The Value of Pulsus Paradoxus in Assessing the Child With Status Asthmaticus

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ABSTRACT. The presence of pulsus paradoxus (PP) in 13 episodes of status asthmaticus in 12 children, ages 13 months to 15 years, was compared sequentially to a clinical score, peak expiratory flow rate (PEFR), heart rate, arterialized capillary pH, carbon dioxide pressure (Pco₂), and the ratio of inspired oxygen to oxygen pressure (FiO₂/Po₂) during the first 48 hours following admission.

There was a significant correlation (P < .01) between the presence of a PP (≥ 5 mm Hg) and the clinical score (r = .79), PEFR (r = .55), and heart rate (r = .49). This was particularly striking when the PP was ≥ 20 mm Hg. There was no significant correlation between the mean PP and the Pco₂ or FiO₂/Po₂ ratio. However, a mean Pco₂ exceeding 40 mm Hg was associated with a highly significant (P < .005) difference in mean PP (22.2 mm Hg) compared to the mean PP (12.2 mm Hg) when the Pco₂ was below 40 mm Hg. Although the PP technique can easily be learned by physician and nursing personnel, there are potential problems. The difficulties in children are compared to those in adults.

The PP is a valuable clinical tool in assessing the severity of airway obstruction in status asthmaticus. The presence of a PP, particularly greater than 20 mm Hg, is associated with moderate to severe airway obstruction. In conjunction with the overall clinical status of the patient and frequent blood gas determinations, the PP allows for better evaluation of the patient with status asthmaticus. Pediatrics 61:46-51, 1978.

Variations in pulse amplitude associated with the respiratory cycle were first reported in 1850 and later called pulsus paradoxus (PP) by Kussmaul, who noted a marked diminution of the pulse in inspiration in patients with constrictive pericarditis and pericardial effusion.¹ Gauchat and Katz found that PP was not limited to pericardial disease and could be found up to 5 mm Hg in normal individuals. They also observed that the PP increased with the elevation of intrathoracic pressure as seen in asthma.² Dornhorst et al. later confirmed this observation in asthma but doubted the clinical importance of relating the magnitude of PP to the severity of asthma.³ Detectable by palpation, but more commonly determined by measuring the arterial blood pressure by auscultation, the PP seen in airway obstruction is thought to be caused by hyperinflation of the lung with mediastinal stretching, which produces an increased intrapulmonary pressure. This impedes venous return to the heart as well as leading to cardiac compression, consequently decreasing cardiac output.⁴ Exaggeration of the normal inspiratory decrease in arterial pressure is termed PP.

Rebuck et al. found a PP greater than 10 mm Hg in adult asthmatic patients whose pulmonary function tests and chest x-ray films indicated severe airway obstruction.⁴,⁵ Knowles and Clark confirmed the presence of severe asthma in those patients with a PP exceeding 15 mm Hg on admission to the hospital by evaluating the clinical score, pulse rate, peak expiratory flow rate (PEFR), and carbon dioxide pressure (Pco₂).⁶ Despite these studies which showed the clinical usefulness of this guide in the adult asthmatic, no comprehensive studies have been reported in children. Rebuck and Tomarken found a PP of 15 mm Hg or greater in hospitalized children with acute asthma and a forced expiratory volume in one second (FEV₁) of less than 60% of predicted normal.⁷ These measurements were not performed sequentially throughout the hospital course, and the PP was not correlated to blood gas...

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status or clinical manifestations. Gluck et al. found that children with a PP exceeding 20 mm Hg did not respond well to bronchodilators and required hospitalization for more intensive care.

The measurement of PP is a relatively simple, noninvasive procedure requiring only a sphygmomanometer and stethoscope. In addition, it may be difficult to measure pulmonary function in the acutely ill asthmatic child. We, therefore, evaluated the usefulness of PP in assessing the hospitalized child with status asthmaticus. In this study, we describe a technique of measuring PP in children, since it is more difficult to correlate systolic blood pressure with the inspiratory phase of respiration in the tachypneic child than in adult patients. To establish what constitutes a significant PP, we have compared the magnitude of PP with a simultaneously obtained clinical score, pulmonary function measurement, and blood gas analysis. Finally, in order to adequately assess the predictive value of the PP in the child with status asthmaticus, we have studied these children with sequential measurements during the first 48 hours following hospital admission.

METHODS
Patients

Thirteen admissions of 12 known asthmatic children (nine boys and three girls), ages 13 months to 15 years (mean age, 7.2 years), with status asthmaticus were evaluated in the pediatric intensive care unit at the University of California Irvine Medical Center. Status asthmaticus was defined as an asthmatic episode that did not improve with appropriate doses of epinephrine. Conventional therapy consisting of oxygenation, intravenous hydration, bronchodilation, and administration of corticosteroids was given when indicated. In addition, 40 asthmatic children from the pediatric allergy clinic population were randomly selected to determine the degree of PP in the asymptomatic ambulatory asthmatic patient. Informed consent was obtained from the parents of each child in the study.

Methods of Assessment

During the first 48 hours, repeated determinations of the PP, arterialized capillary blood oxygen pressure (Po2), Pco2, and pH; PEFR; and clinical score were performed by the nursing personnel under the direction of the pediatric allergy department. The PEFR and PP were measured before and after the use of bronchodilators whenever possible. Our protocol is shown in Table I.

TABLE I

<table>
<thead>
<tr>
<th>PP Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PP, hourly; e.g., 120 mm Hg (initial systolic beats, irregular in intensity) minus 100 mm Hg (initial systolic beats, regular in intensity) equals 20 mm Hg (PP)</td>
</tr>
<tr>
<td>2. Pulse rate &amp; blood pressure, hourly</td>
</tr>
<tr>
<td>3. Clinical score, hourly; score 0-2 each for wheezing, retractions, air exchange, &amp; anxiety, up to maximum of 8 for total symptom score</td>
</tr>
<tr>
<td>4. PEFR, before &amp; after bronchodilators</td>
</tr>
<tr>
<td>5. Blood gases &amp; pH, every 4 hours or less, if needed</td>
</tr>
</tbody>
</table>

Pulsus Paradoxus

The PP was determined at the brachial artery using a sphygmomanometer and stethoscope. To measure the PP (millimeters of mercury), two systolic blood pressures were noted: first, when the pulse sound became uniform in intensity, and second, at the highest initial point when irregular, fading pulse began. The degree of PP was obtained by subtracting the first value from the second. It was often not possible to correlate the PP with the respiratory cycle since most of the acutely ill children were breathing rapidly. In the older patient, we compared our modified technique with the classic method of contrasting the systolic blood pressure in inspiration with that in expiration. The two methods resulted in the same value, indicating that our modification detects the PP. We, therefore, used the modified technique for determining PP in patients of all ages.

Blood Gases and pH

After taking blood pressure and PP measurements, blood gases were obtained by the nursing personnel from the patient’s warmed fingertip. Blood was drawn into a heparinized capillary tube and analyzed on an MK2 Blood Microsystem (Radiometer, Copenhagen). Concurrently, inspired ambient oxygen concentration (FIO2) at the nose was determined by an oxygen analyzer (Beckman). To correct for varying FIO2 (percent oxygen) at the time of blood collection, an FIO2/arterialized capillary Po2 ratio was devised. A ratio of 0.30 to 0.40 (0.20/60 x 100) was established as normal in our pediatric intensive care unit. This was determined in patients who had recovered from a variety of respiratory problems breathing room air when they were being discharged from the pediatric intensive care unit.

PEFR

The PEFR was measured in all patients before and after use of bronchodilators (except for three
TABLE II
RELATIONSHIP OF PP TO pH AND BLOOD GASES*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.41 ± 0.05 (15)</td>
<td>7.42 ± 0.05 (8)</td>
<td>7.37 ± 0.12 (7)</td>
<td>7.41 ± 0.08 (6)</td>
<td>7.37 ± 0.09 (10)</td>
<td>Not tested</td>
<td>7.31 ± 0.04†</td>
</tr>
<tr>
<td>FIO₂/arterialized capillary Po₂</td>
<td>0.54 ± 0.23 (16)</td>
<td>0.47 ± 0.10 (7)</td>
<td>0.73 ± 0.45 (7)</td>
<td>Not tested</td>
<td>0.72 ± 0.60 (8)</td>
<td>0.58 ± 0.13 (4)</td>
<td>0.60 ± 0.15 (6)</td>
</tr>
<tr>
<td>PCO₂ (mm Hg)</td>
<td>36.8 ± 8.8 (16)</td>
<td>35.8 ± 5.4 (8)</td>
<td>41.8 ± 17.2 (7)</td>
<td>35.2 ± 6.6 (4)</td>
<td>45.1 ± 15.9 (9)</td>
<td>38.2 ± 4.3 (4)</td>
<td>44.9 ± 8.1 (6)</td>
</tr>
</tbody>
</table>

*Values are mean and 1 SD of the pH and blood gases for the degree of PP. The number of observations for each parameter is shown in parentheses.
†P < .001.

children under age 2 years who were too young to cooperate) using a Wright Peak Flow Meter. After the patient’s height was recorded, all measurements were compared with both the predicted PEFR for normal children (according to sex) and the patient’s usual PEFR when asymptomatic (at least two months after an asthma exacerbation). The latter did not differ appreciably from the predicted normal value for any of our patients.

Clinical Score

To determine the total clinical score, a value of 0 to 2 was assigned to each of the following four parameters: the degree of wheezing, retractions, air exchange, and anxiety. A score of 8 indicated severe wheezing, retractions, minimal air exchange, and marked anxiety.

Pulse Rate

The heart rate was measured at the radial artery (beats per minute) during blood pressure and PP measurement.

Statistical Methods

Correlation coefficient analysis and unpaired Student’s t test analysis were used to determine the relationship between the overall PP and each parameter, and to compare the magnitude of these parameters in the presence and absence of a PP.

RESULTS

The data have been analyzed in two ways. First, the overall correlation between each parameter and PP was analyzed. Second, the parameters were evaluated by comparing the value of each parameter in the absence of PP with that of an increasing magnitude of PP.

Blood Gases and pH

A considerable difference in pH was found only when comparing PP at 0 and 40 mm Hg (Table II). The difference in the mean pH at 40 mm Hg (7.31) and in the absence of PP (7.41) was significant (P < .02). There was no significant overall correlation between the mean PP and the Pco₂ or the FIO₂/arterialized capillary Po₂ ratio. Furthermore, no significant differences were found in the mean Pco₂ and FIO₂/arterialized capillary Po₂ ratio with any magnitude of PP. Since the Pco₂ was variable, the mean PP was compared when the Pco₂ was either above or below 40 mm Hg. A significant difference (P < .005) was found between means when the Pco₂ exceeded 40 mm Hg (mean PP was 22.2 mm Hg) and when the Pco₂ was less than 40 mm Hg (mean PP was 12.2...
TABLE III  
RELATIONSHIP OF PP TO CLINICAL SCORE, PEFR, AND PULSE RATE*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PP (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Clinical score</td>
<td>1.9 ± 1.4 (88)</td>
</tr>
<tr>
<td>PEFR (%) predicted of normal</td>
<td>47.8 ± 22.4 (66)</td>
</tr>
<tr>
<td>Pulse rate (beats/min)</td>
<td>102.4 ± 20.7 (73)</td>
</tr>
</tbody>
</table>

*Values are mean and 1 SD of the clinical score, PEFR, and pulse rate for the degree of PP. The number of observations for each parameter is shown in parentheses.
†P < .001.
‡P < .05.

mm Hg). In the absence of a PP, the Pco₂ exceeded 40 mm Hg only once in 16 determinations.

**Clinical Score**

The overall correlation between PP and clinical score, r = .79, was significant (P < .01) (Table III). The mean clinical score at a PP of 5 mm Hg was significantly greater than at 0 mm Hg (P < .005). The clinical score doubled at 10 mm Hg and tripled when the PP was 20 mm Hg compared to the score at 0 mm Hg. Figure 1 shows the mean and ranges of the clinical score compared to the PP value.

The correlation between the PP and the percent PEFR of r = .55 was significant at P < .01 (Table III). The PEFR decreased from a mean of 47.8% at a PP of 0 mm Hg to 24.1% at 5 mm Hg (P < .05). At a PP of 20 mm Hg, the PEFR was reduced to 12.2% of the predicted norm (P < .001). The mean and range of the PEFR responses at each PP are shown in Figure 2.

**Pulse Rate**

A significant correlation was seen between PP

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**Fig. 2.** Scattergram illustrating mean and ranges of PEFR (percent predicted of normal) compared to specific PP values.

**Fig. 3.** Scattergram illustrating mean and ranges of heart rate (beats per minute) compared to specific PP values.
and the heart rate \((r = .49)\) (Table III). A statistically significant increase of pulse rate over that seen with no PP was found beginning at a PP of 20 mm Hg \((P < .05)\). At a PP of 0, the mean pulse rate was 102.4 beats per minute compared to 126.8 beats per minute at 20 mm Hg. Figure 3 shows the range of heart rates and the mean at each PP value.

**Hospital Course**

On admission, each child had a high PP (mean, 22.8 ± 10.6 mm Hg), which improved with therapy and generally returned to less than 10 mm Hg by 18 hours. The clinical score closely paralleled the PP. In 11 of 13 admissions, the clinical scores initially were 6 or greater (mean, 6.9 ± 1.6); after 18 hours, the clinical score was generally 4 or less. The PEFR could not be obtained in any patient on admission. The PEFR began increasing as the PP fell below 20 mm Hg, but the PEFR remained below predicted normal values even when the PP disappeared for the first 48 hours following admission. The PP, clinical score, and PEFR are chronologically illustrated as mean values of four or more determinations in Figure 4.

**Ambulatory Asthmatic Patients**

A PP was not present in any of 40 asymptomatic asthmatic children; each had a PEFR of at least 80% of predicted normal. On one occasion, a patient was seen with a PEFR 50% of the predicted normal. Physical examination revealed moderate wheezing and a PP of 22 mm Hg. Following an injection of epinephrine, the PEFR improved to 90% of predicted normal, the chest was clear, and the PP decreased to 5 mm Hg.

**DISCUSSION**

Our data comparing sequentially the magnitude of the PP to the clinical severity of asthma, the PEFR, and blood gases suggest that the PP is a useful clinical tool in the assessment of the child as well as the adult with status asthmaticus. It is especially useful in young children, an age group in which it is difficult to test pulmonary function. It is a simple procedure that is safe and noninvasive, thereby facilitating frequent evaluation by the nursing personnel monitoring the child’s vital signs. However, the technique has not been clearly explained as it applies to children. Since a child may have marked tachypnea, it is virtually impossible to correlate the drop in systolic pressure with the inspiratory phase of respiration as is done in the older patient. This decrease in systolic pressure can be detected by noting the systolic pressure associated with the alternating loss of heartbeat and comparing it with the systolic pressure when the heartbeat remains regular in intensity with all beats. This difference in millimeters of mercury is the PP.

Significantly greater clinical and pulmonary function (PEFR) evidence of airway obstruction was found with any degree of PP \((\geq 5 \text{ mm Hg})\) than in its absence (Table III). This was particularly striking when the PP exceeded 20 mm Hg.
We did not find PP in any asymptomatic asthmatic child in our outpatient population, although a PP of up to 7 mm has been reported in normal children. An important finding was the relationship of PP to Pco₂. Since the Pco₂ was variable, no clearcut correlation was found between a particular PP and the Pco₂. However, when the PP was examined in cases with the Pco₂ elevated above 40 mm Hg, the mean value was 22.2 mm Hg compared to 12.2 mm Hg in cases with the Pco₂ not elevated (< 40 mm Hg). Furthermore, in the absence of PP, the incidence of elevated Pco₂ (> 40 mm Hg) was 6.3% (one in 16 observations). This suggests that the presence of an elevated Pco₂ should be strongly considered when the patient demonstrates a PP, particularly when the PP exceeds 20 mm Hg. Knowles and Clark found the difference in mean Pco₂ in cases with a PP less than 10 mm Hg and the mean for those above 10 mm Hg to be significant.

No clear relationship was seen between the PP and the F'Io₂/arterialized capillary Po₂ ratio. Because of difficulties in obtaining repeated arterial punctures in children, we used arterialized capillary blood for our specimens. However, when collected from an acutely ill child with poor peripheral cutaneous circulation by heating an extremity, this kind of specimen may not reflect peripheral cutaneous circulation by heating an arterial punctures in children, we used arterial blood for our specimens. However, when collected from an acutely ill child with poor peripheral cutaneous circulation by heating an extremity, this kind of specimen may not reflect the arterial Po₂ accurately. The utilization of an F'Io₂/arterialized capillary Po₂ ratio was arbitrary. We felt this would be more meaningful than using the Po₂ alone, since this does not consider the effect of the F'Io₂. Other investigators have also noted a poor correlation between the PP and Po₂. This is understandable since a patient might have the same Po₂ while working hard to ventilate during marked airway obstruction as he would several days later when the obstruction had lessened and he was breathing with much less effort. In the patient with status asthmaticus, a pattern emerges as response to therapy begins. A decrease in PP is associated with improvement in the clinical findings of asthma and the PEFR (Fig. 4). A trend toward greater response to bronchodilators was observed as the PP fell below 20 mm Hg. When the patients were discharged from the intensive care unit at 48 hours, the PP approached 0, and this was associated with a clinical score no higher than 3 in any case and a PEFR approaching 50% of predicted normal. The Pco₂ at this point was less than 40 mm Hg, and the Po₂ was approximately 60 mm Hg in room air (i.e., F'Io₂/arterialized capillary Po₂ ratio of 0.33). The PEFR and the Po₂ may take several days to return to the predicted normal value. Rebuck and Read found that the FEV₁ and the Po₂ may require one week or more to return to normal.

**IMPLICATIONS**

The presence of a PP in the asthmatic child signifies more severe airway obstruction than when it is absent. Those with a PP greater than 20 mm Hg have severe airway obstruction as assessed by clinical and laboratory parameters. The technique for utilizing PP as an indication of the severity of status asthmaticus can be learned easily by physicians and nurses. It should be included in monitoring the vital signs of the patient with status asthmaticus and is a particularly valuable tool in treating the young child who cannot cooperate with pulmonary function testing. When used in conjunction with a careful physical examination and blood gas determinations, the PP technique is a helpful clinical adjunct in evaluating the asthmatic pediatric patient with acute bronchial obstruction.

**REFERENCES**


**ACKNOWLEDGMENT**

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