis) and flow velocity mapping studies (MEDIS Medical Imaging System, Leiden, The Netherlands). For the subset of patients in whom flow studies were feasible, flow volumes were measured for each PV and for the right/left pulmonary arteries. Pulmonary artery redistribution was considered present when right and left pulmonary artery flow ratio was out of the normality range (between 61:39 and 43:57).[14]

Short and long cross-sectional diameters were measured for each PV at the left atrial junction (downstream) and the bifurcation (upstream) (Figure 1). If the site of maximum narrowing did not include the upstream or downstream location, a third measurement was taken at the narrowest portion of the PV, thus representing the site of maximum stenosis. By applying an ellipse model, the diameters were used to calculate the individual PV cross-sectional area indexed to body surface area (PVCSAi) via the Haycock formula.[17] Total PV cross-sectional area indexed to body surface area (TCSAi) was obtained by adding the single PVCSAi for every vein at the designated level (eg, downstream, upstream, or maximal stenosis).

We also calculated the predicted total pulmonary vein cross-sectional area (TCSA) for each patient using the theoretic derivation formulas for cardiovascular structures in children published by Sluysmans and Colan[18] based on the power function model ($TCSA = aX^b$ with an "a" as the constant value of 1.861, "X" equal to body surface area calculated with Haycock formula, and "b" as the exponent with a value of 1.020). The predicted PVCSA was obtained by division of the predicted TCSA by the percentage of contribution of each mean single PV diameter (right upper pulmonary vein [RUPV] = 25.8%, right lower pulmonary vein [RLPV] = 25.8%, left upper pulmonary vein [LUPV] = 25%, left lower pulmonary vein [LLPV] = 23.4%) to the total mean diameter.

For illustrative purposes, the PV morphology was classified into 3 groups based on the ratio between the upstream and downstream PVCSAi. An upstream/downstream PVCSAi ratio cutoff of 1.5 and 0.5 were arbitrarily adopted considering that they correspond to vessel diameter variation greater than 20% to 25% between the 2 locations. The 3 morphologies possible were as follows: (1) PVs that had localized downstream narrowing with dilated upstream tract and a ratio >1.5; (2) PVs that had similar dimensions when comparing the upstream and downstream PVCSAi (ratio 0.5-1.5). This group encompassed normal PVs and veins with string-like stenosis diffusely distributed between the upstream and downstream segments (albeit with clinically evident stenosis). (3) PVs that had a morphology characterized by smaller size upstream and wider size at the left atrial junction (ratio <0.5).

Statistical Analysis and Presentation

Demographic, clinical information, and PV dimensions (indexed to body surface area) before surgical repair were included as baseline variables. Continuous variables are summarized as median with interquartile range (IQR). Categoric and ordinal variables are presented as frequencies and percentages. Data analyses were performed with SAS statistical software (version 9.2; SAS Institute, Inc, Cary, NC) and Stata Statistical Software Release 12 (StataCorp LP, College Station, Tex).

The clinical impact of preoperative PV stenosis was determined, in part, by examining the time-related freedom from death (survival) after surgical correction. The time-related freedom from death was assessed