Balloon Pulmonary Valvuloplasty in Infants: A Quantitative Analysis of Pulmonary Valve-Anulus-Trunk Structure

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**Objectives.** The present study was designed to establish possible predictors of unfavorable outcome in infants with pulmonary valve stenosis.

**Background.** Balloon pulmonary valvuloplasty is the treatment of choice for typical pulmonary valve stenosis. Patients with dysplastic valves may be less suitable candidates for this procedure because they have morphologic abnormalities of the complex valve-anulus-trunk that cause the obstructive phenomenon.

**Methods.** Twenty-five children (mean age ± SD 1.1 ± 0.7 years) with normal anulus diameter underwent balloon pulmonary valvuloplasty using a balloon/anulus ratio of 1.2 ± 0.11. From the lateral view of a right ventricular angiogram, the following variables were quantified and scored: A, supravalvular narrowing; B, texture of the valve surface; C, diastolic deformity of the Valsalva sinuses; D, trunk/anulus ratio; E, systolic valve motion; and F, presence of a contrast jet. Paired t test, stepwise multivariate correlation with “dummy” variable methods were applied for both hemodynamic and valve-anulus-trunk determinations.

**Results.** The right ventricular-pulmonary artery gradient decreased from 66 ± 21 (range 40 to 120) to 24 ± 11 (range 10 to 50) mm Hg (p < 0.001), whereas the right ventricular systolic pressure decreased from 89 ± 20 (range 60 to 130) to 48 ± 15 (range 30 to 80) mm Hg (p < 0.001). Only variables A, B and D had significant influence in a percent reduction in right ventricular pulmonary artery gradient (R² 0.94, SEE 5.7; p < 0.001). A score ≥4 obtained by adding the values from these three variables was correlated with poor outcome.

**Conclusions.** These data show that there is an adequate relation between scores and outcome. We conclude that children <2 years old with pulmonary valve stenosis and a score ≥4 should not be candidates for balloon pulmonary valvuloplasty.

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In children <2 years of age, and especially in infants, these intermediate forms of pulmonary stenosis are frequently observed. When treatment of these children is necessary, the choice of the appropriate method is critical. Whether a balloon procedure should be attempted is a difficult decision when facing these atypical forms of disease. The present study was designed to establish possible predictors of unfavorable outcome in children <2 years of age with pulmonary valve stenosis.

**Methods**

**Study patients.** From July 1985 to February 1990, 200 patients with pulmonary valve stenosis underwent pulmonary balloon valvuloplasty. A subgroup of 25 patients <2 years of age were eligible for this study. Neonates with critical pulmonary valve stenosis, patients with a hypoplastic pulmonary anulus (<2 SD) (15) and those who had no lateral views on right ventricular angiography were excluded from analysis. The patients' age (mean ± SD) at this time of balloon pulmonary valvuloplasty was 1.1 ± 0.7 years (range 0.16 to 2) and their weight was 8.3 ± 2.5 kg (range 4.8 to 13).

**Cardiac catheterization.** Patients were given premedication and local anesthesia. Percutaneous femoral vein catheterization was performed in all patients. Oximetry and
pressure measurements were recorded from the pulmonary artery and right heart chambers. Left heart measurements were obtained through a patent foramen ovale.

A right ventricular angiogram was obtained before and after balloon pulmonary valvuloplasty in both lateral and frontal views. Anulus diameter (mean 10 ± 2.1 mm, range 8 to 15) and morphologic abnormalities of the pulmonary valve-anulus-trunk structure were recorded. Angiographic results and outcome were evaluated.

Balloon valvuloplasty. A single-balloon technique was used in all but one infant (double-balloon technique, bifemoral approach). The balloon/anulus ratio was 1.2 ± 0.11 (range 1.1 to 1.5) (two patients with a 1.1 balloon/anulus ratio). The procedure was similar to that previously described (1). The balloon was inflated with diluted contrast medium under fluoroscopic guidance until the waist produced by the stenotic valve disappeared. Hemodynamic measurements were repeated 15 to 30 min after valvuloplasty to allow the patient's condition to stabilize.

Quantitative analysis of pulmonary valve-anulus-trunk structure. The morphologic features of the pulmonary valve-anulus-trunk structure were quantified and scored by two experienced pediatric angiographers who independently reviewed the lateral view on the right ventricular angiogram while unaware of the clinical outcome. The following qualitative variables were measured (Fig. 1).

Variable A: supravalvular narrowing. This was measured by dividing the size of the pulmonary anulus by the diameter of the pulmonary trunk (measured at the level of the sinotubular junction immediately above the Valsalva sinuses) (score 0 = <0.95; score 1 = 0.96 to 1.1; score 2 = >1.11).

Variable B: texture of the valve surface. This was evaluated during systole (score 0 = uniformly smooth; score 1 = localized thickening at the edges of the cusps; score 2 = diffuse irregular thickening of the entire valve [surface and edges]).

Variable C: diastolic deformity of the Valsalva sinuses (score 0 = symmetric coaptation of the sigmoidal cusps; score 1 = irregular coaptation and radiopaque filling defects in the pulmonary sinus surface).

Variable D: trunk/anulus diameter ratio. Trunk diameter was measured immediately before the right pulmonary branch origin (twice the distance of the measured length of the Valsalva sinus) and divided by anulus diameter (score 0 = 1.26; score 1 = <1.25).

Variable E: systolic valve motion (score 0 = valve excursion surpasses imaginary line drawn at the mid distance of the Valsalva sinus length; score 1 = valve motion does not reach the aforementioned line).

Variable F: contrast jet (score 0 = well defined contrast jet; score 1 = dubious or absent jet).

Statistical analysis. Hemodynamic data are presented as mean value ± SD and range. Statistical analysis performed included a paired t test (before and after balloon pulmonary valvuloplasty) and univariate and stepwise multivariate linear regression with "dummy" variables as needed. In the "dummy" variable analysis, we used the lowest level as a reference, which is explained in the following example (16):

\[
\begin{array}{cccc}
A & A1 & A2 \\
3 & 0 & 0 \\
1 & 1 & 0 \\
2 & 0 & 1 \\
\end{array}
\]

The alpha level was set at 0.01. The dependent variable was arbitrarily defined as an optimal, suboptimal or poor result when the percent right ventricular-pulmonary artery gradient reduction was >50%, 35% to 49% and <35%, respectively. To take into account the degree of intraobserver and interobserver concordance that could be expected to occur by chance, kappa statistics were also generated. Analysis of intra- and interobserver variability was performed without knowledge of other data by two experienced pediatric angiographers.

Results

Hemodynamic effects of pulmonary valvuloplasty. The right ventricular-pulmonary artery pressure gradient in the entire group of 200 patients decreased from 82 ± 31 mm Hg (range 35 to 165) to 25 ± 17 mm Hg (range 5 to 100) (p < 0.001). Hemodynamic baseline data from the 25 patients that form the basis of the study are summarized in Table 1. The right ventricular-pulmonary artery gradient decreased from 66 to 24 mm Hg (p < 0.001). The mean percent gradient reduction was 61% (four patients with <35% reduction). No
Table 1. Hemodynamic Data in 25 Patients Before (Pre) and After (Post) Valvuloplasty

<table>
<thead>
<tr>
<th>Pre</th>
<th>Post</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVSP (mm Hg)</td>
<td>89 ± 20 (60-130)</td>
<td>0.001</td>
</tr>
<tr>
<td>LVSP (mm Hg)</td>
<td>81 ± 11 (60-100)</td>
<td>NS</td>
</tr>
<tr>
<td>RV-PA gradient (mm Hg)</td>
<td>66 ± 21 (40-120)</td>
<td>0.201</td>
</tr>
<tr>
<td>Systemic saturation (%)</td>
<td>74 ± 15 (55-90)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Data are reported as mean value ± SD; range is shown in parentheses.
LVSP = left ventricular systolic pressure; RV-PA = right ventricular-pulmonary artery pressure; RVSP = right ventricular systolic pressure.

correlation was found between the balloon/anulus ratio and the percent gradient reduction in this group.

Right ventricular systolic pressure decreased from 89 to 48 mm Hg (p < 0.001). In 15 patients who had suprasystemic right ventricular systolic pressure, systemic oxygen saturation due to a right to left atrial shunt increased from 74% to 88% after valvuloplasty (p < 0.001).

Complications. There were no deaths. Important complications included transient cerebrovascular accident that left no sequelae (n = 1), femoropopliteal vein junction tear with successful surgical repair (n = 2) and transient edema in the inferior limb used to introduce larger balloons (n = 7).

Morphologic assessment. The assessment of the morphologic variables of the pulmonary valve-anulus-trunk structure showed a high degree of reproducibility and validity of the mathematical model. The kappa index of intra- and inter-observer concordance applied in 11 randomly selected cases was: variable A = 0.76, 0.95; variable B = 0.70, 0.78; variable C = 0.47, 0.52; variable D = 0.78, 0.82; variable E = 0.51, 0.43; and variable F = 0.60, 0.41, respectively. No correlation was found between the variables when univariate analysis was applied.

To determine variables that predict balloon valvuloplasty failure, a stepwise multivariate linear regression was entered into the mathematic model. The data showed a significative influence of variables A, B and D in the percent pressure gradient reduction.

The "dummy" variable analysis showed the absence of linearity in those in whom more than two levels of a partial score were obtained (between a score of 0 to 2 for variables A and B) (Table 2). A score 1 for variable B by regression analysis did not reach statistical significance and its influence on the results could not be evaluated (r = 1.8; p < 0.6).

The scoring system from 0 to 5 obtained by adding the partial values from variables A, B and D represents increasing abnormalities of the complex valve-anulus-trunk morphology from classic pulmonary stenosis to maximal dysplastic obstruction. All patients with a score of 0 to 2 showed an optimal result. The score failed to predict the outcome in patients with a score of 2; only one of the three have had a suboptimal result. Finally, four of the five patients with a score ≥4 exhibited a poor percent pressure gradient reduction (Fig. 2).

These data allowed us to recognize a theoretic scoring that predicts a poor outcome (A1 + B2 + D1; A2 + B2 + D1; and A2 + B2 + D0, where A, B and D are the variables, respectively). All four patients with an unsuccessful result (patients with a percent right ventricular-pulmonary artery gradient reduction <35%) had certain abnormalities of valve-anulus-trunk structure as an expression of a high degree of dysplasia (Table 2).

Follow-up. A 2-year-old child was referred to surgery 1 week after valvuloplasty. The surgeon found typical dysplastic valve tissue and hematoma of the thickened free edge of the leaflets. Three patients (one with Noonan syndrome) are awaiting operation. In one, reoperation was attempted 2 months after the first bifemoral approach because of an increase in the Doppler gradient. Thrombosis of both the right and left femoral veins prevented the second balloon procedure.

The 21 remaining patients have been followed up for 2 to 24 months (mean 16 ± 7) after balloon valvuloplasty without clinical or Doppler evidence of significant changes in the residual right ventricle-pulmonary artery gradient.

Table 2. Stepwise Regression and Dummy Variable Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score</th>
<th>Regression Coefficient</th>
<th>SEE</th>
<th>Student t Distribution</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td></td>
<td>79.4</td>
<td>3.5</td>
<td>22.9</td>
<td>0.0000</td>
</tr>
<tr>
<td>A1</td>
<td></td>
<td>-8.6</td>
<td>2.9</td>
<td>-2.9</td>
<td>0.0086</td>
</tr>
<tr>
<td>A2</td>
<td></td>
<td>-35.3</td>
<td>3.9</td>
<td>-9.1</td>
<td>0.0000</td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td>-1.8</td>
<td>3.6</td>
<td>-0.5</td>
<td>0.6265</td>
</tr>
<tr>
<td>B2</td>
<td></td>
<td>-21.6</td>
<td>4.1</td>
<td>-5.2</td>
<td>0.0000</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>-13.5</td>
<td>2.9</td>
<td>4.5</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Multiple correlation coefficient R² = 0.94; SEE = 5.7.
Table 3. Partial Scores in Patients With a Right Ventricular-Pulmonary Artery Gradient Reduction <35%

<table>
<thead>
<tr>
<th>Pt No.</th>
<th>Variable</th>
<th>RV-PA Gradient Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A 1 B 2 D 1</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>A 1 B 2 D 1</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>A 2 B 2 D 1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>A 2 B 2 D 1</td>
<td>10</td>
</tr>
</tbody>
</table>

*Patient 4 had Noonan syndrome. Pt = patient; RV-PA = right ventricular-pulmonary artery.

Discussion

Balloon pulmonary valvuloplasty is a usual interventional procedure in the pediatric cardiac catheterization laboratory. Its effectiveness in dysplastic valve stenosis is uncertain.

Pulmonary valve morphology. The precise nature of pulmonary valve-annulus-trunk morphology has been reported (17,18). This knowledge aids in successful balloon valvuloplasty (19,20). An inverse relation between the degree of commissural fusion and the severity of valvular dysplasia was confirmed (14). Evidence to date is inconclusive concerning the results of balloon pulmonary valvuloplasty in these atypical valves. The disparate results reported may be related to the inhomogeneity of this type of obstruction, as indicated by the wide spectrum found between classic and severe dysplasia.

In our experience, these observations were particularly evident in infants when selected angiographic features were analyzed. The reported immediate and follow-up success rate ranged from 3% to 75% according to different investigators (1,3,8,9,12–14), but a uniform definition of the valve-annulus-trunk structure was not specified. The Valvuloplasty and Angioplasty of Congenital Anomalies Registry (4) confirmed that patients with atypical stenosis have a persistent high right ventricular systolic pressure and gradient after a balloon procedure.

Transient infundibular reaction after valvuloplasty or a definite unsuccessful result may explain the residual high ventricular pressure. Nevertheless, edema or hematoma in the abnormal vascularized valvular tissue, as seen in one of our patients, may be a potential and unrecognized factor to consider in the analysis of immediate results.

Quantitative evaluation of selected morphologic abnormalities. In our study, this evaluation confirmed that supravalvular narrowing, thickened nodular cusps, and the degree of poststenotic dilation play a major role in the result of balloon valvuloplasty. The combination of these variables defines with certainty the magnitude of commissural fusion or dysplasia.

Infants with a score ≥4 (based on the values of variables A, B, and D) had a poor outcome (Table 3). The prospective use of this mathematic model of the complex pulmonary valve-annulus-trunk structure may identify the best candidates for balloon pulmonary valvuloplasty and exclude patients for whom surgical valvectomy would be a better therapeutic procedure.

Technical considerations. The use of larger balloons (balloon:annulus ratio 1.4 to 1.5) is advocated to obtain the best results with percutaneous balloon valvuloplasty in patients with atypical pulmonary stenosis (12). However, disparity between a larger sized balloon and a small femoral venous lumen in infants, combined with potential damage in the right ventricular outflow tract, may add a serious risk to the more usual technique.

Our experience, confirmed by other investigators, showed that venous rupture and thrombosis were not rare in children <2 years of age when an oversized balloon was used. The last complication, frequently without clinical expression, may prevent the performance of additional dilation, which is often needed in patients with valvular dysplasia (8,9,21).

Conclusions. Assuming that dysplastic valvular stenosis represents a possible contraindication to balloon valvuloplasty (22), we believe, on the basis of this study, that patients <2 years of age and especially infants with a score ≥4 should not undergo balloon pulmonary valvuloplasty. Prospective studies using the quantitative method reported here in a large number of patients are required to confirm our conclusion.

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References


