

Brief Reports



PLETH VARIABILITY INDEX TO ASSESS COURSE OF ILLNESS IN CHILDREN WITH ASTHMA

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Abstract—Background: Status asthmaticus (SA) is a common reason for admission to the pediatric emergency department (ED). Assessing asthma severity efficiently in the ED can be challenging for clinicians. Adjunctive tools for the clinician have demonstrated inconsistent results. Studies have shown that pulsus paradoxus (PP) correlates with asthma severity. Pleth Variability Index (PVI) is a surrogate measure of PP. **Objective:** We investigated whether PVI at triage correlates with disposition from the ED. **Methods:** We recruited children aged 2–18 years old who presented to the pediatric ED of a tertiary care children's hospital with SA. PVI, Respiratory Severity Score, and vital signs were documented at triage and 2 hours into each patient's ED stay. PVI was measured using the Masimo Radical-7® monitor (Masimo Corp., Irvine, CA). **Results:** Thirty-eight patients were recruited. Twenty-seven patients were discharged home, 10 patients were admitted to the general pediatrics floor and 1 patient was admitted to the intensive care unit. PVI values at triage did not correlate with disposition from the ED ($p = 0.63$). Additionally, when trending the change in PVI after 2 hours of therapy in the ED, no statistically significant patterns were demonstrated. **Conclusions:** Our study did not demonstrate a correlation between PVI and clinical course for asthmatics. PVI may be more clinically relevant in sicker children. Furthermore, it is possible that continuous monitoring of PVI may demonstrate more unique trends in relation to asthma severity versus single values of

PVI. Additional studies are necessary to help clarify the relationship between PVI and the clinical course of children with SA. © 2018 Elsevier Inc. All rights reserved.

Keywords—asthma; pediatrics; pediatric emergency medicine; pediatric emergency department; PVI; pulsus paradoxus; triage; Pleth Variability Index; status asthmaticus; asthma exacerbation

INTRODUCTION

Asthma is the most common chronic condition of children in the United States and is responsible for 1.8 million visits to an emergency department (ED) annually (1). The disease burden of asthma on health care resources can be substantial during high-risk time periods and respiratory viral epidemics. An accurate, reliable method of stratifying relative acuity that reduces triage time and personnel resources can be helpful and effective.

Several studies have reported that severity of asthma exacerbations correlates with degree of pulsus paradoxus (PP) (2,3). PP is a decrease by >10 mm Hg in systolic blood pressure during inspiration and can be exacerbated in cases of pericardial effusion or obstructive pulmonary disease, among others. In obstructive pulmonary disease,

such as in status asthmaticus (SA), increased intrathoracic pressure due to hyperinflated lungs causes decreased left heart filling and a corresponding decrease in systolic blood pressure during inspiration. Increased PP correlates significantly with Respiratory Severity Score (RSS) and wheeze in obstructive disease, and PP > 15 mm Hg has been shown to correlate with a very severe asthma attack (2,4,5). Previous studies have also compared PP to forced expiratory volume (FEV), showing that decreased FEV correlates with worsened PP (6,7). However, FEV may be challenging to obtain with an uncooperative patient. Measuring PP, therefore, may be an alternative way of gauging severity of asthma exacerbations.

PP is traditionally measured via sphygmomanometry. However, in uncooperative children, it is challenging to coordinate blood pressure readings with the respiratory cycle, making this a difficult means of measuring PP in the pediatric population. Plethysmography, on the other hand, is more easily obtained in children and can be used as an alternative method for measuring PP. Variability in the amplitude of the pulse oximetry wave form has been shown to correlate with changes in pulse pressure that occur during the respiratory cycle (8). This metric has been termed *Pleth Variability Index* (PVI). Recent studies have shown that PVI is an accurate, noninvasive way of measuring PP via infrared signal (9). These studies have shown that a greater PVI is associated with a higher degree of PP. In general, a patient in normal respiratory status would have a PVI of 10–20, and someone with severe PP would have a PVI of 60–70.

Previously, our group showed significant differences in PVI in patients with different dispositions from our ED (10). In this study, PVI was calculated manually by the research team using printed pulse oximetry tracings. Patients discharged directly from the ED had a lower calculated PVI than those admitted directly to the hospital floor or pediatric intensive care unit (PICU). As manual calculations of PVI are not routinely feasible in a busy ED, we sought to examine whether similar findings would occur with an automated PVI monitor and whether this monitor would detect changes in PVI after treatment. Masimo Corporation (Irvine, CA) produces a commercial PVI monitor capable of measuring PVI automatically. Through an equipment loan from Masimo, we were able to study PVI in our patient population.

OBJECTIVE

We investigated whether automated measurements of PVI could accurately distinguish between patients with mild vs. severe asthma exacerbations and whether PVI at triage in asthmatic patients would correlate with their disposition from the ED. Our hypothesis was that patients

with higher automated PVI values would have an increased likelihood of being admitted to the hospital.

MATERIALS AND METHODS

We prospectively recruited patients through the triage center of a pediatric ED at a tertiary care children's hospital. Patients 2–18 years of age were identified with signs and symptoms of SA or reactive airway disease exacerbation and were then approached for inclusion in the study. Patients with respiratory distress secondary to diseases other than SA (such as bronchiolitis) were excluded. Patients were enrolled in the study from 9 AM to 5 PM on weekdays by a research assistant as part of a convenience sample method of recruitment. The Northwell Health Institutional Review Board approved the study protocol.

Study Protocol

After identification for inclusion in the study, verbal consent was obtained from parents or primary caregiver. Written consent was obtained after initial evaluation by clinical staff. Baseline vital signs, RSS, and PVI were all recorded at triage at the same time. RSS is currently used at our institution to stratify asthma severity; we chose to use RSS as a gold standard to compare to PVI because it was easier to obtain and less user-dependent than other measurements of severity, such as FEV. The parameters used to calculate the RSS at our institution, which is part of our asthma pathway, are listed in [Supplementary Figure 1](#).

Patients received bronchodilator treatments (either albuterol or a combination of albuterol and atrovent) and systemic corticosteroids (if they had an initial RSS in the moderate to severe range or if they required two or more albuterol treatments) as part of routine care. RSS and PVI were repeated and recorded 2 hours after initial assessment in triage. Due to limited equipment availability, PVI was not assessed after transfer from the ED to the inpatient floors. PVI was measured using the Masimo Radical-7[®] monitor, which has been approved by the U.S. Food and Drug Administration for the monitoring of cardiorespiratory parameters. PVI is calculated by the device automatically and is continuously displayed on the screen. All clinicians in the ED were blinded to the output of the monitors and PVI was not taken into consideration for any clinical decisions, including whether to admit the patient to the hospital or to discharge them directly from the ED.

Basic demographic information for these patients, such as age and sex, was also recorded. Patients were followed after initial presentation in the ED, either through phone calls if discharged home or via electronic medical records if admitted.

We excluded all patients under the age of 2 years, as the Masimo Radical-7[®] monitor has only been validated

for patients >10 kg, as well as to decrease any possible confounding effect of bronchiolitis on the data. Further, we surmised that patients younger than 2 years of age would have difficulty cooperating with wearing multiple pulse oximeters. We also excluded all patients older than the age of 18 years. Patients with diagnoses known to cause PP other than asthma (such as pericarditis) were also excluded.

In order to monitor the course of illness for recruited patients, charts were reviewed to determine the final disposition of these patients from the ED and whether there was a change in medical status within 24 hours of admission, such as a transfer to the PICU from the general pediatric inpatient unit. Families were also called to ensure these patients did not present at another hospital after being discharged from our ED. These patients were followed to ensure we were not mistakenly stratifying patients who may have had worse SA than on initial assessment and, therefore, may have had higher PVI at triage.

Data were de-identified and separated into the following groups: those that were discharged home, those admitted to the general pediatric inpatient unit, and those admitted to the PICU. Major outcomes measured were the correlation between PVI score and RSS, as well as the correlation between PVI score and the final disposition of the patient.

Study Analysis

Data were analyzed for each of the three groups: discharged home directly from the ED, admission to the hospital, and admission to the PICU. Medians were calculated for age and sex for each group. Medians were also calculated for PVI and RSS before and after treatment in each group. Significance for age and sex was calculated using a Fisher's exact test. PVI in both groups before and after treatment were compared using a Mann-Whitney test. We also analyzed correlations between PVI before and after treatment for each group using the Wilcoxon matched-pairs signed rank test.

RESULTS

Fifty-six patients were recruited for the study. Of these, 15 were excluded due to incomplete data collection, and 3 were excluded for admission to the hospital for reasons other than SA. The remaining 38 patients were then stratified into different groups based on their disposition from the ED. Twenty-seven were discharged home from the ED, 10 were admitted to the general hospital floors, and 1 was admitted to the PICU. Due to the small number admitted to the PICU, this group was excluded from final analysis. Patients were then divided into two groups: admitted and discharged home.

There were no significant differences in terms of age ($p = 0.74$) or sex ($p = 0.77$) between admitted and discharged patients (Table 1).

Additionally, there were no significant differences in PVI at triage between those discharged directly home from the ED and those admitted to the hospital for further treatment ($p = 0.86$) as seen in Figure 1. However, a significant difference in RSS at triage was noted ($p < 0.01$) (Figure 2). Similarly, there was no statistically significant difference in PVI after treatment between the two groups ($p = 0.18$), although RSS between the two groups continued to be statistically different ($p < 0.01$).

Furthermore, there were no statistically significant differences in PVI obtained before and after treatment, as demonstrated in Figure 3 ($p = 0.73$).

Three of the 38 patients had disposition changes within the next 24 hours. One patient initially discharged home presented to the ED again within 24 hours with similar symptoms and was discharged home again. Another patient initially admitted to the general pediatric inpatient unit required escalation of care to the PICU the day after admission. Finally, 1 patient presented to the ED and was initially discharged home but returned 12 h later and was admitted to the PICU.

For these patients, a higher PVI was not associated with presumed worsened PP. For the patient who was initially admitted to the floors, PVI at triage was 32, which is slightly elevated but not to the levels we would expect from someone with severe PP. PVI after treatment was 23. The second patient who re-presented to the ED later the same day after initial discharge home and was admitted to the PICU had a PVI of 18 at triage and a PVI of 27 after treatment.

DISCUSSION

Determining severity of SA can still be a difficult task for even the most experienced physicians, despite tools such

Table 1. Characteristics of Pediatric Patients Presenting With Status Asthmaticus to Pediatric Emergency Department and Categorized by Disposition (n = 38)

Characteristic	Home (n = 27)	Admitted (n = 11)	p Value
Median age, y	8	8	0.74*
Sex (% male)	66	63	0.77†
Median PVI at triage	27	29	0.86*
Median RSS at triage	4	7	<0.01*
Median PVI after treatment	26	25	0.18*
Median RSS after treatment	4	6	<0.01*

PVI = Pleth Variability Index; RSS = Respiratory Severity Score.

* Mann-Whitney test.

† Fisher's exact test.

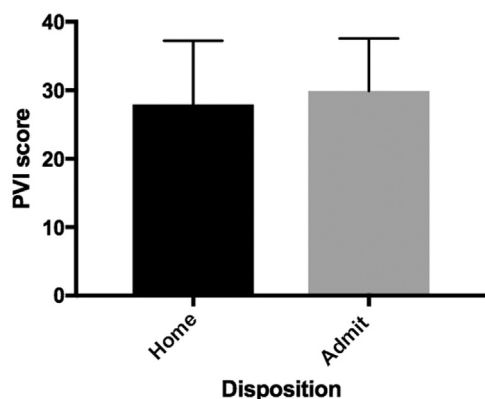


Figure 1. Comparison of Pleth Variability Index (PVI) scores at triage for patients directly discharged from the emergency department vs. those admitted to the hospital for further treatment. PVI scores were obtained at the time of presentation and were compared using a Mann-Whitney test, showing no statistically significant differences between the two groups.

as pulse oximetry and respiratory rate. Readmissions for worsening symptoms or escalation of care to the PICU from the hospital floor still occur, suggesting that additional tools for asthma assessment may be helpful in decreasing these events. With an objective, bedside tool for measurement of PVI and PP, clinicians may be able to more accurately triage children with SA and thereby assure proper allocation of resources.

In previous studies performed at our institution, we found evidence that PVI may be an accurate, rapid assessment tool for determining severity of asthma exacerbations in the ED (10). This was performed by manually calculating PVI from a pulse oximetry waveform. With

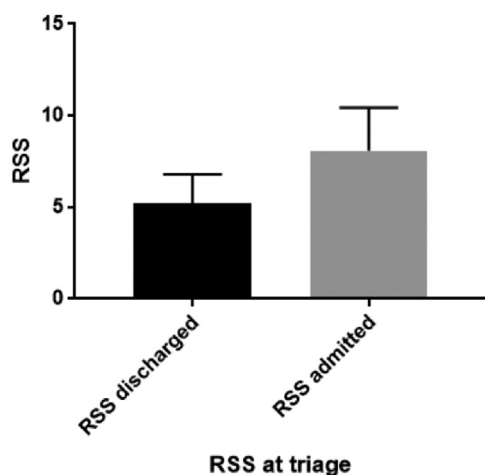


Figure 2. Comparison of Respiratory Severity Score (RSS) scores at triage for patients directly discharged from the emergency department vs. those admitted to the hospital for further treatment. Our institution currently uses RSS scores to determine asthma severity. We found a significant difference in RSS scores between the two groups.

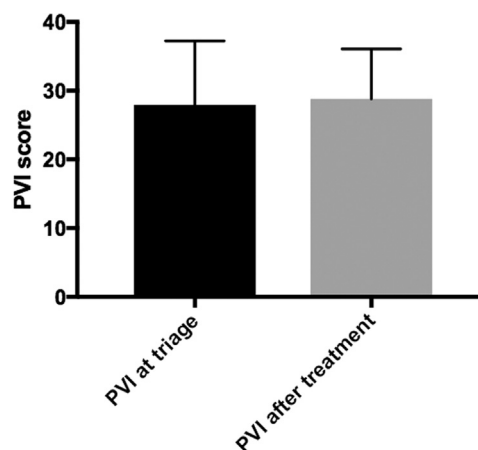


Figure 3. Comparison of Pleth Variability Index (PVI) scores before and after treatment for asthma. We compared PVI scores of recruited patients at triage and then after treatment. No significant differences were found.

an automated PVI monitor at our disposal, we hoped to determine whether a commercial PVI monitor would show similar results in accurately identifying patients with severe SA and to examine whether there were any changes in PVI after treatment.

However, we found no significant difference in PVI between those admitted to the hospital and those discharged directly from the ED, despite a significant difference in RSS scores between the two groups at triage. Additionally, patients who required escalation of care within 24 h of initial assessment in the ED did not have higher associated PVI at triage as we had expected. One patient who was later admitted to the PICU had an increased PVI after treatment. This may be due to increased asthma severity causing increased obstruction, leading to minimal air movement and decreased fluctuations in intrathoracic pressure that could be detected through PVI. After treatment with bronchodilators, however, they may begin to have air movement again and cause increased changes in intrathoracic pressure, which would then create more PP and could be detected as a higher PVI. This suggests that PVI measured intermittently at triage may not be helpful in determining asthma severity and therefore may not be a reliable tool for predicting patient disposition early in their stay if the monitor is not placed on the patient continuously during examination and treatment. PVI measured intermittently, as in this study, might also be less accurate if the monitor is placed on a moving child.

Limitations

Some of the limitations of our study include the fact that we recruited a convenience sample of patients during weekdays from the hours of 9 AM to 5 PM. As evening

hours are generally busier, this considerably reduced our sample size and may have decreased the severity of SA included in the study. Additionally, if a patient was not immediately identified as an asthmatic during triage, they may have been overlooked for study recruitment. Furthermore, incomplete data collection for some of our patients resulted in the exclusion of a number of patients from analysis.

Despite the negative findings in this study, PVI may still be an important adjunctive tool to triage children with severe SA. Higher PVI was shown to correlate with sicker patients in our previous study (10). This suggests that PVI may be more accurate in patients with worse SA and presumably greater degree of PP. Because the current study had a limited number of patients admitted to the PICU, it suggests that the overall population of patients were less ill than the previous study. Furthermore, this study may have been underpowered to detect statistically significant change due to the limited sample size recruited.

Several methods of assessment of patients with SA using algorithms similar to RSS have been shown to accurately determine patients in more severe distress (11). As RSS was already used in our institution to classify asthma severity, we believed that it would be an ideal comparison to PVI to measure accuracy. These algorithms, however, rely on clinical assessment of accessory muscle use, respiratory rate, and auscultation, among other symptoms, to determine asthma severity and may vary between different clinicians. Although clinical assessment of SA remains important and a mainstay of triaging acuity, an additional objective tool that does not rely on clinical judgment or patient effort and is more objective may be helpful. This tool may aid clinicians to more accurately triage patients requiring intensive support for SA, which may decrease redundant time spent assessing patients in a resource limited environment, such as the ED.

CONCLUSIONS

Plethysmography has been shown to be an accurate, noninvasive method of measuring PP and, therefore, asthma severity, which suggests that the role of PVI in triaging SA may still be useful and needs further elucidation (7,12).

More studies are needed to clarify the role of PVI, particularly measuring PVI continuously in patients presenting to the ED in SA, and in patients in SA severe

enough to be admitted to the PICU. If PVI can be shown to accurately correlate with illness severity it could assist clinicians in rapidly determining the disposition of these patients and in reducing readmissions and escalations of care.

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SUPPLEMENTARY DATA

Supplementary data associated with this article can be found in the online version at <https://doi.org/10.1016/j.jemermed.2018.04.058>.

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ARTICLE SUMMARY

1. Why is this topic important?

Asthma is one of the most common causes of hospitalization for children. It can be difficult for clinicians to determine which patient will have a more severe course when they initially present to the emergency department (ED). An adjunctive tool that would rapidly and accurately assess patients at triage would help clinicians determine an appropriate disposition for them. If effective, this tool can help expedite patient throughput in the ED, while assuring that patients are given an appropriate level of care for their severity of illness.

2. What does this study attempt to show?

This study attempts to show whether a monitor measuring Pleth Variability Index (PVI), which has been shown to correlate with more severe asthma exacerbations, will accurately predict a patient's disposition from the ED and thus aid in expediting the triage process.

3. What are the key findings?

Despite an earlier paper from our institution showing a positive correlation between PVI calculated from pulse oximetry tracings and disposition from the ED, we did not find any correlations in the current study when using a commercially available monitor capable of measuring PVI.

4. How is patient care impacted?

Appropriate triage of severely ill patients, as well as triaging of patients with mild asthma exacerbations, will greatly improve throughput through the ED. Furthermore, appropriate assignment of patient disposition can decrease the risk of adverse patient outcomes from inaccurate triaging.

(A)Respiratory Severity Score

	1 point	2 points	3 points
Respiratory Rate			
1 year old	40 or less	41-44	45 or greater
2-3 years old	34 or less	35-39	40 or greater
4-5 years old	30 or less	31-35	36 or greater
6-12 years old	26 or less	27-30	31 or greater
>12 years old	23 or less	24-27	28 or greater
Room air SpO2	96% or higher	90-95%	Less than 90%
Retractions	None or intercostal	Intercostal+sub sternal/subcos tal	Intercostal + substernal/subc ostal, + supraclavicular/ suprasternal
Auscultation	No wheezing/clear Mild end-expiratory wheezing Scattered exiratory wheezes	Expiratory wheezing	Inspiratory and expiratory wheezing Diminished breath sounds