Abstract

Background: The prediction of pulmonary hemodynamic data from non-invasive assessment could exempt some patients with congenital cardiac septal defects from preoperative invasive assessment (catheterization).

Objective: To determine, in simultaneous assessment, whether data obtained from Doppler echocardiography could predict aspects of pulmonary hemodynamics in such patients.

Methods: Echocardiographic parameters related to systolic and systemic pulmonary flow and pulmonary venous flow were related to hemodynamic data in 30 consecutive patients with cardiac septal defects (aged 4 months to 58 years, median 2.2 years, mean pulmonary artery pressure between 16 and 93 mmHg).

Results: The velocity-time integrals of systolic flow in right ventricle outflow tract (VTI_{RVOT} ≥ 22 cm) and pulmonary venous flow (VTI_{VP} ≥ 20 cm) predicted PVR/SVR ≤ 0.1 levels (pulmonary vascular resistance and systemic vascular resistance ratio), with a specificity of 0.81 and odds ratio above 1.0. For VTI_{RVOT} ≥ 27 cm and VTI_{VP} ≥ 24 cm values, the specificity was higher than 0.90 and odds ratio 2.29 and 4.47 respectively. The ratio between pulmonary and systemic flows (Qp/Qs ≥ 2.89 and ≥ 4.0, echocardiographic estimates) was useful in predicting Qp/Qs > 3.0 values through catheterization (specificity of 0.78 and 0.91, odds ratio 1.14 and 2.97, respectively).

Conclusion: In patients with cardiac septal defects, Doppler echocardiography is able to identify those at increased flow and low pulmonary vascular resistance. (Arq Bras Cardiol 2010;94(5):557-564)

Key words: Echocardiography, Doppler; heart defects, congenital; heart catheterization.

Introduction

Currently, most patients, particularly pediatric patients, with congenital cardiac septal defects that cause increased flow and pressure in the pulmonary region are referred to corrective procedures based on non-invasive assessment only. This is due to the advancement of correction techniques, especially surgeries, plus the development of postoperative care, resulting in the possibility of treating early in the first months of life. There is evidence that in infants undergoing early correction of septal defects, particularly under 9 months of age, pulmonary vascular resistance, evaluated one year after it, returns to normal levels, regardless of the severity of vascular lesions observed in lung biopsy samples1. Thus, in most cases, the invasive assessment of pulmonary vascular resistance becomes unnecessary.

Nevertheless, some situations fall out of this rule. The following conditions have been linked to persistent pulmonary hemodynamic changes even after successful correction of cardiac septal defects, requiring a diagnostic evaluation in greater depth, even through invasive methods: 1) patients older than two; 2) presence of certain abnormal conditions such as common arterial trunk, atrioventricular septal defects and transposition of great arteries associated with ventricular septal defects; 3) no history of congestive lung associated with deficits in weight gain. In these situations, despite the development of noninvasive methods for assessing the pulmonary hemodynamics, particularly Doppler echocardiography and magnetic resonance2-4, there is consensus on the need to measure pulmonary vascular resistance through cardiac catheterization5 and the characterization of its behavior in vasodilator stimuli6-10. In the absence or, if necessary, in the presence of vasodilator stimuli, the final pulmonary vascular resistance is expected to lie below 6.0 Wood units m² and pulmonary and systemic resistance ratio should be smaller than 0.3.

There have been efforts to try to estimate pulmonary hemodynamic variables through echocardiography data, especially in patients with congenital heart disease, aiming at the progressive replacement of invasive assessment with noninvasive assessment. Pressure, blood flow and pulmonary vascular resistance have been estimated through a variety...
of echocardiographic indexes. However, the use of such measures in clinical practice is still quite limited, especially in view of the great variability of the correlation coefficients between echocardiographic and hemodynamic data, when different authors are compared. Thus, echocardiography is still limited in its ability to provide timely hemodynamic data usually obtained through catheterization. High values of correlation coefficients are found in studies with limited number of congenital heart disease included, thus not allowing generalizations.

This study, conducted in patients with three types of cardiac septal defects known to cause increased flow and pulmonary pressures, was targeted at answering the following question: would it be possible, through noninvasive assessment (echocardiography), to identify with acceptable accuracy patients in situations of increased pulmonary blood flow without a considerable increase in vascular resistance in that territory, so that cardiac catheterization could be avoided even in the presence of clinical suspicion of pulmonary hypertension? The study was then designed to perform such assessment prospectively.

Methods

Case series

The following patients were found to be eligible for this study: patients with congenital heart defects, namely atrial septal defect, ventricular septal defect or atrioventricular septal defect in preoperative evaluation at the Unit of Pediatric Cardiology and Adult Congenital Heart Diseases, Instituto do Coração, Hospital das Clínicas, Medical School of the University of São Paulo. We only included patients whose clinical and echocardiographic initial assessment suggested, for some reason, the need for cardiac catheterization as a diagnostic complementation, as in the defects cited, invasive assessment is not generally necessary. In our routine, factors that usually lead to the prescription of catheterization in patients with heart defects are: age above 18 months, associated syndromes, absence of pulmonary congestion signs, peripheral oxygen saturation periods below 90% and presence of bidirectional flow through the septal defects. Beyond these criteria, catheterization was occasionally prescribed for anatomical clarifications (for example, on pulmonary venous drainage) in cases of persistent doubts with noninvasive assessment. Exclusion criteria were patients with cardiac arrhythmias, anatomic defects that would lead to inaccurate measurements (pulmonary stenosis or atrial septal defects), or that would require oxygen concentrations above 30% in the air inhaled during cardiac catheterization.

This study, conducted in patients with three types of cardiac septal defects known to cause increased flow and pulmonary pressures, was targeted at answering the following question: would it be possible, through noninvasive assessment (echocardiography), to identify with acceptable accuracy patients in situations of increased pulmonary blood flow without a considerable increase in vascular resistance in that territory, so that cardiac catheterization could be avoided even in the presence of clinical suspicion of pulmonary hypertension? The study was then designed to perform such assessment prospectively.

General diagnostic data

Data obtained were age, sex, type of structural heart defect, associated syndromes, presence or absence of pulmonary congestion, oxygen saturation periods below 90% and the flow direction (from left to right, from right to left or bidirectional) through the septal defect.

Ecocardiographic assessment

Parallel to the assessment of structural heart defects, Doppler echocardiography was used to analysis of variables potentially relatable to hemodynamic data. Echocardiography was performed simultaneously with cardiac catheterization in the hemodynamic laboratory, under sedation or general anesthesia when required, and supply of oxygen in inhaled air ranging from 21% to 30% in concentration. The survey was conducted with use of HDI5000 model equipment (Philips Medical System, Andover, MA, USA) equipped with 2.5MHz and 5MHz transducers. Echocardiographic measurements were made as recommended by the American Society of Echocardiography.

All flow variables on the right were obtained with pulsed-wave Doppler positioned in the right ventricle outflow tract, just below the pulmonary valve. By recording the pulmonary systolic flow curve, the following variables were recorded (average value of three consecutive heartbeats): acceleration time (ACT), ejection time (ET), right ventricle pre-ejective period (PEP); velocity-time integral of total systolic flow in the right ventricle outflow tract (VTI RVOT), AC/ET; PEP/ET and PEP/VTI RVOT indexes. The velocity-time integral value corresponding to the pulmonary venous flow was also determined (VTI v). The pulmonary and systemic flow ratio (Qp/Qs) was obtained by assessing each of them through the following equation:

\[ Q_{(l/min)} = V \times a 	imes 60 \times s/min \times (1000 \text{ml/l})^1 \]

where Q is blood flow, V is the average velocity of the pulmonary or aortic flow (Doppler, cm/s), and “a” is the cross-sectional area (aortic or pulmonary, cm²). Finally, the overall assessment of right ventricular function was made by determining the myocardial performance index (MPI) as previously described.

Cardiac catheterization

Right and left heart catheterization was performed by introducing catheter through femoral vein puncture, requiring intravenous anesthetics (midazolam, fentanyl, ketamine) and occasionally inhalation (sevoflurane) in pediatric patients. Pulmonary artery pressures were recorded (PBP, PBP t and PBP S, respectively, systolic, diastolic and mean), as well as pulmonary wedge pressure (PWP) and systemic arterial pressures (SAP, SAP D and SAP S, respectively, systolic, diastolic and mean). After obtaining blood samples for blood gas analysis, pulmonary and systemic blood flows were calculated by the Fick principle. Subsequently, from the values of pressures and flows, pulmonary and systemic vascular resistance indexes were determined. Both blood flows and vascular resistances in the lungs and systemic circulation were expressed as ratios (respectively, Qp/Qs and PVR/SVR).

Statistical analysis

The results for the variables analyzed were expressed as median and limits. Mean and standard deviation results
were also determined in the case of satisfactory adherence to normal distribution. The potential association between hemodynamic and echocardiographic variables was tested by adjusting mathematical models. Therefore, the transformation of explanatory variables and response variables was necessary. The suitability of adjusted models to predict the extent of hemodynamic variables, was checked by obtaining the coefficient of determination ($r^2$). The possibility of predicting hemodynamic data by category, by means of echocardiographic data, was checked by adjusting the logistic regression models. In this case, the prediction suitability was examined by building operating characteristics curves (ROC). Cut-off values were determined for predicting variables (echocardiographic variables), taking into account the best sensitivity and specificity ratio, but giving priority to the latter. The prioritization of specificity was due to the fact that the study aimed to safely identify patients with most benign pulmonary hemodynamic change. Thus, we focused only on cut-off values with sensitivity around or above 0.80. In all procedures, we adopted the value 0.05 as significance level.

**Results**

The study included 30 patients with ages ranging between 0.41 and 58.2 (median 2.2 years), of which 75% were below 10 years. The sex ratio was 1:1. The mean pulmonary artery pressure ranged between 16 and 93 mmHg (median 28 mmHg) upon catheterization. Individual diagnostic data are displayed in Table 1. With respect to clinical data that could point out to the possibility of high pulmonary vascular resistance (over 18 months, associated syndromes, no pulmonary congestion, peripheral oxygen saturation periods below 90% and bidirectional flow through the cardiac septal defect) the number of patients with none, one, two, three, four or five of these characteristics were respectively 1, 4, 17, 5, 3 and 0.

**Echocardiographic and hemodynamic findings**

Findings of echocardiographic and hemodynamic measures that can be obtained in all 30 patients are summarized in tables 2 and 3, respectively. The number of patients with Qp/Qs > 3.0 upon echocardiography and through catheterization were respectively 12 and 15, suggesting that the study cohort includes a subgroup of individuals in a condition of clear increased pulmonary blood flow (compatible with low vascular resistance). Table 2 shows that there were ACT variable records below 65 ms, and ACET/ET variable records below 0.26, noting that these limits generally identify patients with PBP\textsubscript{PE} over 40 mmHg\textsuperscript{2}. Values below 16.0 cm to VTI\textsubscript{PV} were 19 and VTI\textsubscript{AM} also suggested the absence of increased pulmonary blood flow in some cases. MPI\textsuperscript{RV} values greater than 0.32\textsuperscript{20} were suggestive of right ventricular dysfunction in some patients.

**Point estimation of hemodynamic data**

Table 4 shows that among the various attempts to determine a potential interdependence between echocardiographic and hemodynamic variables it was possible to develop six predictive models with statistical significance, all non-linear. However, based on coefficient of determination values ($r^2$), the point prediction of hemodynamic data was not considered satisfactory (Fig. 1).

**Interval estimation of hemodynamic data**

The echocardiographic variables VTI\textsubscript{PGEV}, VTI\textsubscript{PV}, Qp/Qs, PEPE/ET, and PEP/VTI\textsubscript{SOF} were tested for their ability to predict levels to hemodynamic variables Qp/Qs and PVR/SVR. Table 5 shows sensitivity, specificity and odds ratio values for the models whose development was possible with statistical significance. It was not possible to identify, from the echocardiogram, patients with high pulmonary vascular resistance (eg, PVR/SVR > 0.5). However, through the echocardiographic variables Qp/Qs, VTI\textsubscript{PGEV} and VTI\textsubscript{PV} we could identify patients under hemodynamics of clear increased pulmonary flow (Qp/Qs > 3.0 upon catheterization) and low vascular resistance levels (PVR/SVR ≤ 0.1). The concordance level between echocardiography and catheterization, as measured by the percentage of correctly classified cases, was 70%, 73% and 73% respectively, in predicting Qp/Qs > 3.0 and in the PVR/SVR ≤ 0.1 ratio, from the variables VTI\textsubscript{SOF} and VTI\textsubscript{PV}. Table 5 provides two potential “cut-off values” for each of the echocardiographic variables, suggesting that, for the purposes of clinical use, the specificity should be prioritized. Figure 2 shows the operating characteristic curves corresponding to the prediction (interval) of hemodynamic data from the echocardiographic variables arranged in Table 5. Note that the variable VP\textsubscript{PE} was slightly more robust in its predictive capacity. Patients’ ages, ranging from 0.41 to 58.2, did not influence the results, even when tested alone or in combination with echocardiographic indexes in multiple regression models.

**Discussion**

The findings of this study show a significant association between echocardiographic and hemodynamic data (cardiac catheterization) in patients with congenital cardiac septal defects. There was sufficient precision to point estimation. Basically, we could identify, through Doppler echocardiography (e.g., VTI\textsubscript{PGEV ≥ 22 cm}, VTI\textsubscript{PV ≥ 20 cm} and Qp/Qs ≥ 2.89) in patients under unquestionable condition of increased blood flow (Qp/Qs > 3.0) and low levels of pulmonary vascular resistance (PVR/SVR ≤ 0.1). Although echocardiographic variables could have been tested for their ability to predict other hemodynamic levels (e.g., Qp/Qs > 1.5 and PVR/SVR < 0.3), our goal was not looking for ways to exempt individuals in borderline situations from catheterization. However, not so significant sensitivity levels suggest that, according to the criteria proposed, some patients in situations of increased pulmonary flow would still be assessed invasively.

Attempts to assess hemodynamic data (especially pulmonary data) through Doppler echocardiography begin with the determination of pressures. Thus, the systolic pressure in the right ventricle (and by implication, the PBP\textsubscript{PE} provided that there is no obstruction in the ventricular outflow tract) has been estimated through modified Bernoulli equation, using maximum velocity of tricuspid regurgitation flow\textsuperscript{21,22}, PBP\textsubscript{PE} and PBP\textsubscript{PV} have been estimated by the same principle, but using the initial and final velocities of the pulmonary regurgitation flow. Alternatively, the latter can be predicted...
Table 1 - Diagnoses in 30 patients with congenital heart disease

<table>
<thead>
<tr>
<th>Patient No</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Anomaly (ies)</th>
<th>PBP (_M)</th>
<th>Qp/Qs</th>
<th>Syndromes</th>
<th>Pulmonary congestion</th>
<th>Sat O(_2) &lt; 90%</th>
<th>Direction of flow (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.2</td>
<td>F</td>
<td>ASD / AR</td>
<td>16</td>
<td>1.43</td>
<td>--</td>
<td>not found</td>
<td>no</td>
<td>E-D</td>
</tr>
<tr>
<td>2</td>
<td>50.9</td>
<td>F</td>
<td>ASD</td>
<td>16</td>
<td>3.10</td>
<td>--</td>
<td>not found</td>
<td>no</td>
<td>E-D</td>
</tr>
<tr>
<td>3</td>
<td>49.8</td>
<td>F</td>
<td>ASD</td>
<td>23</td>
<td>5.09</td>
<td>--</td>
<td>not found</td>
<td>no</td>
<td>E-D</td>
</tr>
<tr>
<td>4</td>
<td>37.5</td>
<td>F</td>
<td>ASD</td>
<td>19</td>
<td>3.03</td>
<td>--</td>
<td>not found</td>
<td>no</td>
<td>E-D</td>
</tr>
<tr>
<td>5</td>
<td>1.9</td>
<td>M</td>
<td>AVSD</td>
<td>27</td>
<td>2.35</td>
<td>Down</td>
<td>found</td>
<td>no</td>
<td>E-D</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>M</td>
<td>AVSD</td>
<td>33</td>
<td>1.75</td>
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<td>found</td>
<td>yes</td>
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<td>7</td>
<td>2</td>
<td>M</td>
<td>VSD / MS</td>
<td>40</td>
<td>4.70</td>
<td>--</td>
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<td>M</td>
<td>AVSD</td>
<td>25</td>
<td>3.17</td>
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<td>found</td>
<td>no</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>9</td>
<td>0.66</td>
<td>M</td>
<td>VSD</td>
<td>21</td>
<td>2.92</td>
<td>--</td>
<td>found</td>
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<td>Bidirectional</td>
</tr>
<tr>
<td>10</td>
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<td>M</td>
<td>VSD</td>
<td>42</td>
<td>4.00</td>
<td>--</td>
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<td>no</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>11</td>
<td>1.4</td>
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<td>AVSD</td>
<td>44</td>
<td>3.90</td>
<td>--</td>
<td>found</td>
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<td>Bidirectional</td>
</tr>
<tr>
<td>12</td>
<td>2.4</td>
<td>F</td>
<td>VSD / IM</td>
<td>93</td>
<td>1.73</td>
<td>--</td>
<td>found</td>
<td>no</td>
<td>Bidirectional</td>
</tr>
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<td>13</td>
<td>1.3</td>
<td>F</td>
<td>VSD</td>
<td>35</td>
<td>5.14</td>
<td>--</td>
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<td>Bidirectional</td>
</tr>
<tr>
<td>14</td>
<td>4</td>
<td>F</td>
<td>VSD</td>
<td>28</td>
<td>1.95</td>
<td>--</td>
<td>found</td>
<td>no</td>
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</tr>
<tr>
<td>15</td>
<td>0.41</td>
<td>M</td>
<td>VSD / ASD</td>
<td>28</td>
<td>5.38</td>
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<td>found</td>
<td>no</td>
<td>E-D</td>
</tr>
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<td>16</td>
<td>1.58</td>
<td>M</td>
<td>VSD</td>
<td>24</td>
<td>3.30</td>
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<tr>
<td>17</td>
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<td>F</td>
<td>VSD</td>
<td>43</td>
<td>4.33</td>
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<td>VSD</td>
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<tr>
<td>19</td>
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<td>F</td>
<td>VSD / ASD</td>
<td>19</td>
<td>4.58</td>
<td>Down</td>
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<td>20</td>
<td>1</td>
<td>F</td>
<td>AVSD</td>
<td>25</td>
<td>4.57</td>
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<td>found</td>
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</tr>
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<td>6</td>
<td>F</td>
<td>AVSD</td>
<td>26</td>
<td>6.25</td>
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<td>yes</td>
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</tr>
<tr>
<td>22</td>
<td>36</td>
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<td>AVSD</td>
<td>73</td>
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<td>F</td>
<td>VSD</td>
<td>32</td>
<td>5.21</td>
<td>Down</td>
<td>found</td>
<td>no</td>
<td>Bidirectional</td>
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<tr>
<td>24</td>
<td>0.83</td>
<td>M</td>
<td>AVSD</td>
<td>50</td>
<td>1.63</td>
<td>Down</td>
<td>found</td>
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<td>Bidirectional</td>
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<tr>
<td>25</td>
<td>46.2</td>
<td>F</td>
<td>VSD</td>
<td>82</td>
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<td>D-E</td>
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<tr>
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<td>11</td>
<td>F</td>
<td>VSD</td>
<td>22</td>
<td>4.17</td>
<td>--</td>
<td>found</td>
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<td>Bidirectional</td>
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<tr>
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<td>ASO</td>
<td>20</td>
<td>2.05</td>
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<td>E-D</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>M</td>
<td>AVSD / CoAo</td>
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<td>found</td>
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<td>29</td>
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<td>M</td>
<td>ASO</td>
<td>33</td>
<td>0.92</td>
<td>--</td>
<td>not found</td>
<td>no</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>30</td>
<td>54</td>
<td>M</td>
<td>ASO</td>
<td>19</td>
<td>3.81</td>
<td>--</td>
<td>not found</td>
<td>No</td>
<td>E-D</td>
</tr>
</tbody>
</table>

ASD - atrial septal defect; VSD - ventricular septal defect; CoAo - coarctation of the aorta; AVSD - atrioventricular septal defect; AR - aortic regurgitation; MS - mitral stenosis; PBP\(_M\) - mean pulmonary artery pressure measured during catheterization; Qp/Qs - ratio between pulmonary and systemic blood flow upon catheterization; Sat O\(_2\) < 90% - recorded periods of oxygen saturation below 90%. (*) Direction of flow through the cardiac septal defect. Bidirectional flow in both directions; D-E - predominantly from right to left; E-D - predominantly left to right.

using regression models, taking as independent variables the ACt or ACt/ET (PBP\(_M\)) or PEP/ET indexes (PBP\(_D\))\(^{11}\). All these propositions have constraints. Pulmonary and tricuspid regurgitation are not always present. When present, these do not always reflect pressure increases, as it is the case of valve regurgitation by anatomical abnormality in patients with atrioventricular septal defect. For these reasons, the pressure record through regurgitation flows was not considered in this study. It was possible to develop a regression model to predict the PBP\(_D\) from the PEP/ET ratio, with a weak coefficient of determination, though. It should be noted that for the purposes of making decisions regarding the prescription of corrective treatment (usually surgery) in these patients, blood pressure levels per se have not been taken into account.

More informative than the pressures are the numerical value of pulmonary blood flow (Qp) and its relation to systemic flow (Qp/Qs). In the absence of respiratory disorders or systemic vasodilatation which may alter the Qp/Qs ratio, that has been routinely used as a measure of pulmonary blood flow in cardiac septal defects, mainly because its calculation depends only on blood gas data not requiring the measured value of oxygen consumption. After catheterization, Qp/Qs...
values greater than 1.5 and values above 1.7 or 2.0 have been considered as suggesting “increased pulmonary flow” respectively in ventricular and atrial septal defects.

Several methods have been proposed to estimate, through Doppler echocardiography, the ratio between flows. These methods involve the use of flow velocities in ventricle outflow tracts, as well as the cross-sectional area of the pulmonary artery and aorta\(^2\), as performed in this study. The Qp/Qs ratio can be determined with echocardiographic analysis of flows in different heart positions, for greater accuracy in estimating septal defects in different locations, that is, pre-tricuspid, post-tricuspid or interatrial\(^1\). The same ratio can be estimated in patients with ventricular septal defects by analyzing the flow velocity through such septal defect, considering its diameter\(^2\). However, clinical practice use of Qp/Qs index analyzed by echocardiography has been limited mainly due to the diversity of correlation coefficients with catheterization findings. Coefficients greater than 0.90 are reported in literature, but in case series involving a limited number of heart defects. Therefore, generalization was not possible\(^2\). In most reports, the correlation coefficients are between 0.80 and 0.85 using different methods\(^12\). In this study, despite attempts to adjust several models, based on echocardiography, an acceptable point prediction for the Qp/Qs ratio determined by catheterization could not be established. However, it was possible to determine that

\[ y = \exp(a + bx) \]
Table 5 - Interval estimation of hemodynamic variables from the echocardiographic data

<table>
<thead>
<tr>
<th>Predictor (echocardiogram)</th>
<th>Variable estimated (catheterization)</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Odds ratio</th>
<th>P value (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qp/Qs ≥ 2.89</td>
<td>Qp/Qs &gt; 3.0</td>
<td>0.6</td>
<td>0.78</td>
<td>1.14</td>
<td>0.0263</td>
</tr>
<tr>
<td>Qp/Qs ≥ 4.0</td>
<td>Qp/Qs ≥ 3.0</td>
<td>0.33</td>
<td>0.80</td>
<td>2.97</td>
<td>0.0476</td>
</tr>
<tr>
<td>VTI_RVOT ≥ 22 cm</td>
<td>PVR/SVR ≤ 0.1</td>
<td>0.57</td>
<td>0.61</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>VTI_RVOT ≥ 27 cm</td>
<td>PVR/SVR ≤ 0.1</td>
<td>0.15</td>
<td>0.94</td>
<td>2.29</td>
<td></td>
</tr>
<tr>
<td>VTI_PV ≥ 20 cm</td>
<td>PVR/SVR ≤ 0.1</td>
<td>0.65</td>
<td>0.81</td>
<td>1.21</td>
<td>0.0092</td>
</tr>
<tr>
<td>VTI_PV ≥ 24 cm</td>
<td>PVR/SVR ≤ 0.1</td>
<td>0.32</td>
<td>0.93</td>
<td>4.47</td>
<td></td>
</tr>
</tbody>
</table>

Qp/Qs - pulmonary flow and systemic flow ratio; PVR/SVR - pulmonary vascular resistance and systemic vascular resistance ratio; VTI_RVOT - velocity-time integral of right ventricular flow (cm); VTI_PV - velocity-time integral of right superior pulmonary venous flow (cm). (*) Related to coefficient β of the predictor in the logistic model adjusted.

Figure 1 - Point estimation of the pulmonary and systemic vascular resistance ratio (PVR/SVR, cardiac catheterization) from the velocity-time integral of pulmonary flow, determined by echocardiography with Doppler positioned in the right ventricle outflow tract (VTI_RVOT, systolic flow) or pulmonary tract (VTI_PV). The data correspond to patients with congenital cardiac septal defects (n = 30). The nonlinear models have the format y = EXP (a+b(lnX)).

Figure 2 - Operating characteristic curves (ROC) for predicting hemodynamic data from echocardiographic variables. Dashed line: prediction of values PVR/SVR ≤ 0.1 (pulmonary vascular resistance and systemic vascular resistance ratio upon catheterization) from the echocardiographic variable VTI_PV (velocity-time integral of right superior pulmonary venous flow (cm)); solid line: prediction of values Qp/Qs > 3.0 (pulmonary and systemic blood flow ratio upon echocardiography) from the same variable (Qp/Qs) upon echocardiography; dotted line: prediction of values PVR/SVR ≤ 0.1 from the echocardiographic variable VTI_RVOT (velocity-time integral of systolic flow in the right ventricle outflow tract). We can note a slight superiority of the VTI_PV as a predictor, in relation to others. The areas under the curves are, respectively, 0.80, 0.75 and 0.72, and the total area is assumed as 1.0. The data correspond to patients with congenital cardiac septal defects (n = 30).
patients with Qp/Qs ≥ 2.89 estimated by echocardiography have odds ratios greater than 1.0 on the possibility of being in a range above 3.0 for the Qp/Qs ratio determined by catheterization. For patients with Qp/Qs ≥ 4.0 on echocardiography (that occurred in six individuals in this study), the specificity of this prediction hit 0.91, with odds ratio of 2.97. Thus, for decision-making purposes, the interval prediction of the ratio between the flows seemed safer.

Alternatively, the pulmonary and systemic flows can be predicted indirectly through the velocity-time integral (VTI) determined in ventricular outflow tracts by Doppler echocardiography. In the absence of septal defects that may produce increased pulmonary blood flow, the variable VTI_{RVOT} has values around 16 cm, which seems to be stable across different age groups. However, it is inversely related to heart rate. Patients with increased pulmonary flow associated with cardiac septal defects usually present VTI_{RVOT} values above 20 cm. In this study, the velocity-time integral was more useful in predicting the pulmonary vascular resistance than the flow itself.

In addition to the pressures (pulmonary pressures) and blood flows, attempts have been made to estimate the pulmonary vascular resistance using variables derived from Doppler echocardiography. Among the latter are the ratio between tricuspid regurgitant jet velocity and velocity-time integral on the right (TRV/VTI_{RVOT}), in addition to PEP, ET, PEP/ET, PEP/VTI_{RVOT}, Act and the PEP/Act ratio and the total systolic time. Despite reports of correlation coefficients with hemodynamic data in excess of 0.90, there are a number of difficulties in interpreting and applying these results. The most important one is the exclusion of patients from the final analysis, on the grounds of technical difficulties in determining echocardiographic or hemodynamic data. As the exclusion criteria are not clearly explained in advance, the interpretation of findings is impaired. Other problems include the use of regression procedures in data whose distribution would clearly not allow it and the use of very small case series. Another limitation of the use of these correlations is that findings obtained from case series that do not include patients with congenital heart disease are not applicable to situations of clinical practice involving patients with cardiac septal defects by promoting communication between the systemic and pulmonary circulations.

In the strict context of congenital heart disease, it is worth discussing some predictions based on intervals. Hirschfeld et al. used the cutoff value < 0.30 for the PEP/ET variable in identifying patients with low pulmonary vascular resistance (below 3.0 Wood units, which generally corresponds to the PVR/SVR ratio between 0.40 and 0.60 seconds/meter, respectively, with pulmonary resistance levels below 3.0, between 3.0 and 7.5 and above 7.5 Wood units). In this study, in terms of point prediction, the highest coefficient of determination was obtained for the association between the variables VTI_{RVOT} and VTI_{PV}, still not sufficiently robust. The value of the variable VTI_{RVOT} in this study, represents an increase compared to previous publications. The echocardiographic parameters determined through the analysis of systolic flow in the right ventricle outflow tract cannot be used to check the pulmonary hemodynamics in patients with localized septal defects beyond the pulmonary valve. This would be the case of patent ductus arteriosus and aortopulmonary window. Such patients are usually excluded from the analysis. The analysis of variable VTI_{PV} would then be useful in these situations in the absence of anatomic or functional barriers to pulmonary venous drainage.

Contrary to the findings of Hirschfeld and Ebeid, in this study it was not possible, based on echocardiographic data, to identify, with acceptable accuracy, patients with high pulmonary vascular resistance (e.g., individuals with PVR/SVR > 0.5). It should be noted, however, that such identification would be a limited value in clinical practice, particularly with regard to the characterization of the need for cardiac catheterization. These patients (especially pediatric patients) are generally over the age of one year, without clinical signs of pulmonary congestion, despite the presence of cardiac septal defects. The flow through the defect is often bidirectional, and may be predominantly from right to left, and in some periods, peripheral oxygen saturation is below 90%. In these circumstances, whatever is the estimate in relation to pulmonary hemodynamics by noninvasive methods, the patient will invariably be referred to catheterization in order to determine an accurate measurement of pulmonary vascular resistance and its behavior to vasodilator stimuli.

The main limitations of this study include a relatively small sample, and the fact that patients were aged within broad limits, which could bring some questions about the applicability of findings in pediatric patients and adults. It should be noted, however, that the influence of age on prediction models developed has not been shown. Levels of sensitivity coupled with cut-off values chosen suggest that if these values are adopted, some patients with favorable hemodynamics (increased pulmonary blood flow and not high pulmonary vascular resistance) will still depend on diagnostic catheterization.

In summary, the findings produced by this study show that besides clinical data known and widely used in taking decisions on the operability in patients with cardiac septal defects, some echocardiographic indicators can be placed. Thus, patients with Qp/Qs ≥ 2.89, VTI_{RVOT} ≥ 22 cm and VTI_{PV} ≥ 20 cm, determined through Doppler echocardiography, may be considered as having a positive pulmonary hemodynamics and exempt from preoperative invasive assessment.

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