Non-invasive Assessment of Significant Dehydration in Infants Using the Inferior Vena Cava to Aortic Ratio: Is it Useful?

Doaa El Amrousy, Rasha Gamal, Shaymaa Elrifaey, and Samir Hassan

ABSTRACT

Objectives: The aim of the study was to assess the accuracy of the inferior vena cava to aorta (IVC/Ao) diameter ratio for predicting significant dehydration in infants relative to their percentage weight change and the clinical diagnosis by a physician.
Methods: A prospective observational study was performed on 200 infants presented with acute diarrhea and clinical evidence of significant dehydration whose treatment required intravenous (IV) fluids as determined by the attending physician at the pediatric emergency department of Tanta University Hospital. Weight was recorded at admission before IV fluid treatment and at hospital discharge. The percentage of dehydration was determined using the following formula: (discharge weight − admission weight)/discharge weight × 100%. Patients with a percentage weight change of <5% were considered to be nonsignificantly dehydrated, whereas patients with a percentage weight change >5% were considered significantly dehydrated. The IVC/Ao diameter ratio was measured for all patients before IV fluid rehydration and again at discharge.
Results: Only 134 out of 200 dehydrated infants were found to be significantly dehydrated using the gold standard, percentage weight change. Receiver operating characteristics (ROC) curve analysis of the prehydration IVC/Ao ratio showed a sensitivity of 82%, a specificity of 91%, and an accuracy of 87% for predicting significant dehydration in infants at a cut-off point of less than 0.75. In contrast, physician clinical diagnosis showed a sensitivity of 70%, a specificity of 63%, and an accuracy of 73%.
Conclusions: The IVC/Ao diameter ratio can be used as a reliable predictor for diagnosing significant dehydration in infants.

Key Words: clinical assessment, dehydration, infant, ultrasonography

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What Is Known

- Dehydration is one of the most common causes of mortality in children especially young infants because of high-body water to body weight requirements.
- Assessment of the degree of dehydration is the cornerstone of the management of acute infantile diarrhea.
- The inferior vena cava to aortic diameter ratio is a new marker for assessing body fluid status in both adult and children but studies are lacking in infants younger than 24 months of age.

What Is New

- The inferior vena cava to aortic diameter ratio is a good predictor of significant dehydration in infants.
- Clinical diagnosis by a physician is not a good method for assessing the degree of dehydration alone.

Dehydration due to acute gastroenteritis remains one of the most common causes of morbidity and mortality in children because of significant fluid loss over a short period of time (1,2). Infants younger than 2 years of age have the ones with the highest risk of complications and mortality after acute dehydration because of high body water to body weight requirements. Assessment of the degree of dehydration is the cornerstone of management of acute infantile diarrhea. Precise estimation of the degree of dehydration in these infants promotes the use of oral rehydration therapy in nonsignificant dehydration cases and limits the administration of intravenous (IV) fluids to only significantly dehydrated children (3). Underestimation of the degree of dehydration can also lead to shock and death; however, overestimation of the degree of dehydration can be hazardous and lead to iatrogenic morbidity and mortality (4,5).

Accurate assessment of the degree of dehydration in infants is still a diagnostic challenge. The difference in body weight between the ill weight and the preillness or baseline weight of the patient is the gold standard (6). As the preillness weight, however, is not available in acute cases, other parameters must be sought to assess for the degree of dehydration (7). Noninvasive assessments such as physician judgment, clinical scales derived from signs and symptoms, and laboratory values are typically used (8–10). Popular clinical scales such as the world health organization (WHO) scale, the Gorelick scale and clinical dehydration scale have been studied in many reports. The ability of clinical signs and

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From the Faculty of Medicine, Tanta University Hospital, Pediatric Department, El Geish street, Tanta, Egypt.
Address correspondence and reprint requests to Professor Doaa El Amrousy, MD Pediatrics, Assistant Professor of Pediatrics, Pediatric Department, Tanta University Hospital, El Motasem street No 6, Tanta, Egypt, 31527 (e-mail: doaamoha@yahoo.com).
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symptoms, however, to predict severe dehydration in the pediatric emergency department is considered suboptimal (11–14). Similarly, laboratory parameters have limited diagnostic value for detecting the degree of dehydration (15). There is a need for a rapid, simple, noninvasive method that can accurately predict the volume status in infants with dehydration.

Bedside ultrasound has been reported as a rapid, noninvasive method for assessing intravascular volume in children especially in emergencies (5,16–23). The inferior vena cava (IVC) is a thin-walled, collapsible vessel that varies in size with changes in intravascular volume. In contrast, the aorta (Ao) is a thick-walled vessel that does not significantly vary in size with changes in intravascular blood volume. In the pediatric population, few studies have compared bedside ultrasound of the IVC/Ao ratio with the patient's weight change to estimate the degree of dehydration in children (5,16,21). None of them, however, has studied the predictive value of the IVC/Ao diameter ratio to detect significant dehydration exclusively in infants younger than 24 months of age who are the most vulnerable group to experience significant dehydration and its associated morbidity and mortality. To the best of our knowledge, this is the first study to assess the accuracy of the IVC/Ao diameter ratio for predicting significant dehydration exclusively in infants younger than 24 months of age relative to the percentage weight change and to assess the accuracy of clinical diagnosis of significant dehydration made by a physician based on WHO scale relative to percentage weight change.

PATIENTS AND METHODS

This prospective, observational study was conducted at the pediatric emergency department of Tanta University Hospital on 200 consecutive infants with acute diarrhea and dehydration who required IV fluid for treatment during the period from January 2016 to May 2017. This study was approved by the local ethics committee of the faculty of medicine of Tanta University under registration number of 30624/12/15. Written informed consent was signed by the parents.

Inclusion criteria: patients younger than 24 months who presented with acute diarrhea and clinical evidence of significant (moderate and severe) dehydration whose treatment required IV fluid as determined by the attending pediatric physician according to the WHO scale.

Exclusion criteria: patients receiving oral rehydration solution only or patients with congenital heart disease, pulmonary hypertension, Marfan syndrome, malnutrition, or acute blood loss.

Acute diarrhea was defined as the passage of loose or watery stool or an increase in the frequency of stools (at least 3 times per day) with or without vomiting or fever for less than 14 days (24). Clinical assessment of dehydration was performed according to the WHO criteria (25) as shown in Supplemental Table 1 (Supplemental Digital Content 1, *http://links.lww.com/MPG/B236*). All patients were subjected to a thorough history collection, complete clinical examination, and weight recording upon admission before IV fluid treatment and again at discharge. Infants were weighed 2 hours after complete IV rehydration and then weighed again every 2 hours until they achieved a stable weight that differed by less than 2% from the previous weight. At that time, the rehydrated infants were considered ready to be discharged as long as their clinical examination allowed. Weight was measured while the infants were undressed using the same calibrated study scale. The percentage dehydration was determined using the following formula: (discharge weight − admission weight)/discharge weight × 100%. The post-dehydration or discharge weight was defined as the first weight with less than a 2% of difference between 2 consecutive weight measurements. Patients with a percentage weight change of less than 5% were considered to be mildly (nonsignificant) dehydrated, whereas a 5% to 10% change was considered moderate dehydration and >10% was considered severe dehydration. Significant dehydration was defined as greater than a 5% weight change (6,12,13). We followed rapid rehydration protocol (20–40 ml/kg of isotonic sodium chloride 0.9% solution or Ringer lactate over 1–2 hours) (26). After rapid rehydration, ORS usually introduced after about 1 to 2 hours to complete the rehydration process with 50 to 100 ml of ORS after each diarrheal stool according to WHO recommendation.

BEDSIDE ULTRASOUND

Bedside ultrasound (US) was performed by a pediatric cardiologist or expert radiologist who were on duty during patient's enrollment using a Vivid 7(GE Healthcare, Horten, Norway) machine with 7 and 4S probes. The physicians performing ultrasound were blinded to the treating pediatrician's clinical diagnosis of the degree of dehydration and the treating pediatricians were blinded to the ultrasound results. The ultrasound examination was performed with patients in the supine position with measurements obtained in B mode. The probe was placed in the sub-xiphoid region in the transverse plane to visualize both the Ao and IVC in cross-section immediately above the vertebral column. A short video loop of this view was saved for future review. The maximum internal anteroposterior (AP) diameter of the IVC during expiration was measured. The maximum internal AP diameter of the Ao during systole was measured. The IVC/Ao diameter ratio was measured by dividing the maximum IVC diameter (obtained at expiration) by the maximum Ao diameter (obtained during systole). The probe position was chosen based on where the study investigator felt the best view could be obtained. The video loops saved by the radiologist were again reassessed later by our pediatric cardiologist, and the video loops captured by the pediatric cardiologist were reassessed by the expert radiologist to assess inter-rater reliability.

All these measurements were taken before IV fluid therapy and again at hospital discharge. After enrollment, the treating pediatricians recorded their clinical determination of the degree of dehydration. The patient's vital signs, clinical score, and volume of IV fluid administered were also recorded.

The primary outcome was the assessment of the accuracy of the IVC/Ao diameter ratio for predicting significant dehydrations in infants compared with the percentage weight change, where a percentage weight change greater than 5% was considered the gold standard criterion for significant dehydration. The secondary outcome was to assess the accuracy of clinical diagnosis by a physician for predicting the degree of dehydration relative to the percentage weight change.

STATISTICAL ANALYSIS

The sample size was calculated using a value of 0.72 for the area under the curve (AUC) of the IVC/Ao diameter ratio for predicting significant dehydration in infants based on a previous study (22). On the basis of this calculation, we found that 110 infants with significant dehydration would be needed to achieve a power of 80% with $\alpha = 0.05$. The collected data were organized, tabulated, and statistically analyzed using SPSS version 17 (SPSS Inc, Chicago, USA). All parametric data were analyzed by independent Student *t*-test. All nonparametric data were analyzed by chi-squared test. The percentage weight changes as well as changes in the IVC/Ao ratio and the IVC and Ao diameters between the prehydration and posthydration ultrasound examinations were calculated. A receiver operating characteristic (ROC) curve was used to assess the diagnostic value of the IVC/Ao diameter ratio and physician opinion for predicting significant dehydration compared with the gold standard, percentage weight change after rehydration.

TABLE 1. Characteristics of patients' groups according to the degree of dehydration (by % weight change)

	Degree of dehydration (% weight change)			
Variables	Nonsignificant (n = 66)	Significant (n = 134)	Test of variable	*P* value
Age (months) [mean ± SD]	12.33 ± 5.14	11.37 ± 6.09	*t* = −0.779	0.438
Diarrhea Duration (days) [mean ± SD]	6.85 ± 1.89	6.61 ± 1.84	*t* = −0.599	0.551
Diarrhea Frequency (motions/day) [mean ± SD]	6.61 ± 2.32	6.67 ± 2.21	*t* = −1.948	0.054
Intravenous fluids ($mlg \cdot kg^{-1} \cdot h^{-1}$) [mean ± SD]	23.64 ± 4.89	32.84 ± 10.56	*t* = 4.751	<0.001*
Pre-hydration Weight (kg) [mean ± SD]	8.83 ± 2.31	9.02 ± 2.05	*t* = 0.423	0.673
Post-hydration Weight (kg) [mean ± SD]	9.18 ± 2.39	9.79 ± 2.27	*t* = 1.247	0.215
Weight change (%) [mean ± SD]	3.85 ± 0.92	7.79 ± 2.08	*t* = 10.370	<0.001*
Sex, N (%)				
Male	20 (30)	64 (47.7)	$X^2 = 2.766$	0.132
Female	46 (70)	70 (52.3)		
Dehydration (weight %)				
Mild	66 (100)	0 (0)	$X^2 = 1.000$	<0.001*
Moderate	0 (0)	114 (85)		
Severe	0 (0)	20 (15)		
Residence, N (%)				
Urban	34 (51.5)	62 (46.3)	$X^2 = 0.244$	0.674
Rural	32 (48.5)	72 (53.7)		
Feeding, N (%)				
Breast	28 (42.4)	54 (40.3)	$X^2 = 0.041$	0.989
Nonbreast	38 (57.6)	80 (59.7)		

*Significant.

The inter-rater reliability in this study was assessed between the ultrasound measurements performed by the pediatric cardiologist and those performed by the expert radiologist using a 2-way mixed-effects model. The interclass correlation coefficients (ICCs) and their 95% confidence intervals (CI) were calculated to assess the degree of reliability. A *P* value was considered statistically significant if <0.05.

RESULTS

Two hundred dehydrated infants younger than 24 months were included in the study (96 boys and 104 girls); their characteristics are shown in Table 1. Infants with nonsignificant dehydration (n = 66) and those with significant dehydration (n = 134) as determined by the percentage weight change between their prehydration and discharge or posthydration weight were compared. Volumes of IV fluid used for treatment were 20 ml/kg per 1 to 2 hours in 35% of patients, 20 to 40 ml/kg per 1 to 2 hours in 48% of patients, and greater than 40 ml/kg per 1 to 2 hours in 17% of patients. Children with significant dehydration received more IV fluid than those with nonsignificant dehydration ($P < 0.001$). The mean change in weight was greater in infants with significant dehydration (7.79%) than in infants with nonsignificant dehydration (3.85%; $P < 0.001$), with a mean difference of 3.94% (95% CI −4.54% to −3.34%) between groups (Table 1).

Overall, the mean IVC diameter increased by 28.12% between the prehydration and posthydration ultrasound exams in all studied infants. The IVC diameter increased from 7.57 ± 0.89 to 9.69 ± 1.02 mm in infants with nonsignificant dehydration and from 7.07 ± 0.61 to 10.37 ± 1.21 mm in infants with significant dehydration. The mean change in IVC diameter was greater in subjects with significant dehydration (31%) than in those with nonsignificant dehydration (22%; $P < 0.001$), with a mean difference of 9% (95% CI −12.15% to −6.75%) between groups. The mean Ao diameter, however, increased by only 1.28% between the prehydration and posthydration ultrasound exams in all studied infants. It increased from 9.64 ± 0.94 to 9.75 ± 0.87 mm in infants with nonsignificant dehydration and from 9.94 ± 0.94 to 10.08 ± 0.95 mm in infants with significant dehydration. The mean change in Ao diameter was not significantly different between infants with significant dehydration (1.36%) than infants with nonsignificant dehydration (1.12%; $P = 0.645$), with a mean difference of 0.5% (95% CI −1.25% to 0.87%) between groups. The mean change in the IVC/Ao diameter ratio was greater in infants with significant dehydration (30.38%) than in those without significant dehydration (20.9%; *P* value < 0.001), with a mean difference of 9.45% (95% CI −12.31% to −6.75%) between groups. It increased from 0.78 ± 0.04 to 0.99 ± 0.05 in infants with nonsignificant dehydration and from 0.71 ± 0.05 to 1.03 ± 0.06 in infants with significant dehydration (Table 2 and Supplementary Figure 1, Supplemental Digital Content 2, *http://links.lww.com/MPG/B237*).

The test characteristics of the prehydration IVC/Ao ratio and physician clinical diagnosis using the percent change in body weight as the gold standard are shown in Table 3. The IVC/Ao ratio had an AUC of 0.87 with a sensitivity of 82% and a specificity of 91% for predicting significant dehydration at a cut-off point of 0.75 (Fig. 1). In contrast, a physician's clinical diagnosis had an AUC of 0.73, with a sensitivity of 70%, and a specificity of 63% for predicting significant dehydration relative to the percent weight change. Assessment of the inter-rater reliability showed that the IVC/Ao diameter ratio measurement in our study had an ICC of 0.80% (95% CI 0.75% to 0.83%).

DISCUSSION

Accurate assessment of dehydration, which is common in infants and children, is essential as it can direct treatment to either IV or oral fluid rehydration. Unrecognized dehydration or incorrect estimation of its degree can adversely affect the morbidity and mortality of a dehydrated infant (27). Therefore, the search for a rapid, noninvasive, and accurate method for assessing the degree of hydration in infants is mandatory especially in countries with limited resources.

TABLE 2. Ultrasound measurements in studied patients

	Degree of dehydration (% weight change)		t-test	
	Non-significant (n = 66)	Significant (n = 134)		
Variables	Mean ± SD	Mean ± SD	t	P value
Prehydration IVC diameter, mm	7.57 ± 0.89	7.07 ± 0.61	−3.270	0.001*
Posthydration IVC diameter, mm	9.69 ± 1.02	10.37 ± 1.21	2.757	0.007*
Prehydration aortic diameter, mm	9.64 ± 0.94	9.94 ± 0.94	1.497	0.138
Posthydration aortic diameter, mm	9.75 ± 0.87	10.08 ± 0.95	1.701	0.092
Prehydration IVC/Ao ratio	0.78 ± 0.04	0.71 ± 0.05	−6.522	<0.001*
Posthydration IVC/Ao ratio	0.99 ± 0.05	1.03 ± 0.06	3.134	0.2

Ao = aorta; IVC = inferior vena cava.
*Significant.

TABLE 3. Sensitivity, specificity, positive likelihood ratio, negative likelihood ratio and accuracy of prehydration inferior vena cava to aorta ratio compared with those of physicians' clinical diagnosis for detection of significant dehydration in studied infants

Assessment method	Sensitivity, %	Specificity, %	LR+	LR −	Accuracy. %
Prehydration IVC/Ao ratio (<0.75)	82	91	7.88	3.12	87
Physicians clinical diagnosis	70	63	2.13	0.352	73

Ao = aorta; IVC = inferior vena cava; LR− = negative likelihood ratio; LR+ = positive likelihood ratio.

The ultrasound measurement of IVC/Ao diameter ratio represents a new, quick, and simple noninvasive method of assessing dehydration in children (5,16). The Ao has lower compliance than the IVC; therefore, the change in aortic diameter with a change in intravascular volume is minimal, in contrast to the IVC. In our study, the mean increase in the aortic diameter between the prehydration and posthydration examination was only 1.28%, whereas the mean increase in the IVC diameter between the prehydration and posthydration examination was 28.12%. These findings were consistent with previous studies (5,16).

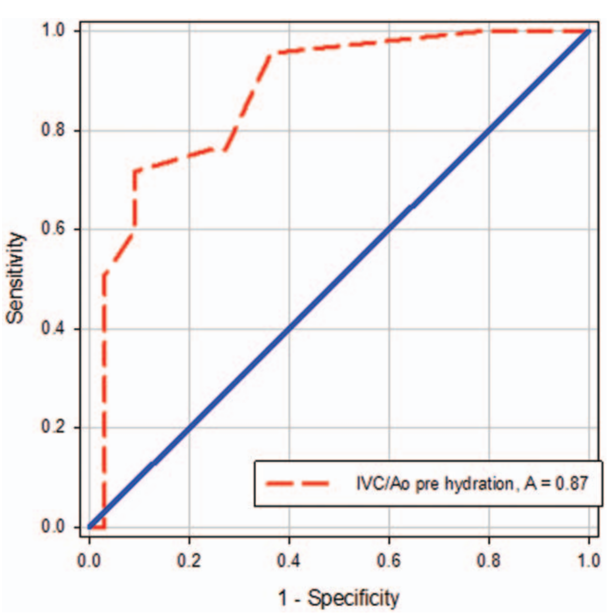

FIGURE 1. Receiver operating characteristic curves of the prehydration inferior vena cava to aorta ratio for detecting significant dehydration relative to the percent weight change. The area under the curve is 0.87. IVC/Ao = inferior vena cava to aorta, ROC = receiver operating characteristic.

In our study, the IVC/Ao diameter ratio had an AUC of 87% (95% CI 0.79–0.95) with a sensitivity of 82% and a specificity of 91% at a cut-off point of less than 0.75. Contradictory results have been obtained regarding the efficacy of the IVC/Ao diameter ratio in assessing the degree of dehydration in children. Levine et al (16) studied 73 children under the age of 15 years with acute diarrhea in Rwanda and reported that the IVC/Ao diameter ratio had an AUC of 76% for predicting severe dehydration, with a sensitivity of 93% and a specificity of 59%. Another study performed by Jauregui et al (22) reported that the IVC/Ao diameter ratio had a sensitivity of 67% and a specificity of 71% at cut-off point of 0.8 for predicting significant dehydration in children younger than 18 years. A similar study conducted by Chen et al (5) demonstrated that the IVC/Ao diameter ratio predicted significant (>5%) dehydration in 112 patients under 18 years with a sensitivity of 86% and a specificity of 51% at a cut-off point of 0.8. These prior 3 studies showed similar results to our study despite the lower specificity of the IVC/Ao ratio, which could be explained by the wide age range of the children involved in these studies (up to 18 years of age), whereas our study included only infants younger than 24 months. Our results, however, contradict the results obtained by Modi et al (23), who found that the IVC/Ao diameter ratio was a poor predictor for dehydration in children younger than 5 years because of its low sensitivity (67%) and specificity (49%), with an AUC of 60%. This difference could be because of the performance of bedside ultrasonography by clinical nurses with some training in their study, whereas our study was performed by a well-trained radiologist or a pediatric cardiologist. Other reasons for the difference could include the choice of a different cut-off point or the use of a more specific age group in our research. Finally, the inter-rater reliability of our study had an ICC of 0.80 (95% CI 0.75%–0.83%).

We included clinical diagnosis by a physician because this is frequently used in clinical practice to assess dehydration. Clinical diagnosis by a physician had an AUC of 0.73, with a sensitivity of

70%, and a specificity of 63% for predicting significant dehydration. Therefore, our study confirmed the findings of Jauregui et al (22), who found that clinical diagnosis by a physician is a poor predictor for significant dehydration in children.

Therefore, an IVC/Ao diameter ratio below 0.75 can be considered as an accurate, simple, rapid, and dependable method for detecting significant dehydration in infants, thus limiting the unnecessary use of IV fluids and decreasing the duration of hospital stays, as recommended by the American College of Emergency Physicians (ACEP) (28). This finding is of extreme importance in low-income countries such as ours, where resources such as hospital beds and IV fluids are limited. Further studies are needed to evaluate whether ultrasound combined with clinical assessment can more accurately predict dehydration in infants than either ultrasound or clinical assessment alone.

Limitation of the study: performance of ultrasound by specialists, which may not be applicable in many settings. We assessed the discharge weight as the first stable weight that was less than 2% of difference on 2 consecutive weight measurements; therefore, the time period during which the discharge weight was obtained was not standardized for all included infants.

CONCLUSIONS

The IVC/Ao diameter ratio can be used as a reliable predictor for diagnosing significant dehydration in infants.

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