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The use of Pleth Variability Index (PVI) for the assessment of patients with dehydration in the pediatric emergency department

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ABSTRACT

Objective: There is not a non-invasive, valid, and reliable criterion yet that can be used to determine the degree of dehydration and responsiveness to fluid treatment. In the literature, Pleth Variability Index (PVI) has been studied as one of the additional tools that can be used to determine the degree of dehydration. Studies on this topic have been conducted mainly on patients who are connected to mechanical ventilators. This study was conducted to assess the feasibility of PVI measurement in paediatric patients who breathe spontaneously, are dehydrated moderately and need fluid repletion.

Material and Methods: For this purpose, PVI, blood gas (pH, HCO3, lactate), and body weights of the patients were measured before and after fluid replacement. The delta (Δ) values were calculated by taking the difference between the values before and after fluid therapy, and the correlation was examined.

Results: After one hour of fluid treatment, weight, physical examination, blood gas (bicarbonate, lactate, pH) values improved significantly compared to pre-fluid levels, and high PVI values were found to decrease significantly. However, no significant correlation was found between PVI change (ΔPVI) and other variables (Δ kilo, pH, lactate, bicarbonate), which are used to determine the degree of dehydration.

Conclusion: According to the findings of our study, PVI alone does not provide adequate and reliable data in children who are dehydrated moderately and breathe spontaneously.

Keywords: Pediatric, Dehydration, Pleth Variability Index

INTRODUCTION

Gastroenteritis is still the second most common cause of child death today. According to statistics, it causes approximately 1.5-2 million deaths annually in children under the age of five worldwide. In countries with limited resources, infants experience an average of six episodes, and children experience an average of three episodes per year (1, 2). In addition to preventive approaches to preventing diarrhea, it is essential to accurately determine the dehydration levels of patients and administer appropriate fluid treatment. Otherwise, fluid loss due to diarrhea and vomiting compromises tissue and organ perfusion by reducing the adequate circulatory volume. If severe hypovolemia is not corrected in time, it will lead to ischemic end-organ damage that results in serious morbidity and mortality (3).

Weight loss is the most objective finding used to detect fluid loss in children with gastroenteritis. However, because pre-disease weight information cannot be obtained most of the time, a set of physical examination findings as well as the clinical history are used to help assess the severity of hypovolemia (4). Accordingly, dehydration of the patient is classified into three degrees as mild (3-5% fluid loss), moderate (6-9% fluid loss), and severe (10% or more fluid loss). This rating guides the treatment of the patient.

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In mildly dehydrated children, serum electrolytes are usually normal, and the acid-base balance is unimpaired. Metabolic acidosis and electrolyte imbalances often occur in moderately to severely dehydrated patients who need intravenous fluid treatment. Serum bicarbonate is the most useful laboratory test to assess the degree of dehydration in children. It is below 17 mEq/L in moderately and severely dehydrated children (3, 4).

The clinical findings used to determine the degree of dehydration and responsiveness to fluid treatment are subjective and are influenced by physician experience. There is not yet a criterion that will allow non-invasive, practical, and objective diagnosis and treatment follow-up in children, especially in moderately and severely dehydrated patients. In the literature, Pleth Variability Index (PVI) has been studied as one of the additional tools that can be used for this purpose. Unlike other invasive dynamic indexes, PVI provides clinicians with a non-invasive, automated, and continuous quantitative value. Based on respiratory variations in arterial pulse pressure, PVI (Masimo Corp., Irvine, CA, USA) focuses on the non-invasive measurement of fluid responsiveness. It calculates ventilation-induced respiratory changes in the maximum and minimum perfusion index (PI) over a certain period (5). PVI is calculated on the basis of PI. The PI value is generated by the pulse oximeter and the absorption scale of red and infrared light. The pulsatile fraction (AC, caused by blood flow) and a non-pulsatile fraction (DC, affected by skin and other tissues) of red and infrared light are summarized by the following formula: PI = (AC/DC) × 100(%). PVI reflects measurements of ventilation-induced respiratory changes in PI over a fixed period of time and is calculated as follows: PVI = [(PI max - PI min)/PI max] × 100(%). The most common measurement area is the finger due to its simple operation. It has been shown that PVI is affected by many PI-related factors and that the accuracy of PVI in predicting fluid responsiveness decreases at lower PI values. Peripheral vasoconstriction caused by vasoactive drugs, hypothermia, or the surgical stress response may reduce the safety of PVI. These may limit the use of PVI to guide fluid treatment during dynamic intraoperative conditions. Therefore, when PVI is used to predict fluid responsiveness, it should be evaluated whether there are factors affecting peripheral perfusions, such as vascular disease, hypothermia, low CO2, surgical stress response, and drug-induced vasoconstriction (6). PVI can be used to determine a patient's volume status non-invasively, and it is based on volume, not pressure. Therefore, the use of PVI to predict fluid responsiveness in pediatric patients is theoretically possible, but more data are needed to support this claim (7).

In the literature, studies on PVI are mostly related to the evaluation of fluid responsiveness in patients receiving mechanical ventilation. Studies on neonatal, premature, and adult patients are available. PVI was mostly found successful in demonstrating fluid responsiveness in these patients. We aimed to determine the feasibility of PVI measurement in pediatric patients who breathed spontaneously and were dehydrated moderately and who needed fluid replacement. According to our literature review, our study is the first study conducted in this sample group.

MATERIAL and METHODS

This study was conducted to determine the extent to which PVI values could be used to determine the level of dehydration and fluid responsiveness in pediatric patients who breathed spontaneously and were dehydrated moderately and needed fluid therapy. For this purpose, patients who were accepted as moderately dehydrated by a pediatric emergency specialist in the pediatric emergency department made up the population of the study.

The study group consisted of patients who presented to the Şanlıurfa Training and Research Hospital, Pediatric Emergency Department, with diarrhea and vomiting complaints between June and August 2017.

Patients who were found to have dehydration due to acute gastroenteritis in their initial examination by the physician, who could not receive oral fluid treatment, who were planned to have intravenous line access, and whose tests were requested were evaluated by a pediatric emergency specialist.

Age, gender, and day and number of diarrhea were questioned. Vascular access was opened for patients who were considered moderately dehydrated according to the World Health Organization (WHO) Dehydration Scale. Blood gas, hemogram, and biochemistry (glucose, urea, creatine, sodium, potassium, calcium, chlorine, AST, ALT), and C-reactive protein tests were sent. Weight was measured when the patient first presented to the emergency service. Heart rate, respiratory rate, capillary refill time, and fever were monitored. As a result, a total of 56 patients whose initial blood gas values were pH<7.35 and HCO3<17 were included in the study.

Exclusion criteria: Patients who had comorbidities, chronic diarrhea, and fever above 38 degrees were excluded from the study.

Initial PVI (Radical-7 pulse co-oximeter, Masimo®, Irvine, CA, USA) values of all patients included in the study were measured for 5 minutes in a quiet environment, accompanied by their parents. Afterward, 20 cc/kg/hour saline infusion was started. PVI values of the patients were monitored for one hour. After the fluid treatment, PVI, weight, Heart rate, respiratory rate, capillary refill time, body temperature, and blood gas measurements were repeated. The patients were followed up as inpatients.

A paired-samples t-test was employed to compare the pre-and post-replacement values. The Pearson Correlation test was used for the relationship between the change in PVI (Δ PVI) and changes in blood gas values (ΔHCO3, Δ pH, Δ lactate) and weight change. The significance value was accepted as $p<0.05$ with 95% CI and a 5% margin of error. Analyses were conducted on the IBM SPSS Statistics 24 software package.

RESULTS

Data from a total of 56 patients were analyzed in the study. All patients were evaluated as moderately dehydrated according to the WHO dehydration scale and were administered fluid treatment. The characteristics of the patients at the first presentation are given in Table 1. Thirty-one of the patients were male, the mean age was 10.4 months, and the mean weight was 7.9 kg.

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All of our patients had diarrhea for at least two days, at least three times a day. The complaint of diarrhea was accompanied by vomiting at least once a day.

It was observed that all physical examination and laboratory parameters improved statistically significantly after the fluid treatment (Table 2). The mean initial PVI value of the patients was 32.5 (15-69) before the fluid treatment and 17.9 (6-49) after the fluid therapy. The decrease in these values was found to be statistically significant (p=0.0001).

Blood gas and weight values were re-measured after the fluid treatment, and delta values were calculated for each parameter (after-before= Δ). The relationship between Δ values of weight and blood gas parameters and ΔPVI values was examined by using Pearson correlation analysis (Table 3). There was no significant correlation between ΔPVI values and others (p<0.05).

Children with high creatinine values had higher PVI values before the fluid treatment (37.9±12.8) than those with normal creatinine values (30.2±7.8) (Mann Whitney-U test, p:0.017). Similarly, those with high creatinine levels (19.1±7.2) had a significantly higher Δ PVI than those with normal levels of creatinine (12.6±9.1) (Mann Whitney-U test, p:0.015). Similar analyses for PVI values were also conducted for patients with high urea values and those with normal levels, and no significant difference was found (Mann Whitney-U test, p>0.05).

All of the patients were followed up as inpatients, and the average length of stay was found to be 4.05 (2-7 days). In stool examinations conducted during hospitalization, 48% (n=27) of the cases were found to be rotavirus positive and 1.78% (n=1) adenovirus positive.

Table 1: Characteristics of the patients (n=56)

Variable	
Male : female , n	31:25
Age, months	10.4 (1-36)
Weight, kg	7.9 (3.8–15.7)
HR, beats/min	144 (105–198)
Respiratory rate, beats/min	33 (25–45)
Capillary refill time, sec	2 (1–4)
Diarrhea, n/day	9.8 (5-14)
Diarrhea, day	3.5 (2-8)
Vomiting, n/day	7.6 (3-12)
Vomiting, day	2 (1-9)
Hb (gr/dl)	11.2 (7.7-17.0)
Htc (%)	34.9 (24-47)
WBC (K/uL)	12.6 (4.7-26.4)
Plt (K/uL)	462 (160-1121)
Glucose (mg/dl)	86.5 (43.5-160)
Urea (mg/dl)	36.8 (3.7-153)
Creatinine (mg/dl)	0.41 (0.16-1.49)
Na (mmol/L)	139 (125-159)
K (mmol/L)	4.4 (3-6)
Cl (mmol/L)	107 (90-132)
Ca (mg/dl)	9.5 (8.5-10.4)
ALT (U/L)	31.6 (10-89)
AST (U/L)	44 (24-87)
CRP (mg/ml)	5.3 (0.1-46)

Table 2. Baseline and changes in PVI and other variables (n=56)

Variables	Before fluid treatment	After fluid treatment	*p** value
Weight, kg	7.9(3.8–15.7)	8.2 (3.9–15.9)	0.0001
HR, beats/min	143 (105–198)	126 (90–165)	0.0001
Respiratory, n/min	33 (25-45)	27 (21-38)	0.0001
Capillary refill time, sec	2 (1–4)	1.7 (1-3)	0.0001
pH	7.22 (7.06-7.33)	7.28 (7.11-7.38)	0.0001
HCO3	11.6 (6.2-14.8)	13.8 (8.6-19.4)	0.0001
Lactate	2.2 (0.8-6.5)	1.7 (0.8-2.9)	0.003
PVI	32.5 (15-69)	17.9 (6–49)	0.0001

PVI=plethysmographic variability index, HR=heart rate *Paired-sample t-test

Table3. The relationship between the change in weight and blood gas parameters and the change in PVI

	Δ PVI		Δ kilo		Δ pH		Δ HCO3	
	r	p	r	p	r	p	r	p
Δ PVI								
Δ kilo	0.115	0.400						
Δ pH	0.253	0.060						
Δ HCO3	0.082	0.547	-0.085	0.535	0.246	0.067		
Δ Lactate	0.011	0.933	-0.116	0.395	0.462*	0.0001	-0.406*	0.002

Pearson correlation test

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DISCUSSION

In the study, we evaluated the feasibility of PVI for the assessment of the degree of dehydration and fluid responsiveness in children who were considered moderately dehydrated according to physical examination findings. After the analysis, it was observed that weight, physical examination, blood gas parameters (bicarbonate, lactate, pH) improved significantly after one hour of fluid treatment and that PVI values, which were measured as high previously, decreased significantly. However, no significant correlation was found between the change in PVI (ΔPVI) and other variables (Δ weight, pH, lactate, bicarbonate). As a result, PVI alone does not provide adequate and reliable data in spontaneously breathing, moderately dehydrated children.

In their review, Chu et al. evaluated 18 published studies investigating the use of PVI in the evaluation of fluid responsiveness in the operating room and intensive care unit. In this review, a total of 665 fluid replacements, including 124 children (97 non-cardiac surgery, 27 congenital cardiac surgery patients, OR) the rest of adults, were examined. When the results of this study were evaluated, PVI measurement was found to have a high value in predicting fluid responsiveness based on 77% (95% CI 68-78) sensitivity and 82% (95% CI 77-86) specificity in patients receiving mechanical ventilation and having no arrhythmia. Spontaneous respiratory activity, arrhythmia, and decreased peripheral perfusion were found to be limiting factors for the use of PVI. The most important limitation of this study is the evaluation of patients receiving mechanical ventilation only (6). Broch et al. showed that PVI was affected by most factors affecting PI, and the sensitivity of PVI in demonstrating fluid responsiveness decreased in the presence of low PI (8).

In the literature, few studies have investigated the capacity of PVI to predict responsiveness to fluid treatment in the pediatric population. In addition, the results are highly conflicting. These studies were conducted primarily on patients under anesthesia connected to MV in the operating room and the intensive care unit (9). In the meta-analysis study conducted to examine four studies and 187 fluid bolus results by Desgrandes et al., sensitivity was 72% (95% CI 62-81), specificity was 81% (95% CI 71-88), and diagnostic odds ratio was 14% (95% CI 7-31). This meta-analysis suggested that PVI might be reliable in predicting fluid responsiveness in children connected to MV in operating room conditions. The low number of studies and the low number of participants included in the evaluation and heterogeneity between studies in terms of sensitivity suggest that additional studies are needed before a routine assessment can be recommended (9).

In the light of these studies, although the results of pediatric studies are more contradictory, PVI seems to be a parameter that can be used in the evaluation of fluid responsiveness in patients receiving MV in the operating room and intensive care conditions. Since spontaneous respiratory activity and low perfusion are the two most important parameters affecting the accuracy of PVI measurement, the number of studies on patients breathing spontaneously is very limited. Invasive interventions in children are complicated, and not all centers have the necessary equipment and experienced staff to do this in developing countries.

Therefore, non-invasive measurements that can be used in the diagnosis and treatment phase are essential in physicians' diagnosis and treatment decisions. As far as we know, our study is the first study conducted on patients with spontaneous breathing, impaired perfusion due to fluid loss, and metabolic acidosis. We aimed to find an easy-to-use, objective criterion for the quick evaluation of diarrhoea and related dehydration cases, which are very common in our country, and application of the right amount of fluid treatment.

There are very few studies in the literature on the determination of PVI reference values in spontaneously breathing pediatric patients or the evaluation of responsiveness to fluid treatment. In their study in which the normal PVI measurements of 242 term, healthy, and spontaneously breathing newborns were done on the 1st day, Latini et al. found 10th percentile cutoff as 12% (95% CI 11-12), 90th percentile as 28% (95%CI 27-29), and 97.5th percentile as 35%(95%CI 34-38). While PVI was positively correlated with PI and pulse rate values, it was negatively correlated with oxygen saturation. It was determined that PVI values were significantly affected by the behavioural status of the newborn, and high PVI values were recorded in the case of crying and agitation. In conclusion, PVI was evaluated as a promising non-invasive procedure for the early detection of cardiorespiratory changes in the early postnatal period. Similarly, Den Boogert et al. (11) found the diagnostic value of PVI to be low in spontaneously breathing premature infants in their study, in which they evaluated the feasibility of PVI in monitoring peripheral perfusion in premature infants aged under 32 weeks. To reduce the respiratory activity change that increases with crying and agitation, PVI measurements of all our patients were made in a quiet and not too bright room, accompanied by parents, while the children were calm. The mean initial PVI value of our patients was 32.5 (15-69) before the fluid treatment and 17.9 (6-49) after the fluid therapy. The decrease in these values was found to be statistically significant (p=0001). However, no correlation was found between other markers of dehydration (weight, pH, Hco3, lactate). A cutoff value could not be used because normal values of PVI were not studied in the spontaneously breathing patient outside the neonatal period.

In their study on the evaluation of the prediction of PVI values on the course of the disease in 1-18-year-old patients with asthma who presented to the pediatric emergency department, Brandwein et al. (12) determined a significant difference between the median PVI values of patients who were discharged from the emergency department, admitted to the pediatric service and admitted to the pediatric intensive care unit. It was stated that PVI could be used together with physical examination and pulse oximetry, and it could strengthen physicians' medical decisions. In this study, PVI measurement was done manually by using plethysmographic wave tracing.

Similarly, in another study that was conducted to determine the severity and course of the disease in patients with asthma and compared respiratory severity score and PVI values, no correlation was found between PVI and clinical practice. The low number of patients who were seriously ill and hospitalized in the intensive care unit was reported as a limitation in this study.

It was suggested that continuous PVI monitoring was more valuable compared to a single measurement and that PVI measurement was more valuable in the presence of severe disease. In our study, children with high creatinine values had higher PVI values before fluid treatment (37.9±12.8) than those with normal creatinine values (30.2±7.8) (Mann-Whitney-U test, p:0.017). Similarly, those with high creatinine values (19.1±7.2) had a significantly higher Δ PVI than those with normal (12.6±9.1) values. Based on these results, it can be thought that the use of PVI may be more valuable as the severity of the disease increases.

The most important limitation of our study is the absence of a gold standard to compare with PVI. The pre-disease body weight measurement is still the most frequently used gold standard for grading dehydration. Unfortunately, in developing countries, parents do not know the current weight of their children.

CONCLUSION

In conclusion, according to the results of our literature review, this is the first study to evaluate the feasibility of PVI in the spontaneously breathing and dehydrated patient group. In this patient group, PVI values alone seem inadequate to predict the degree of dehydration and fluid responsiveness. However, when used together with physical examination and laboratory findings, it may shorten the time for the physician to make a diagnosis and decide on treatment. According to our experience, the use of PVI measurement during the triage phase may allow the patient to start fluid therapy more quickly.

In addition to studies on normal PVI values in spontaneously breathing patients out of neonatal period, it is necessary to conduct investigations involving more patients with moderate to severe dehydration to determine the degree of dehydration and assess fluid responsiveness.

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Ethical approval: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by Local Ethical Committee.

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