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Interobserver Agreement of Inferior Vena Cava Ultrasound Collapse Duration and Correlated Outcomes in Children With Dehydration

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Objective: Dehydration is a common concern in children presenting to pediatric emergency departments and other acute care settings. Ultrasound (US) of the inferior vena cava (IVC) may be a fast, noninvasive tool to gauge volume status, but its utility is unclear. Our objectives were to determine the interobserver agreement of IVC collapse and collapse duration, then correlate IVC collapse with the outcome of intravenous (IV) versus oral (PO) rehydration.

Methods: We conducted a prospective study by enrolling patients 0 to 21 years old with emesis requiring ondansetron or diarrhea requiring IV hydration. Clinical operators interpreted US examinations in real time to determine whether the IVC was collapsed. Two blinded reviewers interpreted the US videos to determine IVC collapse and collapse duration. Cohen's kappa(κ) was calculated for reviewer-reviewer and reviewer-operator agreement. Primary outcomes were PO versus IV rehydration, and admitted versus discharged.

Results: One hundred twelve patients were enrolled, and 102 had complete data for analysis. The mean age was 7.2 years with 51% female. Twenty-nine patients received IV hydration. The reviewer-operator agreement for IVC collapse was κ = 0.57 (95% confidence interval [CI], 0.38–0.75) and interreviewer agreement was κ = 0.93 (95% CI, 0.83–1.0). The interreviewer agreement for collapse duration was κ = 0.66 (95% CI, 0.51–0.82). All patients with noncollapsed IVCs tolerated PO hydration. The likelihood of receiving IV hydration was correlated with the duration of IVC collapse (P = 0.034).

Conclusions: Based on a novel dynamic measure of IVC collapse duration, children with increasing duration of IVC collapse correlated positively with the need for IV rehydration. Noncollapsing IVCs on US were associated with successful PO rehydration without need for IV fluids or emergency department revisits.

Key Words: inferior vena cava, point-of-care ultrasound, IVC collapse duration, dehydration

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Dehydration is a common concern in children presenting to pediatric emergency departments (EDs) and other acute care settings.[1] Clinical management often hinges upon the decision of oral (PO) versus intravenous (IV) rehydration. Clinical dehydration scores have been used in children younger than 5 years,[2] but its utility in guiding clinical management in suspected dehydration is unclear.[3,4]

Point-of-care ultrasound assessment of the inferior vena cava (IVC) is a quick and noninvasive technique to assess intravascular volume status. In pediatric patients, it has been shown that IVC ultrasound can be obtained with good interrater reliability.[5] It has been observed that healthy euvolemic children do not have 100% collapse of the IVC[6]—that is, the inner walls of the IVC do not come into contact—whereas such collapse is commonly observed in pediatric ED patients with various degrees of dehydration.

We developed a novel measure for IVC ultrasound. Unlike prior work analyzing static images to determine IVC diameters measured against aorta diameters,[7–10] which was found to be insufficiently accurate for predicting dehydration[11] and thus seldom used in clinical pediatric practice,[12] we tracked IVC collapse as a function of time, conceptualized as the "IVC collapse duration." Our goal was to assess the interreviewer reliability of IVC ultrasound in children with suspected dehydration and correlate the collapse duration with the clinical outcomes of PO versus IV rehydration.

METHODS

Study Design

We conducted a prospective observational study by enrolling a convenience sample of patients up to 21 years old who presented to our pediatric ED from October 1, 2015, to December 31, 2016. Our ED receives 35,000 visits per year. Inclusion criteria were as follows: (1) history of emesis being treated with ondansetron and/or (2) history of diarrhea with suspected dehydration. Unstable patients (eg, hypotension) requiring resuscitation were excluded, but we did not exclude patients with chronic medical conditions. We

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Author Contributions: A.Z.Z. conceptualized and designed the study, performed initial data analyses, drafted the initial manuscript, and critically reviewed the manuscript for important intellectual content. R.S.G. supervised overall conduct of the study, including data analyses; provided statistical and technical support; and critically reviewed the manuscript for important intellectual content. E.J.H. conceptualized and designed the initial study protocol, enrolled patients into the study, collected data, and reviewed and revised the manuscript. M.N.V. and E.T.T. enrolled patients into the study, collected data, and reviewed and revised the manuscript. J.W.T. supervised overall conduct of the study, enrolled patients into the study, collected data, performed data analyses, provided statistical and technical support, conceptualized and designed the study, performed initial data analyses, drafted the initial manuscript, and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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consented and enrolled patients after triage. The clinical operators assessed the patient and made the decision of PO versus IV hydration. Subsequently, they performed the IVC ultrasound. Patient demographics, clinical dehydration scores,[3,4] and outcomes were recorded: IV versus PO hydration, and admitted versus discharged. Enrolled patients were followed for unscheduled health care or ED revisit 1 week from the index ED visit. Our institutional review board approved this study. We obtained written informed consent from parents/guardians for patients younger than 18 years, and from patients 18 to 21 years. In addition, we obtained assent from patients 7 to 17 years old.

A Sonosite M-Turbo ultrasound system with a 5- to 1-MHz P21 phased-array transducer on cardiac preset was used to image the IVC. Six-second videos of the IVC, via the retrospective save option, were obtained using point-of-care ultrasound with patients in the supine position during spontaneous, normal tidal breathing. The transducer was placed in the subxiphoid region using the liver as the acoustic window to visualize the IVC in sagittal view at the level of entry into the right atrium (Fig. 1). The IVC diameter was visualized just caudal to the junction of the IVC and hepatic vein. One to three videos were recorded for each patient. A single operator acquired and interpreted the videos in real time and determined whether the IVC was collapsed (Video 1, https://youtu.be/CbxneCiP-bI) or not (Video 2, https://youtu.be/RSunFFxRjN4). Collapse was defined as the opposing walls of the vein coming into contact at any point in time. In reference to prior literature in IVC imaging,[7] this means the vein was "100% collapsed" at some point in time.

The operators consisted of 4 pediatric emergency medicine (PEM) attendings and 1 PEM fellow. Two of the attendings had performed more than 25 scans and were considered "experienced." The other 2 attendings and 1 fellow, who had received standard emergency ultrasound training for credentialing at our institution, were trained in IVC assessment by one of the experienced operators. They imaged the IVCs of at least 3 patients under direct supervision by the senior PEM ultrasound investigator until adequate views of the IVC were obtained before study enrollment. Each patient was evaluated by 1 of these 5 operators in the ED.

Two blinded reviewers (one novice, one experienced) independently reviewed the videos to determine whether the IVC was collapsed or not. For videos in which there was IVC collapse, the duration of IVC collapse was stratified into 3 semiquantitative categories: brief, intermediate, and extended collapse. The stratification was done by visual estimation, where a reviewer marked the duration as "intermediate" if the opposing walls of the IVC are in contact for approximately half the total duration of the video. If the contact time seemed significantly less than half the time, it was marked as brief collapse. If the contact time was significantly greater than half the time, it was marked as extended collapse (videos: http://bit.ly/2rJbYoN, http://bit.ly/2DF8Gol and http://bit.ly/2DIZKSI). If a reviewer was uncertain, the video was replayed at one-half to one-third the frame rate until the reviewer felt confident in the decision. If multiple videos were obtained on a patient, they were all reviewed at the native frame rate and at slower rates as needed. The novice reviewer was taught by the experienced reviewer using a training set of ten 6-second IVC videos at both the native and half frame rates.

Data Analysis

Cohen's kappa(κ) with 95% confidence intervals (CIs) was calculated between the 2-blinded reviewers, and between the reviewers and the operator. Pearson χ^2 test was performed to correlate the prevalence of IV rehydration with IVC collapse duration (brief, intermediate, extended). Statistical analyses were performed using IBM SPSS Statistics 25.

RESULTS

One hundred twelve patients were enrolled, and 102 had complete data for analysis. The other 10 patients had difficult-to-visualize IVCs because of limited subxiphoid windows, crying, or both. The mean age was 7.2 years, with 51% being female. Twenty-nine patients (28%) received IV rehydration, and of those, 20 of 29 were offered IV fluids based on initial clinical evaluation, whereas 9 of 29 received IV fluids after failing PO hydration due to emesis. Five patients were admitted: 2 for gastroenteritis and diarrheal illnesses and 3 for nongastroenteritis diagnoses (Crohn flare, cyclic vomiting syndrome, and migraine headache). All 5 patients had IVC collapse on point-of-care ultrasound.

Between the operators and the blinded reviewers, there was moderate agreement as to whether the IVC was collapsed ($\kappa = 0.57$; Table 1). Approximately half of the patients were imaged by the 2 experienced operators (n = 51). Between the experienced operators and the blinded reviewers, there was substantial agreement on IVC collapse ($\kappa = 0.84$).

Between the two blinded reviewers, there was excellent agreement on IVC collapse ($\kappa = 0.93$; Table 1). In determining the IVC collapse duration—brief, intermediate, or extended—there was substantial agreement ($\kappa = 0.66$). In each case of disagreement, the 2 reviewers were only one category apart: brief versus intermediate, or intermediate versus extended duration of collapse.

Patients with IVC collapse were significantly more likely to receive IV rehydration, with an odds ratio of 5.82 (95% CI, 1.27–26.65; Pearson $\chi^2 = 6.23$; $P = 0.013$; Table 2). In fact, all

FIGURE 1. The IVC in sagittal view. Left panel: collapsed IVC; right panel: noncollapsed IVC.

TABLE 1. Agreement (κ) of IVC Collapse

	κ	95% CI
Observer-Operator Agreement		
All operators (n = 102)	0.57	0.38–0.75
Experienced operators (n = 51)	0.84	0.67–1.0
Interobserver agreement		
Yes/no IVC collapse (n = 102)	0.93	0.83–1.0
Duration of collapse: brief/ intermediate/extended (n = 78)	0.66	0.51–0.82

patients without IVC collapse tolerated PO hydration and were discharged without ED revisit within 1 week. The 2 exceptions were nongastroenteritis cases: one patient had Crohn's Colitis flare and was started on IV fluid per standard of care, and the other developed abdominal pain suspicious for appendicitis after enrollment and was made nil per os and started on IV fluid. Five patients required inpatient admission; all had IVC collapse—1 brief, 3 intermediate, and 1 extended duration of collapse—and all received IV fluids (Table 2).

When stratified by the semiquantitative measure of the duration of IVC collapse (none, brief, intermediate, and extended; http://bit.ly/2DIZKSI), the percent of patients receiving IV hydration was significantly correlated with the duration of IVC collapse: χ^2 8.65, $P = 0.034$ (Fig. 2).

DISCUSSION

In this study, we described a novel measure for IVC ultrasound. Prior work analyzing static images or M-mode to determine maximum and minimum IVC diameter and normalizing to aorta diameter in pediatric patients has been well described in the literature,[7–11] but in our experience, it is seldom used, if at all in clinical practice.[12] We tracked IVC collapse as a function of time, conceptualized as the IVC collapse duration. In analyzing the dynamic videos, we set out to determine the interobserver agreement of the duration of IVC collapse: specifically, the duration of contact of the opposing walls over several respiratory cycles in 6-second videos. Once substantial interreviewer and experienced operator-reviewer agreements were established, we correlated the IVC collapse duration—as assessed by the blinded reviewers—with the clinical decision of PO versus IV rehydration. Our results suggest that the lack of IVC collapse may predict successful PO rehydration and discharge from the ED.

The novel concept of IVC collapse duration as a semiquantitative measure is based on visual estimation, not exact automated tracking of how long the opposing walls of the IVC come in contact. Although the categorization of brief, intermediate, and extended collapse is not an exact quantitation, the substantial interreviewer agreement (κ = 0.66) suggests that it is a feasible method of estimating a patient's volume status. To our knowledge,

TABLE 2. IVC Collapse and Rehydration Outcome

	Tolerated PO	Received IV
No IVC collapse	22	2*
Has IVC collapse	51	27†

*Nongastroenteritis cases: 1 Crohn disease and 1 suspected appendicitis.
†Five of the 27 patients required inpatient admission.

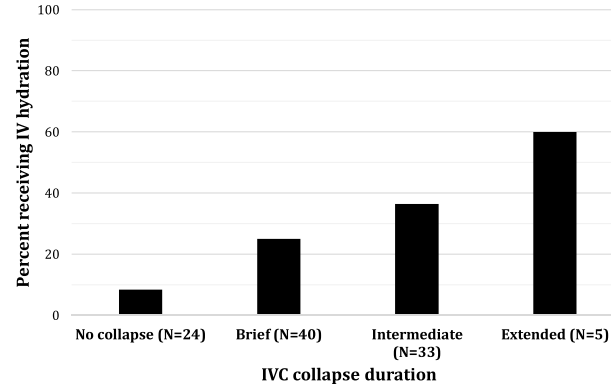

FIGURE 2. Percent of patients receiving IV hydration as a function of IVC collapse duration. $\chi^2 = 8.65$, $P = 0.034$.

the dynamic analysis of IVC ultrasound as a function of time has not been reported. We showed substantial interreviewer agreement in the IVC collapse duration. Children with more extended IVC collapse were more likely to receive IV rehydration, which suggests that our novel method can facilitate the management decision of PO versus IV rehydration.

In adult patients, there is good interrater reliability of the IVC diameter,[13] and the diameter has been shown to correlate well with the central venous pressure and right atrial pressure.[14] In pediatric patients, it has been shown that the IVC can be imaged with high reliability.[5] The IVC-to-aorta diameter ratio, but not the IVC diameter itself, has been shown to have moderate sensitivity for children with severe dehydration in the developing world, but was insufficiently accurate for clinical use.[9,11] It is seldom used in advanced health care settings,[10,12] and current evidence does not support the routine use of ultrasound to evaluate the hydration status in children.[15]

In a prior study by one of the authors,[6] it was noted that healthy euvolemic children in a general pediatric clinic did not have 100% collapse of the IVC viewed in long axis—that is, the inner walls of the IVC never come into contact—whereas such collapse is commonly observed in our pediatric ED patients with various degrees of dehydration. This prompted our conceptualization of the aforementioned measurement, which may be useful in identifying children that can be discharged from the ED without an PO rehydration trial.

Limitations

There were a number of limitations to our study. First, we enrolled a convenience sample of patients when clinician-sonologists were available as operators in our pediatric ED; thus, it is difficult to know if our sample approximates the general population of children with suspected dehydration. Second, the disease severity in our population was skewed toward mild dehydration, as the number of admitted patients was very low at 5%. Third, we were unable to analyze 9% of patient data owing to difficulties in visualizing the IVC. However, this percentage is similar to that previously reported in a study of adults.[13]

Finally, the reviewers had the luxury of time to analyze the videos outside the clinical setting. However, we believe that the assessment of IVC collapse duration can be performed in real time by clinician-operators after sufficient training and experience. We believe that it is a simple finding that may facilitate clinical decision making in children with suspected dehydration. This is in contrast to the IVC-to-aorta diameter ratio[7–11] and cross-sectional area index,[16,17] which, in our experience, is difficult to apply in real-time clinical practice and has insufficient accuracy.[11,18] With

advances in computer vision technology and artificial intelligence algorithms, it may be possible in the near future to precisely calculate IVC collapse duration that augments visual estimation, and better informs the management of dehydration in real time (eg, IVC ultrasound with artificial intelligence algorithm video: https://youtu.be/sIep-S74hd8).

CONCLUSIONS

Based on a novel dynamic measure of IVC collapse duration, children with increasing duration of IVC collapse correlated positively with the need for IV rehydration. Noncollapsing IVCs on ultrasound were associated with successful PO rehydration without the need for IV fluids or ED revisits.

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