Comparison of Traditional and Plethysmographic Methods for Measuring Pulsus Paradoxus

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Background: In the evaluation of patients with acute asthma, pulsus paradoxus (PP) is an objective and noninvasive indicator of the severity of airway obstruction. However, in children PP may be difficult or impossible to measure. Indwelling arterial catheters facilitate the measurement of PP, but they are invasive and generally reserved for critically ill patients.

Objective: To determine the utility of the plethysmographic waveform (PPpleth) of the pulse oximeter in measuring PP.

Methods: Patients from the pediatric intensive care unit, emergency department, and inpatient wards of a tertiary care pediatric hospital were eligible for the study. A total of 36 patients (mean age [SD], 11.2 [4.7] years) were enrolled in the study. Pulsus paradoxus was measured using the traditional auscultatory (PPausc) method with a sphygmomanometer. Pulsus paradoxus was then measured using a blood pressure cuff observing for the disappearance and reappearance of the PPpleth on the pulse oximeter. Mean difference and 95% confidence intervals were calculated for each method. The 2 methods were also analyzed for correlation and agreement using the Pearson product moment correlation and a Bland and Altman plot.

Results: Patients with status asthmaticus had higher PPausc and PPpleth readings compared with nonasthmatic patients. Pulsus paradoxus measured by plethysmography in patients with and without asthma was similar to PPausc readings (mean difference, 0.6 mm Hg; 95% confidence interval, −0.6 to 2.1 mm Hg). Individual PPpleth readings showed significant correlation and agreement with PPausc readings in patients both with and without asthma.

Conclusion: Measurement of PP using the pulse oximeter–pulse plethysmographic waveform offers a simple and noninvasive method for evaluating patients with airway obstruction.


Despite advances in the treatment and prevention of asthma, it remains one of the most common reasons for hospitalization in the pediatric age group. Periodic assessment of the severity of airway obstruction is an integral part of the management of status asthmaticus. However, there are limitations to the various subjective and objective factors that are routinely used for assessment. There is a wide variation in how patients perceive and describe their symptoms. The symptoms of an attack such as cough, difficulty breathing, and wheezing frequently do not correlate with severity. In addition, there is a significant interobserver variability among physicians in evaluating physical signs such as the extent of wheezing and magnitude of respiratory distress. Some helpful tools in evaluating the severity of asthma are pulse oximetry, blood gas sampling, and bedside spirometry. However, a decrease in oxygen saturation may occur with only very mild airway obstruction or, conversely, may not occur at all even with severe airway obstruction. In addition, hypoxemia may be masked by administration of small amounts of supplemental oxygen, such as with aerosol treatments. Spirometry, such as peak expiratory flow rate, can be useful as an indicator of airway obstruction and as a measure of decreased pulmonary function from baseline in asthmatic individuals who use them regularly. Despite this, the utility of the peak expiratory flow rate is limited in a child with severe respiratory distress. Measurement of the partial pressure of arterial carbon dioxide (PaCO₂) is a useful tool in evaluating alveolar ventilation. In mild and moderate asthma the PaCO₂ is usually low. “Normalization” or significant elevations in PaCO₂ are encountered only when air-
way obstruction is severe enough to result in overall alveolar hypoventilation. In addition, measurement of PaCO₂ requires blood sampling.

Pulsus paradoxus (PP) reflects an exaggeration of the normal decrease in systolic blood pressure (SBP) during inspiration and is a quantifiable indicator of airway obstruction. It has been shown to correlate well with other objective indicators of airway obstruction such as PaCO₂ and peak expiratory flow rate (PEFR) however, it is noninvasive and does not require cooperation with pulmonary function tests. Pulsus paradoxus may be a useful adjunct in assessing the severity of airway obstruction at a given time, as well as documenting response to therapy, especially in situations in which more invasive tests are not readily available, such as an office setting. Timing of PP measurement to inspiration and expiration can be difficult in asthmatic children who are tachypneic, tachycardic, and likely to be uncooperative. Therefore, instead of attempting to correlate SBP with phases of respiration, measurement of PP using variations in SBP has been proposed in children. Nevertheless, such a measurement is cumbersome and subject to considerable interrater and intrarater variability as well as observer bias. Improvements in the method of determining PP may allow it to be a more useful tool in evaluating airway obstruction.

Newer pulse oximeters are equipped with a visual display of the pulse plethysmographic waveform (PPpleth). We proposed that the PPpleth of the pulse oximeter would be an acceptable substitute for Korotkoff sounds for the measurement of PP. Our hypothesis was PP measured by the pulse oximeter PPpleth would be greater in asthmatic children compared with nonasthmatic children. Furthermore, PP measured using the pulse oximeter plethysmograph would have good agreement with the value obtained by the traditional method of auscultation of Korotkoff sounds.

### METHODS

Thirty-six patients from the pediatric intensive care unit, emergency department, and inpatient wards of the Children’s Hospital of Michigan, Detroit, were enrolled over a 4-month period. Both asthmatic and nonasthmatic patients were evaluated. All asthmatic patients were at the time of evaluation diagnosed as having status asthmaticus, which was defined as the period. Both asthmatic and nonasthmatic patients were evaluated.

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The PP was significantly higher in the asthmatic group compared with the nonasthmatic group when measured by either auscultation or plethysmography (Table 2). When PPpleth readings were compared with PPpause readings, no statistically significant difference was found (Table 2).

Pearson product moment correlation was used to determine the correlation between the values for PP determined by the 2 methods (Figure 1). The PP pause and the PPpleth method showed significant correlation among both asthmatic patients ($r^2=0.76$, $P<.01$) and nonasth-
Pulsus paradoxus is a phasic variation in SBP with the lowest pressure occurring during Pin and the highest during Pex. The physiologic mechanisms for this are thought to be related to changes in left ventricular stroke volume and afterload during the respiratory cycle. The reduction in pleural pressure causes a decrease in intrathoracic pressure, and increases the pressure gradient from the systemic venous reservoir to the right ventricle. This increases venous return to the right ventricle. Since there is no increase in the gradient from the pulmonary veins to the left ventricle, a concurrent increase in left ventricular filling does not occur. Therefore, the interventricular septum at end-diastole is displaced to the left, and left ventricular end-diastolic volume decreases, with a resultant drop in left ventricular stroke volume. In addition, an increase in negative intrathoracic pressure increases the pressure gradient against which the left ventricle has to pump (left ventricular afterload), which decreases left ventricular stroke volume. As left ventricular stroke volume falls during Pin, SBP decreases. During Pex, these physiologic changes are reversed, resulting in an increase in preload and a decrease in afterload of the left ventricle, leading to an increase in stroke volume and an increase in the SBP. With airway obstruction, such as that seen in asthma, these changes are magnified, resulting in a greater drop in SBP during Pin and an increase in PP. The magnitude of PP has been shown by Galant et al. to correlate with other objective indicators of airway obstruction, such as an increase in PaCO₂, and a decrease in forced expiratory volume in the first second and peak expiratory flow rate in asthmatic children.

Because PP provides an objective measure of airway obstruction, the National Heart, Lung, and Blood Institute has recommended its measurement as one estimate of the severity of an asthma exacerbation. The recommendations of the National Heart, Lung, and Blood Institute for management of an acute asthma exacerbation are based on severity, so PP provides an objective measure to guide treatment. The National Heart, Lung, and Blood Institute recommendations for measuring PP are based on the mean of the differences between auscultated and plethysmographic measurements, with 95% confidence intervals, taking into account the correlation between the methods.
the difference in systolic blood pressure between the pressure at which an observer first hears sporadic, faint pulse sounds and the pressure at which he or she hears all sounds. No attempt should be made to correlate pulsus paradoxus with the phase of respiration in small children.\(^{(10,16)}\)

Despite this, relative tachypnea, tachycardia, small size, and inability of children to remain still make the measurement of PP difficult or impossible. Indeed, it was necessary to exclude 5 patients from our study because of an inability to determine PP\(_{\text{ausc}}\). The use of indwelling arterial catheters has made the measurement of PP easier, but their use is invasive and not without risk, and is generally reserved for critically ill patients.

Newer pulse oximeters are equipped with a visual display of the (PP\(_{\text{pleth}}\)). The generation of the PP\(_{\text{pleth}}\) is based on the fact that the pulsatile absorbance between the light source and the detector of the pulse oximeter probe is from arterial blood. A PP\(_{\text{pleth}}\) is generated by separating the pulsatile component of the absorption from the nonpulsatile component. The nonpulsatile component represents absorption from the tissue bed, including the venous, capillary, and nonpulsatile arterial blood. The amount of “pulse-added” absorption is calculated by the pulse oximeter and a PP\(_{\text{pleth}}\) is generated that corresponds to pulsatile flow through the tissue.\(^{(10)}\) To our knowledge, the use of measuring PP using the pulse oximeter PP\(_{\text{pleth}}\) has not been examined.

Potential pitfalls in the method used here are that a single observer (J.A.C.) obtained all data, and PP readings were not taken randomly. Both of these issues introduce the possibility of observer bias. Because PP is present under normal conditions, our design was meant to demonstrate the utility of using the pulse oximeter to measure PP. However, most patients included in this study had mild asthma, and it is possible that agreement between the PP\(_{\text{ausc}}\) and PP\(_{\text{pleth}}\) methods may yield results that do not agree when PP is further exaggerated. Additional study into this is warranted, possibly including comparison to PP measured by intra-arterial pressure monitoring.

Our data show that the PP\(_{\text{pleth}}\) of the pulse oximeter can be used to measure PP. This may be helpful in situations in which auscultation is difficult, such as a noisy emergency department, or with a crying child. Because PP can be useful in quantifying the severity of an asthma exacerbation, such data may be helpful in directing therapy or determining the need for continued observation. Nevertheless, technical difficulties still exist. Although it may be easier to measure PP using a visual PP\(_{\text{pleth}}\), patient cooperation may still be necessary because movement artifact can result in inadequate pulse oximeter waveforms.\(^{(11,12)}\) Advances in pulse oximeter technology that help remove artifact from the waveform are being evaluated and may alleviate this problem.\(^{(11,12)}\) In addition, standardization of the PP\(_{\text{pleth}}\) to actual arterial pressures would simplify PP measurements further. This would make PP measurement similar to that of PP measurement based on the difference in heights of the P\(_{\text{ao}}\) and P\(_{\text{es}}\) SBP waveforms from indwelling arterial catheters but without the invasive arterial catheter placement. Unfortunately, this technology is not widely available. Until such time, we recommend the use of the PP\(_{\text{pleth}}\) for the measurement of PP when PP\(_{\text{ausc}}\) may be difficult to obtain.

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REFERENCES


What This Study Adds

Pulsus paradoxus has been shown to be one of the few noninvasive and objective indicators of airway obstruction. However, in children, PP can often be difficult or impossible to measure. Therefore, any technique that would facilitate its measurement would enhance our ability to objectively assess asthma severity in children.

It is apparent from the existing literature that the reappearance of the pulse oximeter PP\(_{\text{pleth}}\) during arm cuff deflation correlates with the return of pulsatile blood flow as measured from a radial artery catheter. It has not been demonstrated that the reappearance of the pulse oximeter PP\(_{\text{pleth}}\) can be used to measure PP. From our data, we believe that PP\(_{\text{pleth}}\) offers an easier yet accurate alternative to PP\(_{\text{ausc}}\).