Use of Ultrasound Measurement of the Inferior Vena Cava Diameter as an Objective Tool in the Assessment of Children with Clinical Dehydration

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Abstract

Objectives: Bedside ultrasonography (US) measurement of the inferior vena cava (IVC) and aorta (Ao) may be useful in objectively assessing children with dehydration. The objectives of this study were 1) to compare the IVC and Ao diameters (IVC/Ao) ratio of dehydrated children with controls and 2) to compare the IVC/Ao ratio before and after intravenous (IV) rehydration in children with dehydration.

Methods: This prospective observational study was performed in an urban pediatric emergency department. Children between 6 months and 16 years of age with clinical evidence of dehydration were enrolled. Bedside US measurements of the IVC and Ao were taken before and immediately after IV fluids were administered. An age-, gender-, and weight-matched control without dehydration was enrolled for each subject. The IVC/Ao ratios of subjects and controls were compared using Wilcoxon signed rank test, as were the ratios before and after IV hydration for each subject.

Results: Thirty-six pairs of subjects and matched controls were enrolled. The IVC/Ao ratios in the subjects were lower as compared with controls (mean of 0.75 vs. 1.01), with a mean difference of 0.26 (95% confidence interval = 0.18 to 0.35). In subjects, the IVC/Ao ratios were significantly lower before IV hydration (mean of 0.75 vs. 1.09), with a mean difference of 0.34 (95% confidence interval = 0.29 to 0.39).

Conclusions: As measured by bedside US measurement, the IVC/Ao ratio is lower in children clinically assessed to be dehydrated. Furthermore, it increases with administration of IV fluid boluses.

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Dehydration is a common condition encountered in the emergency department (ED). In the United States, there are about 220,000 hospitalizations each year for gastroenteritis and dehydration in children younger than 5 years.[1] Accurate assessment of the degree of dehydration in children is important in appropriately managing these patients in the ED. Dehydration, if unrecognized and untreated, can progress to profound shock and even death. On the other hand, overestimation of the severity of dehydration may result in inappropriate utilization of limited resources such as prolonged care in the ED and hospitalization. Furthermore, aggressive intravenous (IV) rehydration is a known cause of iatrogenic morbidity and even mortality.[2–4]

Symptoms of dehydration in children may be subtle and nonspecific. Clinical signs are also variable in children with dehydration. One definition of the degree of dehydration is the change in body weight that has occurred over a limited period.[5] This number is difficult to ascertain for children, because their body weight is constantly changing. In clinical settings, the assessment of dehydration involves taking into account a constellation of symptoms and signs, some of which are subjective or unreliable. Current methods for determining the degree of dehydration, defined as a deficit of 5% or more of body weight, have been evaluated. In a prospective study assessing the combination of clinical signs and symptoms, one such method has a sensitivity of 0.87 and a specificity of 0.82.[6] Other efforts at developing more objective scoring systems have yielded similar results.[7] Laboratory values can also be used to judge the

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severity of dehydration in children. It is generally acknowledged that these have limited sensitivity and specificity.[5,8] There is a need for a noninvasive, rapid, and objective tool that accurately reflects the volume status in children with dehydration.

Bedside emergency ultrasonography (EUS) is a relatively new imaging modality in pediatrics.[9,10] EUS is fast, painless, and noninvasive. In recent years, many new pediatric indications for EUS have been developed. Ultrasonography (US) assessment of the inferior vena cava (IVC) has been used as a noninvasive diagnostic tool for the assessment of intravascular volume and right heart function. Specifically, IVC diameter and collapsibility have been used as methods of assessing fluid status in adults as well as children on hemodialysis.[11]

IVC diameter has also been used to assess acute blood loss in adults.[12,13] In these studies, contraction of the intravascular volume resulted in measurable decreases in IVC diameters. Conversely, research has shown that the diameter of the descending aorta (Ao) remains mostly constant, despite intravascular volume depletion.[12] Because the sizes of the IVC and Ao in pediatric patients vary with their ages and sizes, we hypothesized that the ratio between the IVC and Ao diameters, as measured by bedside US, may be of value to objectively determine the intravascular volume status in children with dehydration.

Figure 1. Placement of the probe in the subxiphoid region.

METHODS

Study Design

This was a prospective observational study. The study was approved by the Human Investigation Committee at Yale University School of Medicine. Informed written consent was obtained from a parent or guardian for each subject and control. Written assents were obtained from children ages 7–16 years.

Study Setting and Population

The study was performed between June 2006 and July 2007 in the pediatric ED at Yale–New Haven Hospital, an urban pediatric ED. Children between 6 months and 16 years of age were eligible as subjects if they presented with clinical evidence of dehydration and were judged to need IV fluids as determined by the pediatric emergency attending physician on duty. They were approached to be study subjects when one of the investigators was available. Children were excluded from the study if they had a history of congenital heart disease, Marfan syndrome, or acute blood loss. They were also excluded if there were concerns for systemic infections.

For each subject, an age-, gender-, and weight-matched control was enrolled. The age was matched to within 15% of the subject's age. The weight was matched to within 15% of the subject's weight. Children who were clinically assessed to be euvolemic who presented with minor complaints were approached to be controls. The same exclusion criteria for subjects applied to the controls.

Study Protocol

Bedside US measurements of the IVC and Ao were taken before and immediately after IV fluids were administered. For controls, bedside US was performed once. The Sonosite 180+ ultrasound machine (Sonosite, Bothell, WA) with the C60 curvilinear probe was used for each subject and control (Figure 1). The subjects and controls were placed into a supine position. The probe was placed at the subxiphoid region, just rostral or caudal to the insertion of the left renal vein into the IVC. In this view, the liver could be used as an acoustic window. No graded compression was used to displace intestinal gas. In addition, we took great care not to compress the abdomen. A transverse view of the IVC and Ao was imaged using cine-loop capture. Images were recorded over several respiratory and cardiac cycles. The maximal anterior-posterior IVC diameter and descending Ao diameter were measured (Figure 2A). The maximal IVC diameter was obtained during the expiratory phase of the respiratory cycle, whereas the maximal Ao diameter was obtained during systole of the cardiac cycle. After the initial bedside US examination, the subjects underwent bolus IV fluid infusion with normal saline, as is the standard of care in our pediatric ED. Immediately after the first bolus infusion, the measurements were repeated in the same region of the abdomen (Figure 2B). Two investigators performed the US measurements during the course of the study. One (LC) was a pediatric emergency attending physician who attended an American College of Emergency Physicians–sponsored two-day US workshop, in addition to spending a six-week period in an EUS rotation in an academic ED. The other operator (YK) was a medical student who underwent training given by LC.

Data Analysis

Previous pilot data indicated that a difference of up to 40% in IVC diameter could be detected between normal and dehydrated subjects. To detect a 20% change in IVC diameter in dehydrated children compared with controls using an α of 0.05 and a power of 0.8, 36 pairs of controls and subjects needed to be enrolled. The IVC/Ao ratios of subjects and controls were compared using the Wilcoxon signed rank test, as were the ratios before and after IV hydration for each subject. The differences were considered statistically significant when the p-value was <0.05. Statistical calculations were performed with SPSS 14.0 (SPSS Inc., Chicago, IL).

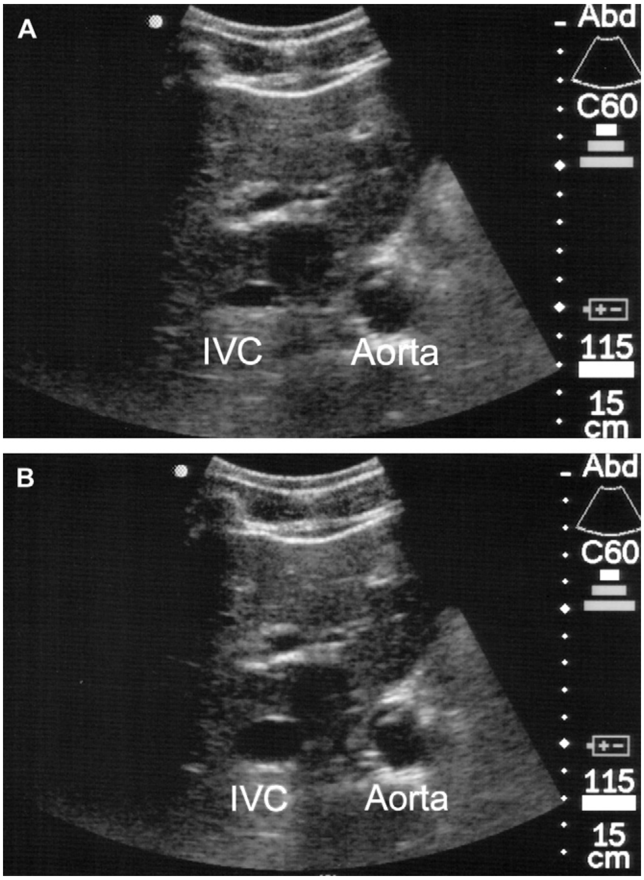

Figure 2. Transverse views of the abdomen (A) before and (B) after IV fluid administration in a 16-year-old subject with viral gastroenteritis.

RESULTS

A total of 36 pairs of subjects and controls were enrolled. There were 10 male subjects and 26 female subjects with a mean (±SD) age of 7.3 (±5.0) years (range, 9 months to 16 years), compared with ten male controls and 26 female controls with a mean (±SD) age of 8.0 (±5.3) years (range, 8 months to 16 years) (Table 1). The majority of the subjects (53%) were diagnosed with viral gastroenteritis. Other final diagnoses included peritonsillar abscess, urinary tract infection, postoperative tonsillectomy, hyperemesis gravidarum, and heat exhaustion. The amount of bolus IV fluid administered was determined by the treating physician and ranged from 15 to 50 mL/kg of normal saline, with a median of 20 mL/kg. In the subjects, the Ao diameters did not vary significantly before and after IV hydration (0.99 cm vs. 1.02 cm, with a mean difference of 0.03 cm [95% confidence interval {CI} = −0.04 cm to 0.10 cm]). The IVC diameters were significantly different before and after hydration (0.75 cm vs. 1.12 cm, with a mean difference of 0.27 [95% CI = 0.24 cm to 0.32 cm]). Their IVC/Ao ratios were significantly different before and after hydration (mean of 0.75 vs. 1.09, with a mean difference of 0.34 [95% CI = 0.29 to 0.39; $p < 0.001$]). Compared with matched controls, the prehydration ratios in the subjects were lower (mean of 0.75 vs. 1.01, with a mean difference of 0.26 [95% CI = 0.18 to 0.35; $p < 0.001$]) (Figure 3). The IVC/Ao ratio did not vary appreciably with age in the controls, with a mean (±SD) of 1.01 (±0.15).

Table 1
Patient Demographics

	Subjects	Controls
N	36	36
Female (*n*)	26	26
Male (*n*)	10	10
Age range (yr)	0.8–16	0.8–16
Mean age (yr)	7.3	8.0
Weight range (kg)	10.0–65.5	10.6–68.5
Mean weight (kg)	30.0	35.6

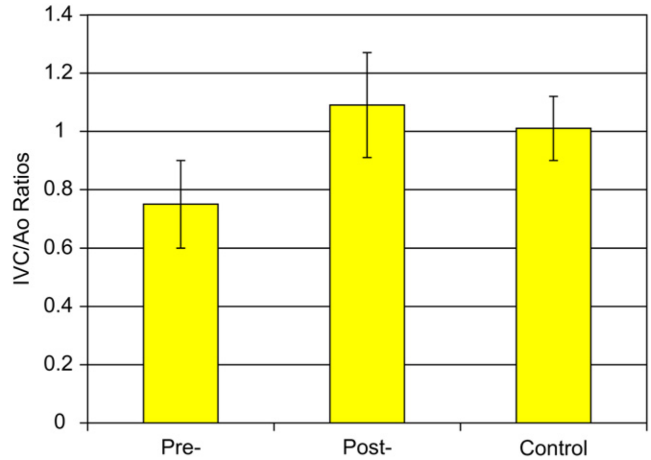

Figure 3. Mean inferior vena cava/aorta ratios in subjects before (pre-) and after (post-) hydration as compared with controls. Error bars represent 1 SD. (Color version of this figure available online at www.aemj.org.)

Using the clinical judgment of dehydration as the standard, the test characteristics of the IVC/Ao ratio were calculated. A receiver operator characteristics curve was constructed (Figure 4). The area under the curve was 0.91 (95% CI = 0.84 to 0.98). With a cutoff ratio of 0.72, the test had a specificity of 100% and a sensitivity of 39%. On the other hand, with a cutoff ratio of 1.0, the test had a specificity of 58% and a sensitivity of 97%.

DISCUSSION

Objective assessment of intravascular volume status in children in the ED is fraught with difficulties. Historical information such as oral intake, stool and urine output, and well weight are often inaccurate or difficult to obtain. Clinical signs and symptoms of dehydration are inconsistent. Laboratory testing is invasive and potentially of dubious utility. Studies using IVC measurements to assess intravascular volume status have been conducted in adults.[12,13] In addition, one study compared IVC diameters in children of various ages undergoing hemodialysis.[11] Our study confirms earlier research showing that IVC diameters were lower in children with dehydration. Furthermore, this is the first study to show increases in IVC diameter in direct relation to increases in intravascular volume in children with dehydration.

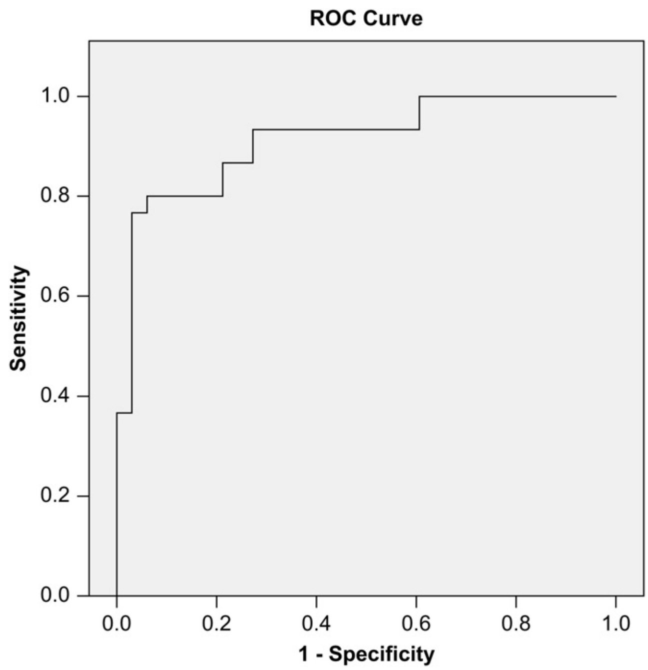

Figure 4. Receiver operator characteristic (ROC) curve of inferior vena cava/aorta ratio and clinical assessment of dehydration. Area under the curve is 0.91.

We designed the study around a novel parameter: the ratio between the IVC and Ao diameters. The Ao is a vessel with low compliance, especially when compared with the IVC. In our study, the Ao diameter was found to remain stable in each subject before and after hydration. This finding is consistent with previous research. In a study of adults in hypovolemic shock, the diameter of the abdominal Ao remained constant despite large blood losses.[12] In euvolemic control subjects, the IVC/Ao ratio appeared to be consistent regardless of age and weight. In contrast, we were able to demonstrate a correlation between the IVC/Ao ratio in our study subjects, as assessed by bedside US examination, and the intravascular volume. This ratio is demonstrably smaller in children clinically assessed to be dehydrated as compared with controls. Furthermore, measurable increases in the ratios were observed after IV hydration.

There are many potential applications of this novel parameter. Oral rehydration therapy has been found to be a good alternative to IV rehydration in children with mild to moderate dehydration.[1,14,15] The IVC/Ao ratio may be used in the initial assessment as well as subsequent evaluation in children undergoing oral rehydration. Because repeated examinations do not incur significant additional cost, this modality may be used to follow up the children longitudinally for ongoing fluid losses as well as to follow up the efficacy of rehydration.

It is relevant to mention that this technique only evaluates intravascular fluid status. It does not detect other metabolic derangements common to children with dehydration, such as hyponatremia, hypoglycemia, and acidosis. In a recent study, Nagler et al. demonstrated that serum bicarbonate concentration is lower in children with vomiting and diarrhea and can be detected noninvasively by end-tidal CO_2 measurement.[16] Together with other noninvasive modalities, this novel ratio may assist in the rapid triage and timely management of large numbers of patients in the acute care setting.

LIMITATIONS

We enrolled a relatively small number of subjects. The main reason for that was the difficulty in matching the subjects with appropriate controls. Our results are encouraging in that the IVC/Ao ratio remained consistent in the group of control subjects. More data are needed, however, to establish normal values in children with euvolemia.

Throughout the research study, two U.S. operators performed the studies. One operator was a pediatric emergency attending physician who underwent formal EUS training with an American College of Emergency Physicians–approved EUS course, in addition to spending six weeks on an EUS rotation in an adult ED. The other operator was a medical student with limited training on vascular US, as provided by the first operator. Intraobserver and interobserver variabilities were not measured, although previous research has demonstrated good interobserver agreement in the measurement of the IVC as performed by pediatric emergency physicians.[17] Formal evaluation in methods to generalize this technique is warranted.

We did not attempt to correlate our measured deficits with another standard of assessing fluid deficits, namely measuring the ill and well weights of the subjects. This pilot study was designed to demonstrate a correlation between IVC/Ao ratio and intravascular fluid status. This relationship was confirmed by our preliminary data. Future plans include longitudinal studies of children with dehydration, correlating repeat measurements of the IVC/Ao with weight changes during acute illness and convalescence. These studies would help establish the validity of this modality to prospectively identify patients with dehydration.

Unlike previous studies, we did not limit the subjects to children with gastroenteritis. The inclusion of a range of different diagnoses serves as a strength as well as a potential weakness. By including patients with a variety of mechanisms for dehydration, including decreased intake (due to oral lesions and postoperative pain) and increased losses (vomiting and diarrhea), this method may potentially have greater generalizability than other methods that measure specific electrolyte abnormalities that are commonly the result of gastroenteritis.

CONCLUSIONS

As measured by bedside US examination, the novel ratio of IVC to Ao diameters varies with intravascular volume status in children. The ratio is lower in children clinically assessed to be dehydrated. Furthermore, it increases with administration of IV fluid boluses.

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REFLECTIONS

Please Don't Change the Bedsheets!

Our new bed has a zillion pillows and is very high off the floor—high enough I almost need a step stool to get into the bed. I continually tell my wife I might need oxygen to do what comes naturally—besides sleep—in a bed.

Every week, she insists on changing the bedsheets. I willingly and obligingly help with a lot of household chores; however, something in my self-consciousness keeps nagging at me and telling me "don't change the bedsheets." It finally has occurred to me why I don't like to change bedsheets.

Our hospital and medical school recently moved to a "paperless" emergency department, that is, computer documentation. Faculty, staff, and residents have expressed their various thoughts about this endeavor. I have serenely told everyone "get over it and live with it"—the phrase used by my dear wife when I cross the proverbial line.

I am known around our emergency department as a curmudgeon, so my attitude has surprised a lot of my colleagues, residents, students, and staff. I tell them going paperless is déjà vu for me. Forty years at Cook County Hospital in Chicago, we didn't always have paper charts available and we certainly didn't have computers. In true emergencies, we often used the bedsheets as charts; if the bedsheets got washed, our charting disappeared.

Now I know why I don't like to change the bedsheets—my wife still doesn't understand!

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