Anatomical risk factors, surgical treatment, and clinical outcomes of left-sided pulmonary vein obstruction in single-ventricle patients

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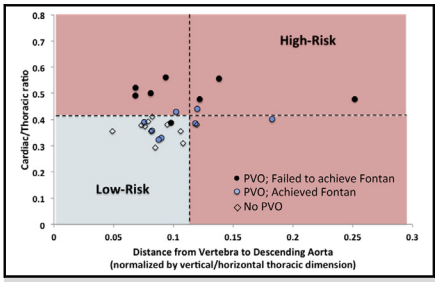
ABSTRACT

Background: Patients with single-ventricle physiology frequently develop left-sided pulmonary vein obstruction (PVO), in which the pulmonary veins traverse the descending thoracic aorta. We hypothesized that a combination of cardiomegaly and an anteriorly positioned descending aorta is associated with PVO.

Methods: Among 494 consecutive single-ventricle patients, 15 were diagnosed with PVO by cardiac magnetic resonance, defined as anatomically localized narrowing of the pulmonary vein diameter. Using axial slices at the level of the left lower pulmonary vein, normalized dimensions were obtained to characterize the anatomic relationships of intrathoracic structures. Measurements were compared between patients with PVO and ''control'' patients (single-ventricle patients with normal pulmonary veins, n = 12).

Results: Patients with cardiac magnetic resonance–diagnosed PVO had larger cardiac size and more antero-laterally located descending aorta when compared with controls (normalized dimensions: cardiac/thoracic area ratio: 0.43 vs 0.38, $P = .035$, distance from vertebra to descending aorta normalized by the horizontal dimension of thoracic cavity: 0.09 vs 0.08, $P = .049$). Seven (47%) patients underwent PV sutureless repair, and 3 (of 7) failed to achieve Fontan. Patients who failed to achieve Fontan had a larger normalized cardiac size than those who achieved Fontan (cardiac/thoracic area ratio: 0.49 vs 0.39, $P = .001$).

Conclusions: The combination of relative cardiomegaly within the context of the thoracic cavity at the level of the pulmonary veins and antero-lateral displacement of the aorta is associated with left-sided PVO and subsequent failure to achieve Fontan completion. Further characterization of these unique geometric relationships may help inform both surveillance strategies and decision making in the timing of interventions, and guide the intraoperative objectives at the time of PVO repair. (J Thorac Cardiovasc Surg 2015;149:1332-8)



Combination of cardiomegaly and antero-latellary located descending aorta is a risk for left PVO.

Central Message

Characterization of both anatomic and physiologic feature of left PVO helps decision making in the timing and type of repair.

Perspective

In comparison with biventricular repair, the clinical significance of PVO is magnified in patients with single-ventricle physiology because PVO may prevent progression to second stage and Fontan procedures. This study showed that combination of cardiomegaly and antero-laterally displaced descending aorta was associated with left PVO and subsequent failure to achieve Fontan completion; hence, further characterization of this unique condition is important.

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Previous studies have noted that left-sided pulmonary vein obstruction (PVO) commonly occurs in close proximity to the descending thoracic aorta.[1-3] In comparison with biventricular repair, the clinical significance of PVO is magnified in patients with single-ventricle physiology because PVO may prevent progression to second stage and Fontan procedures. Indeed, atrioventricular valve regurgitation (AVVR), which is commonly associated with single-ventricle volume loading, and PVO remain important risk factors for Fontan failure.[4,5] We hypothesized that a combination of cardiomegaly and an anteriorly displaced descending aorta predisposes patients to left-sided PVO in the region where the pulmonary veins traverse the descending aorta (Figure 1). To test this hypothesis, we developed geometric models of intrathoracic anatomy using cardiac magnetic resonance (CMR) imaging obtained in patients with and without evidence of PVO. Furthermore, we correlated these anatomic models with progression to Fontan completion. Finally, we evaluated clinical outcomes in terms of Fontan candidacy of this unique pathology.

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Abbreviations and Acronyms
AVVR = atrioventricular valve regurgitation
CMR = cardiac magnetic resonance
IQR = interquartile range
PVO = pulmonary vein obstruction

METHODS

A total of 494 single-ventricle patients who underwent staged Fontan palliation at The Hospital for Sick Children in Toronto between January 2000 and June 2012 were reviewed. Patients with total anomalous pulmonary venous connection were excluded. Twenty-four (4.9%) patients were diagnosed with left-sided PVO. Among the 24 single-ventricle patients with PVO, 15 had left-sided PVO, defined as anatomically localized narrowing of the PV diameter by CMR, and were included as the study group (Table 1); the remaining 9 patients were diagnosed on the basis of echocardiograms (ie, no CMR) and were excluded because the planned anatomic comparisons require CMR studies.

A control group was selected among single-ventricle patients who did not have a diagnosis of left-sided PVO and did have CMR studies available for comparison. Matching criteria included age, ventricular morphology, type of initial palliation, and stage of palliation. Twelve patients were selected for the control group based on matching criteria and the availability of CMR for comparison. Approval for the study was granted by The Hospital for Sick Children Research Ethics Board, which waived any requirement for patient consent.

Diagnostic Studies

The CMR protocol was performed on a 1.5-Tesla magnet (Avanto, Siemens Medical Solutions, Erlangen, Germany) and consisted of phase contrast flow velocity measurements of all great arteries and veins, as described elsewhere.[6] Using an axial slice at the level of the left lower pulmonary vein, normalized dimensions were obtained to characterize the anatomic relationships of intrathoracic structures. The slice was selected to maximize the diameter of the most stenotic portion of the pulmonary veins in PVO patients and to go through the midpoint of the left pulmonary veins in the control patients (Figure 2). If the assessments of the 2 investigators differed, the image was reviewed until consensus was reached. Raw measurements were normalized using vertical and horizontal thoracic dimensions. The pulmonary to systemic flow ratio (Qp/Qs) was calculated by using CMR, as follows:

$$\frac{\textit{Right pulmonary veins flow}\left(\frac{l}{\min}\right)+\textit{Left pulmonary veins flow}\left(\frac{l}{\min}\right)}{\textit{Descending aortic flow}\left(\frac{l}{\min}\right)+\textit{Superior vena cava flow}\left(\frac{l}{\min}\right)}$$

The cardiothoracic ratio at the time of PVO was assessed by chest radiograph. Severity of AVVR was obtained from the echocardiographic assessment close to the time that left-sided PVO was diagnosed (in the study group) or that CMR was performed (in the control group). More than mild AVVR was considered to be significant AVVR. Patients who did not achieve Fontan completion or who required heart transplantation were categorized as being in the "failure group."

Surgical Technique

Seven (47%) patients underwent pulmonary vein sutureless repair. A detailed surgical description has been provided elsewhere.[7] In brief, moderate hypothermic cardiopulmonary bypass was used. The posterior pericardium and the anterior wall of the left pulmonary veins were opened and unroofed. The anterior wall of the individual pulmonary veins were cut back and unroofed if necessary. The anastomosis between the atrium and the posterior pericardium was performed with a continuous suture technique, using 6-0 or 7-0 polypropylene sutures (Prolene, Ethicon, Inc, Somerville, NJ).

Statistical Analysis

Continuous data are presented as median (interquartile range [IQR]). Discrete data are presented as frequency (percentage). The level of statistical significance was set at $P \leq .05$. Differences between the groups were analyzed with the Mann-Whitney U test. Event frequencies were compared with χ^2 analysis.

RESULTS

Among patients with left-sided PVO, the left lower pulmonary vein was the most frequent site of obstruction in 13 of 15 patients (87%) (Table 1). PVO was diagnosed between stage I and II in 5 patients, between stage II and III in 9 patients, and after Fontan completion in 1 patient. Seven (47%) patients had corroborative echocardiographic evidence of physiologic PVO (flow acceleration with mean gradients of >3 mm Hg). Eight patients did not have any evidence of PVO on echocardiography, defined as a mean gradient of >3 mm Hg across the pulmonary vein. Seven patients (47%) with PVO had significant AVVR, and 2 patients (17%) in the control group had significant AVVR ($P = .10$).

Anatomic and Physiologic Relationship of Intrathoracic Structures

The CMR-derived intrathoracic dimensions are shown in Table 2. The normalized distance from vertebra to aorta in patients with left-sided PVO was greater than that in control patients (0.09, IQR [0.08-0.10] vs 0.08, IQR [0.07-0.09], $P = .049$). Patients with left-sided PVO had a larger cardiac cross-sectional area normalized to total thoracic cross-sectional area than control patients (cardiac/thoracic: 0.43, IQR [0.39-0.49] vs 0.38, IQR [0.36-0.38], $P = .035$). This difference was accentuated in the comparison of the portion of the cardiac area in the left portion of the thorax (left cardiac/left thoracic: 0.60, IQR [0.52-0.64] vs 0.52, IQR [0.47-0.54], $P = .014$). The comparison of physiologic data showed a non–statistically significant trend toward less left–pulmonary vein flow in patients with left-sided PVO compared with controls (1.02 vs 1.57 l/min/m^2, $P = .061$) (Table 3). In contrast, patients with left-sided PVO had larger right–pulmonary vein flows (2.25 vs 1.47 l/min/m^2, $P = .025$); therefore, the left-to-right PV flow ratio was lower in PVO patients compared with controls (0.52 vs 1.05 l/min/m^2, $P = .028$), indicating an unequal distribution of pulmonary blood flow. The ratio of pulmonary to systemic flow (Qp/Qs) was comparable between patients with left-sided PVO and those in the control group (0.97 vs 0.96, $P = .748$), reflecting compensatory flow in the right lung offsetting diminished flow in the left lung of PVO patients. The cardiothoracic ratio was comparable between the left-sided PVO and control groups (0.54 vs 0.54, $P = .111$) (Table 3).