Lung Mechanics in Infants With Left-to-Right Shunt Congenital Heart Disease

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Summary. To clarify which hemodynamic measurement correlates best with lung mechanics in infants with congenital heart disease and left-to-right shunts, dynamic pulmonary function tests and echocardiography were performed in 26 infants with such disease (study infants) and in 37 normal, healthy infants (control infants). The tidal volume and pulmonary compliance (Ct) were lower and airway resistance higher in infants with congenital heart disease than in control infants. A significant correlation was demonstrated between Ct, expiratory resistance (Re), and the right pulmonary artery-to-aortic size ratio (RPA/DAO). Ct and Re also correlated well with the corrected acceleration time \(\times RR\) ratio (ACT/\(\times RR\)): ACT, acceleration time and RR, length of the cardiac cycle) of pulmonary flow velocity. Stepwise multiple regression analysis revealed that RPA/DAO correlated best with both Ct and Re. It is concluded that infants with congenital heart disease and left-to-right shunts have lower lung compliance and higher expiratory airway resistance than normal children, and that RPA/DAO is the echocardiographic parameter that correlates best with the changes in lung mechanics. Pediatr Pulmonol. 1996; 21:42-47.

Key words: Pulmonary function; pulmonary blood flow; pulmonary hypertension; right pulmonary artery-to-aortic size ratio; acceleration time of pulmonary flow velocity.

INTRODUCTION

Infants with congenital heart disease (CHD) and left-to-right shunts usually suffer from tachypnea, dyspnea, and recurrent pulmonary infections. Abnormal lung mechanics leading to increased work of breathing (WOB) have been suggested as a cause contributing to these findings. Although some studies observed no changes in lung mechanics, most studies documented decreased lung compliance in children and adults with significant CHD, pulmonary hypertension, and left-to-right shunts. The mechanisms causing this decrease in lung compliance have not been clarified. Some studies attributed this change to increased pulmonary blood flow (PBF) or pulmonary hypertension, while others found a decrease in lung compliance only in patients with an increase in both PBF and pulmonary arterial pressure (PAP). There were also reports that found no correlation between reduced lung compliance and elevated PBF, PAP, or pulmonary vascular resistance.

Most previous studies that correlated lung mechanics with measurements of PBF and PAP used data obtained by cardiac catheterization. Only recently has echocardiography been used to study the relationships between hemodynamic parameters and lung mechanics. In the study by Davies et al., the correlation of lung mechanics with an x-ray score and the pulmonary artery-to-aortic ratio was evaluated. Since the use of echocardiography to diagnose and follow up patients with CHD is convenient and non-invasive, and since pulmonary function testing in children is not available in many hospitals, it might be helpful to study the echocardiographic parameters that correlate best with changes in lung mechanics in patients with CHD and left-to-right shunts.

With improvements in medical management and early surgical intervention, the general condition of infants with CHD and left-to-right shunts is better than before (fewer patients with increased pulmonary arterial resistance). Therefore, it was hypothesized that lung mechanics in these infants might be better correlated with the increase in PBF than with PAP.

This study was, therefore, designed to evaluate the
correlation between lung compliance or airway resistance and pulmonary hemodynamics, as evaluated by echocardiography in infants with left-to-right shunts due to CHD.

MATERIALS AND METHODS

Subjects

Twenty-six infants (13 males, 13 females) with CHD and left-to-right shunt were enrolled in this study from the Cardiology Special Clinic or the Pediatric Ward of the National Taiwan University Hospital. The disease spectrum among the 26 cases included ventricular septal defect (VSD; 12 cases); patent ductus arteriosus (PDA; 4 cases); atrial septal defect (ASD; 3 cases); VSD plus PDA (2 cases); VSD plus ASD (2 cases); VSD plus ASD and PDA (1 case); VSD plus mild aortic stenosis (AS) and aortic regurgitation (AR; 1 case); and coarctation of the aorta plus PDA (1 case). Age at the time of study ranged from 9 days to 11 months (median, 3.3 months). Ten cases had pulmonary artery hypertension detected by echocardiography and underwent cardiac catheterization. None of them had pulmonary arterial resistance greater than 2.5 units. Eleven cases received standard anticongestive treatment (digoxin and furosemide); two of them also received captopril. None of the study infants had received ventilatory assistance, had undergone previous thoracic surgery, or had intractable heart failure or pulmonary infection at the time of evaluation of pulmonary mechanics. Three of the study cases were born prematurely, and five were small-for-gestational age infants. The body weight of 42% of the patients was below the 3rd percentile for age, and in 31% it was below the 3rd percentile for body length. All infants were followed at the outpatient clinic for at least 6 months.

Another 37 normal, healthy infants (21 males, 16 females) were enrolled randomly from the nursery of the National Taiwan University Hospital as a control group. All were born at term, but four were small for gestational age. None of the control infants had experienced perinatal illness or had ever suffered from lower respiratory disease, and none of them had cardiac disease. The median (range) age of the control infants was 3.1 months (6 days to 9 months). This study was approved by the National Science Council of Taiwan. Informed parental consent was obtained for all infants studied.

Pulmonary Function Test

Pulmonary function tests were performed on each subject at the time of enrollment. The air flow was measured with a heated pneumotachometer (Fleisch 0 or 00, depending on tidal flow rates) and a Validyne differential pressure transducer. The response of the pneumotachometers was linear for flow rates of 0 to 10 L/min (Fleisch 00) and 0 to 18 L/min (Fleisch 0). The pneumotachometer-
Echocardiographic Assessment

Color Doppler echocardiography was done on each patient within 2 weeks of performing the pulmonary function test. Infants were examined with an Aloka 880 (Aloka Co., LTD, Tokyo, Japan) or Acuson 128XP (Acuson Co., California, USA) color Doppler machine. Parameters used to estimate the magnitude of left-to-right shunt were the left atrial-to-aortic root diameter ratio (LA/AA ratio) and the left ventricular end-diastolic dimension (LVED). The right pulmonary artery-to-aortic ratio (RPA/DAO) was also obtained to indicate the degree of pulmonary vascular engorgement. The degree of PAP was estimated by the corrected acceleration time (ACT/VRR; RR, length of cardiac cycle). The left atrium (LA) and left ventricle were measured by the M-mode.14 The diameter of the aorta (DAO) was measured from the subcostal view; the right pulmonary artery diameter (RPA) was measured from the suprasternal view.15 The Doppler pulmonary artery velocity signal was obtained approximately 1 cm distal to the pulmonary valve. Acceleration time (ACT) was measured as the time interval in seconds from the onset of ejection to peak flow velocity.16 Because on the wide range of heart rates, the corrected acceleration time (ACT/VRR), which had been shown to have better correlation with either systolic or mean pulmonary arterial pressure,16 was used in this study.

Statistical Analysis

All measured variables were expressed as mean ± SD. Student’s t-test was used to compare the differences between each group for nonparametric variables. The level of significance was accepted at P < 0.05. Linear regression analysis was used to evaluate the correlation of CI, Rr, and Re with the pulmonary blood flow parameters RPA/DAO and ACT/VRR. A stepwise multiple regression test was then run separately to analyze which factor most closely correlated with CI, Rr, and Re. The independent variables were the ones that showed a significant correlation with the dependent variable (CI, Rr, or Re) by linear regression analysis.

RESULTS

Table 1 shows the basic data and results of pulmonary mechanics in the 26 study infants and 37 control infants. The two groups were comparable in age, yet infants in the study group showed poorer growth. Study infants had a significantly higher respiratory frequency, Rr, and Re each of the echocardiographic variables, it was noted that RPA/DAO and ACT/VRR had a significant correlation with CI (r = 0.65 and 0.52, respectively), (Fig. 1) and Re (r = 0.44 and 0.38, respectively) (Fig. 2). Rr had no correlation with any of the variables. Among these two factors, stepwise multiple regression analysis revealed that RPA/DAO had the highest correlation with both CI and Re.

DISCUSSION

This study demonstrated decreased lung compliance in infants with left-to-right shunt CHD. A negative correlation between lung compliance and the degree of pulmonary vascular engorgement, and between lung compliance and pulmonary artery hypertension was also demonstrated. This study relied extensively on valid methods to estimate intrapleural pressure, PBF, and PAP. In previous studies intrapleural pressure was usually measured by inserting an air-filled esophageal balloon or a water-filled catheter into the esophagus. Intraesophageal pressure is not always a reliable measurement of intrapleural pressure because of uneven distribution of local pressure caused by chest wall distortion. In this study, the intrathoracic position of the catheter was verified by the largest negative reflection on pressure tracing during inspiration, and only breaths without changes of intraesophageal pressure baseline and without evidence of distortion of the pressure-volume relationship were taken for analysis. This made this method as reliable as possible. However, it has to be kept in mind that several conditions in cardiac patients—such as pulmonary congestion and cardiomegaly—might interfere with the transmission of pleural pressure to the esophagus. Wallgren et al.9 found no discernible difference in the pressure recorded from different levels in the upper half of the esophagus. Therefore, they concluded that the influence of the cardiac impression on the esophagus might be considered negligible. None of the CHD patients in the present study had pulmonary congestion while the lung function was measured.

Accurate assessment of PAP has usually been obtained with cardiac catheterization, which is invasive, expensive, and cannot be done very often in follow-up evaluations. Noninvasive methods, such as physical examination, chest x-ray, and M-mode or two-dimensional echocardiography, are generally insensitive for the detection and quantification of pulmonary hypertension of mild-to-
TABLE 1—Clinical Characteristics and Pulmonary Mechanics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Study group(^1) (n = 26)</th>
<th>Control group(^2) (n = 37)</th>
<th>t</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (months)</td>
<td>3.6 ± 2.6</td>
<td>3.4 ± 1.8</td>
<td>0.391</td>
<td>0.698</td>
</tr>
<tr>
<td>BW (g)</td>
<td>4.549 ± 1.361</td>
<td>6.353 ± 1.490</td>
<td>-4.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BL (cm)</td>
<td>55.5 ± 6.6</td>
<td>61.5 ± 6.1</td>
<td>-3.714</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RF (min)</td>
<td>58.1 ± 18.0</td>
<td>37.9 ± 9.7</td>
<td>5.748</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>VT (ml/cm)</td>
<td>0.44 ± 0.19</td>
<td>0.64 ± 0.18</td>
<td>-4.16</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CL (cmH₂O/cm)</td>
<td>0.092 ± 0.045</td>
<td>0.133 ± 0.036</td>
<td>-3.991</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R, (cmH₂O/L/sec)</td>
<td>43.6 ± 19.9</td>
<td>28.9 ± 14.6</td>
<td>3.386</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^1\)BW, body weight; BL, body length; RF, respiratory frequency; VT, tidal volume; CL, inspiratory lung compliance; R, inspiratory resistance, R, expiratory resistance.

\(^2\)Values are mean ± SD.

TABLE 2—Echocardiography Parameters Estimating the Magnitude of Pulmonary Blood Flow and Pulmonary Arterial Pressure

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Study group(^1) (n = 32)</th>
<th>Control group(^2) (n = 37)</th>
<th>t</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAV/AO</td>
<td>1.24 ± 0.23</td>
<td>1.11 ± 0.12</td>
<td>3.027</td>
<td>0.003</td>
</tr>
<tr>
<td>LVED</td>
<td>2.49 ± 0.51</td>
<td>2.10 ± 0.36</td>
<td>3.692</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RPA/DAO</td>
<td>0.91 ± 0.40</td>
<td>0.76 ± 0.12</td>
<td>2.190</td>
<td>0.032</td>
</tr>
<tr>
<td>ACT/V/RR</td>
<td>108.3 ± 36.2</td>
<td>138.4 ± 12.2</td>
<td>-4.752</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^1\)LAV/AO, ratio of left arterial and aortic diameter; LVED, left ventricular end-diastolic size; RPA/DAO, ratio of right pulmonary arterial diameter to descending aortic diameter; ACT, acceleration time of pulmonary flow velocity; RR, length of cardiac cycle.

\(^2\)Values are mean ± SD.

\(^3\)Number of measurements.

Recently, Doppler echocardiography has been introduced, and various indices have been found to correlate well with catheterization values of PAP in adults\(^{16,22}\) and in children.\(^{16,23}\) Among the three commonly used Doppler methods for estimating PAP (namely tricuspid regurgitation, pulmonary flow indices, and right ventricular relaxation time), the tricuspid gradient measurement and the corrected acceleration time from pulmonary flow analysis have been shown to predict the PAP well.\(^{18}\) However, up to 28% of patients did not have Doppler-detected tricuspid regurgitation.\(^{18,22}\) Therefore, in this study we used ACT/V/RR as the noninvasive echocardiographic parameter to predict PAP.

The size of pulmonary artery is an indicator of pulmonary vascular engorgement. The echocardiographically measured vessel diameter was shown to correlate with the cardiac output determined invasively by the indicator dilution method.\(^{24}\) In children with left-to-right shunt CHD, altered growth and development of the pulmonary vascular bed has been demonstrated.\(^{25}\) Therefore, a large pulmonary artery might also occur with elevated PAP. However, a large pulmonary artery without high pulmonary flow may occur in several conditions, such as elevated pulmonary vascular resistance, pulmonary valve insufficiency, after pulmonary artery banding, and after dilatation in pulmonary stenosis.\(^{8}\) None of our study cases had any of those conditions. Difficulty in measuring the

![Fig. 1. Relation between lung compliance (Cₕ) and RPA/DAO (A), and CL and ACT/V/RR (B) in study cases (closed squares) and control infants (open triangles). The solid line is the regression curve and the dotted lines are the 95% prediction curves.](image-url)
In conclusion, young infants with left-to-right shunt CHD exhibit a decrease in dynamic compliance and an increase in airway resistance. These changes in lung mechanics correlate better with the magnitude of pulmonary vascular engorgement than with the degree of pulmonary artery hypertension.

ACKNOWLEDGMENTS

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