Observational Study

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Usefulness of end-tidal carbon dioxide as an indicator of dehydration in pediatric emergency departments

A retrospective observational study

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Abstract

Physician assessment of hydration status is one of the most important factors in the management of dehydration in the pediatric emergency department (ED). Overestimating dehydration may lead to overtreatment with intravenous fluids or unnecessary hospitalization, whereas underestimation may lead to delayed therapy and aggravation of symptoms. Various methods to estimate hydration status have been proposed, including use of physical findings, body weight, and laboratory results. These methods are subjective, invasive, or inappropriate for application in the ED. A few studies have investigated the use of end-tidal carbon dioxide ($ETCO_2$) as an acidosis parameter in cases of gastroenteritis and diabetic ketoacidosis. We aimed to evaluate the usefulness of $ETCO_2$ as an objective and noninvasive dehydration parameter for children.

A retrospective observational study was conducted in the regional emergency center of a tertiary university hospital for a period of 1 year. We included patients from the ED whose primary diagnosis was acute gastroenteritis. Among these, we enrolled patients with recorded $ETCO_2$ and bicarbonate concentration (HCO_3^-) levels. We collected information of clinical characteristics, vital signs, clinical dehydration scale (CDS) scores, laboratory test results, and final disposition. Correlations between $ETCO_2$ and HCO_3^- as well as CDS scores were analyzed.

A total of 105 children were finally enrolled in the study. All participants underwent laboratory testing and were mildly to severely dehydrated, with mean serum HCO_3^- 20.7 ± 3.5 mmol/L. A total 95 (90.5%) patients had a CDS score <5, which is considered mild dehydration, and 10 (9.5%) patients had CDS ≥5, considered moderate-to-severe dehydration. The mean $ETCO_2$ level was 32.1 ± 6.1 mmHg. Pearson correlation indicated a weak link between $ETCO_2$ and HCO_3^- (correlation coefficient = 0.32), despite being statistically significant ($P = .001$). In addition, $ETCO_2$ and CDS score showed a weak negative correlation ($r = -0.20$, $P < .05$).

$ETCO_2$ can be considered a simple, noninvasive parameter for identifying dehydration among patients in the pediatric ED. Though weak, $ETCO_2$ showed a correlation with HCO_3^- level as well as CDS. In the future, a prospective study with a large number of pediatric patients is warranted.

Abbreviations: AGE = acute gastroenteritis, CDS = clinical dehydration scale, DKA = diabetic ketoacidosis, ED = emergency department, $ETCO_2$ = end-tidal carbon dioxide, HCO_3^- = bicarbonate concentration, IV = intravenous, ORT = oral rehydration therapy.

Keywords: capnography, dehydration, end-tidal carbon dioxide, pediatrics

1. Introduction

Dehydration in children can result from a variety of causes. Because treatment is determined based on the severity of the condition, accurate initial assessment is important. Oral rehydration therapy (ORT) is the preferred treatment for children who exhibit symptoms of mild-to-moderate dehydration, whereas intravenous (IV) fluid is administered to those suspected of severe dehydration.[1–4] ORT is a simple, noninvasive dehydration treatment that can reduce the duration of hospital stay and prevent unnecessary deployment of medical resources. Unfortunately, failure to accurately assess the degree of dehydration in children often leads to the administration of invasive IV therapy.[5–7] For this reason, various dehydration indicators have been proposed, which are designed to help make an accurate initial assessment. The Clinical Dehydration Scale (CDS) is a simple, noninvasive indicator used to evaluate dehydration.[8] However, the scale has limited accuracy as scoring of each item introduces a degree of subjectivity depending on who is performing the evaluation. The most accurate indicator of dehydration is body weight measured before and after the appearance of symptoms of dehydration.[9] Unfortunately, it is often difficult to determine the accurate baseline body weight of a child brought in to the emergency department (ED), and variation among different weight scales use can make it challenging to apply the readings in diagnosis. Other studies have reported that because a low level of serum bicarbonate (HCO_3^-) as an

Editor: Abdelouahab Bellou.

This work was supported by the new faculty research fund of Ajou University School of Medicine.

The authors report no conflicts of interest.

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Medicine (2017) 96:35(e7881)

Received: 24 April 2017 / Received in final form: 13 July 2017 / Accepted: 14 July 2017

http://dx.doi.org/10.1097/MD.0000000000007881

Table 1

Clinical Dehydration Scale.

Score*	General appearance	Eye	Oral mucosa (tongue)	Tear
0	Normal	Normal	Moist	Normal
1	Thirsty, restless, lethargic but irritable	Mildly sunken	Sticky	Decreased
2	Drowsy/nonresponsive, limp, cold, diaphoretic	Very sunken	Dry	None

* Sum of each score 0–4, some dehydration; sum of each score ≥5, moderate-to-severe dehydration.

indicator of metabolic acidosis is correlated with the level of dehydration, HCO_3^- can be used to verify the efficacy of ORT or to determine the need for hospitalization.[10] However, obtaining a blood sample from a dehydrated pediatric patient for HCO_3^- measurement is invasive. Furthermore, it is difficult to find veins in small children, which makes this method even more impractical for use in a pediatric ED setting.

Use of end-tidal carbon dioxide ($ETCO_2$) levels may offer a solution, which is based on basic metabolic rate, cardiac output, and total ventilation. The body's physiological compensation for metabolic acidosis is respiratory alkalosis via increased per-minute ventilation. Increased per-minute ventilation reduces the partial pressure of carbon dioxide dissolved in arterial blood ($PaCO_2$) and the amount of HCO_3^-, and also results in changes in $ETCO_2$.[11–14] Therefore, an $ETCO_2$ level that falls into the abnormal range not only indicates abnormal gas exchange but also abnormalities in perfusion or metabolism.[15] Recently, several studies have reported that low $ETCO_2$ levels indicate the severity of conditions among adults who exhibit symptoms of shock, septicemia, and metabolic abnormalities, and that the $ETCO_2$ level is associated with mortality.[16–20] However, insufficient studies have been conducted that support the correlation between these 2 indicators when it comes to dehydration in children.[21] If $ETCO_2$ is proved to accurately reflect the HCO_3^- level, it could be used as a noninvasive and objective indicator of dehydration in children. Therefore, we set out to investigate the utility of $ETCO_2$ as an objective, noninvasive indicator of dehydration by examining children who presented to the ED with acute gastroenteritis (AGE).

2. Methods

2.1. Study participants

In this retrospective observational study, we reviewed the medical records of children (aged 1 month–15 years) who presented to the ED of our regional emergency medical center during a 1-year research period between May 2015 and April 2016. Of these, those children selected for analysis had received a primary discharge diagnosis of AGE and had initial vital sign measurements that included $ETCO_2$ level as well as serum HCO_3^- measurement. Children with respiratory symptoms or conditions that could potentially affect the baseline $ETCO_2$ or HCO_3^-, as well as those with diabetes, heart disease, renal disease, or congenital metabolic disease were excluded from the analysis. We also excluded patients who were missing data needed for this study, such as CDS score. The study was approved by the Ethics Committee of our hospital (AJIRB-MED-MDB-17-042).

2.2. Study methods

Medical records of the selected pediatric patients were reviewed to collect data on age (months), sex, initial vital signs including $ETCO_2$ and HCO_3^- levels, duration of ED stay, and hospitalization/discharge status. The CDS consists of 4 clinical characteristics: general appearance, conditions of eye and oral mucous membranes, and the amount of tears; these are scored on a scale of 0 to 2 and this numerical score is used to calculate the CDS. A total CDS score exceeding 5 points indicates moderate-to-severe dehydration (Table 1). To compare participants' dehydration levels in our study against the those of children reported in previous research, a frequency analysis was performed using HCO_3^- measurements divided into groups with values of 13, 15, and 17 mmol/L.[20,21] In addition, the frequency of children with an overall CDS score of ≥5 points (moderate to severe dehydration) was analyzed.

Our primary goal in this study was to determine whether a correlation exists between $ETCO_2$ and HCO_3^-. A secondary aim was to determine the correlation between $ETCO_2$ and CDS score. For the study, a Nellcor N-85 hand-held capnograph/pulse oximeter with OxiMax (Medtronic, Boulder, CO) that uses infrared absorption spectroscopy was employed to measure $ETCO_2$ via nasal cannula.

2.3. Data analysis

Data collected from the selected participants were analyzed and expressed in the following manner. Continuous variables that proved to be following a normal distribution were expressed as mean ± SD. Those variables that were not found to follow a normal distribution were expressed as median, percentile, and quartile. Categorical variables were expressed as frequency and percentile. A Pearson correlation test was performed to examine the relationship between $ETCO_2$ and HCO_3^-, as well as the relationship between $ETCO_2$ and CDS score. In addition, a partial correlation analysis was carried out that included those factors estimated to influence $ETCO_2$ and HCO_3^-. SPSS version 15.0 (SPSS Inc, Chicago, IL) was used for all statistical analyses, with the significance level set at $P < .05$.

3. Results

3.1. Participant characteristics

In the end, a total of 105 children were included in the analyses. The mean age of children was 47.4 ± 37.0 months (range: 1–179 months) and the median age was 40.0 months (interquartile range [IQR] 21.0–months). A total 55.2% (58) of participants were male. The mean respiratory rate was 20.7 ± 5.5 breaths/min (range: 17–47 breaths/min). The mean $ETCO_2$ was 32.1 ± 6.1 mmHg (range: 17–47 mmHg), and mean HCO_3^- was 20.7 ± 3.5 mmol/L (range: 10.2–26.2 mmol/L).

To evaluate participants' dehydration levels, a frequency analysis was performed according to HCO_3^- level. The analysis results showed that there were 7 children (6.7%) with $HCO_3^- \leq 13$ mmol/L, none with 13 mmol/L < $HCO_3^- \leq 15$ mmol/L, 5 children (4.7%) with 15 mmol/L < $HCO_3^- \leq 17$ mmol/L, and 93 children (88.6%) with $HCO_3^- > 17$ mmol/L. CDS scores for

Table 2

Characteristic of study sample (n = 105).

Age, mean ± SD, mo	47.4 ± 37.0
Male sex, n (%)	58 (55.2)
Respiration rate, mean ± SD, breaths/min	26.5 ± 5.5
$ETCO_2$, mean ± SD, mmHg	32.1 ± 6.1
HCO_3^-, mean ± SD, mmol/L	20.7 ± 3.5
HCO_3^-, n (%), mmol/L	
≤13	7 (6.7)
13 < ≤15	0 (0)
15 < ≤17	5 (4.7)
17 <	93 (88.6)
Clinical dehydration scale, n (%)	
<5	95 (90.5)
≥5	10 (9.5)
Disposition, n (%)	
Discharge	76 (72.4)
Admission	29 (27.6)

$ETCO_2$ = end-tidal carbon dioxide, HCO_3^- = serum bicarbonate.

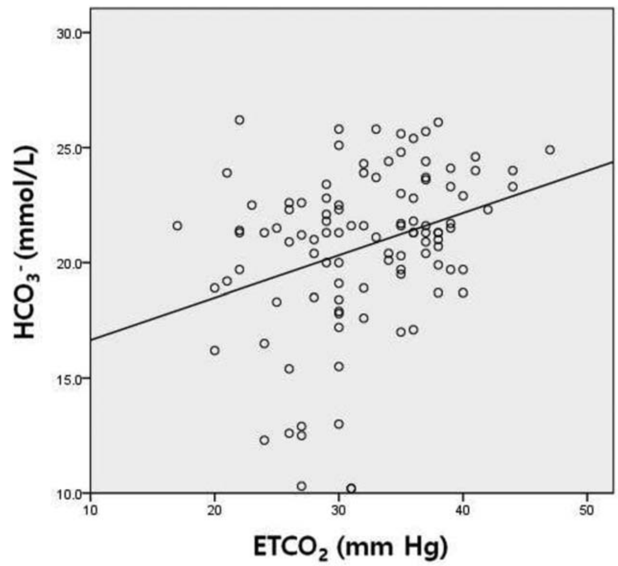

Figure 1. Scatter plot of end-tidal carbon dioxide ($ETCO_2$) and serum bicarbonate (HCO_3^-). Correlation coefficient = 0.32 (P = .001).

all children fell between 0 and 7 points. A total of 10 children (9.5%) had a CDS score of ≥5 points (moderate-to-severe dehydration), whereas 95 children (90.5%) had scores <5 points (mild dehydration). Following treatment received in the ED, 29 children (27.6%) were admitted to the hospital and 76 (72.4%) were discharged from the ED (Table 2). The mean ED stay was 5 hours 27 minutes ± 3 hours 31 minutes (range: 1 hour 46 minutes to 23 hours 7 minutes), and the median ED stay was 4 hours 38 minutes.

3.2. Correlations between $ETCO_2$, HCO_3^-, and CDS

A Pearson correlation analysis was performed to examine the relationship between $ETCO_2$ and HCO_3^-. The analysis produced a coefficient of r = 0.32, indicating a significant positive correlation between the two measures (P = .001; Fig. 1). Another partial correlation analysis was performed while controlling the respiration rate, based on the assumption that this rate varied by age. The analysis yielded a coefficient of r = 0.27, indicating a significant but weak correlation between $ETCO_2$ and HCO_3^- (P = .007). The coefficient for $ETCO_2$ and CDS was r = –0.20, indicating a weak negative correlation (P = .04).

4. Discussion

The present study is the second to examine the effectiveness of $ETCO_2$ as an indicator of dehydration in children, a condition frequently encountered in the ED. It is, however, the first study to examine the correlation between $ETCO_2$ and CDS score, a widely used noninvasive indicator of dehydration. The authors verified that compared with HCO_3^- and CDS, $ETCO_2$ is an objective and noninvasive indicator of dehydration that may be used to assess dehydration in children.

Several existing studies have indicated that low HCO_3^- effectively reflects metabolic acidosis and thus may be used to assess dehydration in children, and HCO_3^- is related to the duration of ED stay.[16,20,21] Previous studies among children exhibiting symptoms of acidosis caused by AGE-induced dehydration or children with diabetic ketoacidosis (DKA) have reported a strong correlation between HCO_3^- and $ETCO_2$.[20,21] Nagler et al[21] studied 118 children with enteritis to examine the link between $ETCO_2$ and HCO_3^-. They found a mean HCO_3^- of 17.3 ± 4.3 mmol/L among participants, with 31% of children with an HCO_3^- level <15 mmol/L; a Pearson coefficient of r = 0.80 (P < .0001) indicated a strong correlation between the 2 indicators. A study by Fearon et al[20] examined a total of 42 children suspected of DKA. Those authors reported that 12 children (29%) had an HCO_3^- <15 mmol/L, with a mean HCO_3^- of 10.1 ± 3.5 mmol/L; linear regression analysis yielded an R^2 = 0.80 (P < .0001), indicating a high correlation between $ETCO_2$ and HCO_3^-. Departing from the results of previous studies, those of the present study indicate a weak link between $ETCO_2$ and HCO_3^- (correlation coefficient of 0.32), despite the link being statistically significant (P = .001).

Several factors can explain the weaker correlation between these two indicators found in our study. One reason may be that the present study included a large number of children with mild dehydration. In fact, 10 children (9.5%) had moderate-to-severe dehydration (CDS >5), and only 12 children (11.4%) had an HCO_3^- level <15 mmol/L. Such a makeup among study participants may have influenced the coefficient for $ETCO_2$ and HCO_3^-. In the study by Fearon et al,[20] whereas a close linear relationship was found between $ETCO_2$ and HCO_3^- in children with DKA, these 2 indicators did not show the same relationship pattern among children who exhibited symptoms of hyperglycemia but did not have metabolic acidosis. That result may be because neither the children with mild dehydration nor those with hyperglycemia developed metabolic acidosis. Thus, compensatory responses to respiratory abnormalities did not have to kick in among these children, which in turn left their $ETCO_2$ levels unaffected; this may explain why we did not find a strong correlation between $ETCO_2$ and HCO_3^-. Another reason might be that the children included in the present study were generally younger than those in previous studies, resulting in larger deviations in respiratory rates and a lower level of compliance when measuring $ETCO_2$; the latter may have compromised the accuracy of the measurements. The children in our study ranged from age 1 month to 14.9 years, with mean age 47.4 ± 37.0 months, median age 40 months, and IQR of 21 months and 66.5 months. In Fearson et al's study,[20] the ages of children with DKA ranged from 2 to 18 years; those in the work of Nagler et al[21] had mean age 48.0 ± 50.4 months. In comparison, participants in the present study consisted largely of younger children. During the 1-year study period, we collected information of all patients diagnosed with AGE. After excluding those who were unsuitable for inclusion in the study, the remaining participants were analyzed. The included children were younger because our hospital is a tertiary referral institution. There are many cases of school-age children with AGE symptoms who are simply treated with ORT and IV hydration in primary clinics. However, young children can easily develop dehydration and are difficult to treat with ORT and IV hydration therapy at primary medical centers. So, younger patients are often referred to tertiary hospital emergency centers.

A third reason for the weaker correlation between $ETCO_2$ and HCO_3^- in our study might be that the $ETCO_2$ monitoring device used here displayed continuous waves on graphs, as well as constantly shifting numerical values. Because the numerical values shifted constantly and changed over a wide range, the nurses responsible for recordkeeping may have been unable to consistently capture the most frequently flashing values; this may have resulted in compromised accuracy of measurement.

The secondary goal of the present study was to examine the correlation between $ETCO_2$ and CDS score when CDS was used as a dehydration indicator. CDS is an indicator that is used to evaluate dehydration in terms of general appearance, eyes, oral mucous membranes, and tears. Each characteristic is given a score based on a scale of 0 to 2. A higher number indicates more severe dehydration. Therefore, we hypothesized that a higher CDS score indicates lower $ETCO_2$. Unlike the HCO_3^- test, CDS is noninvasive, as it relies on clinical observation. For this reason, it is widely used in the clinical field, despite the potential for subjectivity. In the present study, $ETCO_2$ and CDS were found to have a weak negative correlation; CDS increased as $ETCO_2$ decreased ($r=-0.20$, $P=.04$).

The contribution of the present study lies in the following. Whereas previous studies involving children affected with AGE or DKA compared $ETCO_2$ levels with dehydration symptoms and diagnostic blood test results, we compared the correlation between $ETCO_2$ and CDS to assess suspected dehydration in children. In determining the appropriate treatment for a child brought into the ED for suspected dehydration, it appears that $ETCO_2$ measurement, when used alongside CDS, would boost objectivity when assessing the degree of dehydration.

As mentioned previously, dehydration is a common cause of ED visits in children, and it must be appropriately treated with fluids depending on the severity of the condition. For most mild-to-moderately dehydrated children, ORT is the preferred initial treatment. However, accurate assessment of dehydration can be challenging in an ED, in which case ORT may be inappropriately administered or its efficacy undervalued. Children treated with ORT typically remain in the ED for approximately 3.8 hours, which is shorter than the 5- to 6-hour ED stay required for children treated with IV therapy.[22] In fact, all children examined in the present study had received IV therapy, which resulted in a mean ED stay of 5 hours 27 minutes ± 3 hours 31 minutes. Nevertheless, blood tests performed concurrent with IV therapy indicated that only 12 children (11.4%) had an $HCO_3^- < 15$ mmol/L and were likely to be >10% dehydrated, according to one reference study.[20] This suggests that a majority of these children did not develop metabolic acidosis, as they were only mildly dehydrated; therefore, they could have been treated with ORT. We did not ascertain from the treating physician the reason why these children were treated with IV fluids (eg, not tolerating oral fluids, just looked dry, anxious parents). Swift and accurate dehydration assessment for pediatric patients could help avoid unnecessary administration of rather invasive IV therapy, decrease the length of ED stay, and facilitate more efficient deployment of available resources. In this sense, use of $ETCO_2$ before deciding the method of hydration could be considered an effective assessment tool for children.

There are some limitations in the present study. First, the study used data obtained from the pediatric ED of a single regional emergency medical center. As such, the sample size was small (105 children) and was not calculated considering the statistical power. In addition, not all children who presented to the ED during the research period were measured for $ETCO_2$. Therefore, it is difficult to say that the sample represented a wide range of dehydration levels in children. Second, as previously mentioned, the children in the present study were younger than those in previous studies. Because our hospital is a tertiary referral center, younger children who were difficult to treat in private clinics were enrolled in this study; therefore, inevitable selection bias was present in this study. For this reason, respiratory rates may have varied widely, and the typically low compliance among small children may have affected the accuracy of $ETCO_2$ measurement. Finally, there are limitations inherent to retrospective studies. Because medical records were examined retrospectively, it was impossible to control the quality of measurements when it came to respiratory rates and $ETCO_2$. Furthermore, not all variables that increase CDS score and affect $ETCO_2$ measurement compliance could be reflected, such as fever-induced tachypnea, electrolyte imbalance, and hypoglycemia. A follow-up prospective study involving a patient group with a more diverse range of dehydration levels and that addresses the above-mentioned limitations would be beneficial.

5. Conclusion

In mildly dehydrated children, $ETCO_2$ was found to have weak, yet significant correlations with both $HCO_3^-$and CDS score, the latter of which is a clinical indicator of dehydration. As such, it is worth considering using $ETCO_2$ level as a simple and noninvasive dehydration assessment tool for children who present to the ED with AGE.

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