Correlating IVC Measurements with Intravascular Volume Changes at Three Distinct Measurement Sites

A Thesis submitted to the University of Arizona College of Medicine – Phoenix
in partial fulfillment of the requirements for the Degree of Doctor of Medicine

Kimberly Yang

Class of 2014

Mentor: Teresa Wu, MD, FACEP

DEDICATION

The author would like to thank the following for their integral role in this study:

Daniel Haase, MD

Shannon K. Gust, MD

Kai-Ning Khor, BS, MPH

David Drachman, PhD

And also to TWu for her great mentorship and most importantly, because she's always got my back.

ABSTRACT

Bedside ultrasound of the inferior vena cava (IVC) has grown to be an important tool in the assessment and management of critically ill patients. This study endeavors to examine which location along the IVC is most highly correlated with changes in intravascular volume status: (1) the diaphragmatic juncture (DJ) (2) two centimeters caudal to the hepatic vein juncture (2HVJ) or (3) left renal vein juncture (LRVJ). Data was collected in this prospective observational study on patients in the emergency department who were at least 16 years of age, being treated with intravenous fluids (IVF). Measurements of the IVC were recorded at each site during standard inspiratory and expiratory cycles, and again with the patient actively sniffing to decrease intrapleural pressures. IVF was then administered per the patient's predetermined treatment, and the same six measurements were repeated after completion of fluid bolus. The difference in caval index (dCI) was calculated for all six data sets and correlated with the mL/kg of IVF administered. There was a statistically significant correlation between mL/kg of IVFs administered and dCI at all three sites (DJ: $r = 0.354$, p value = 0.0002; 2HVJ: $r = 0.334$, p value = 0.0003; LRVJ: $r = 0.192$, p value = 0.03). The greatest correlation between amount of fluids administered and dCI was observed along the IVC at the site 2 cm caudal to the juncture of the hepatic veins (2HVJ). This site is also where the largest change in diameter can be appreciated on ultrasound during intravascular volume resuscitation. Our data also suggests that every mL/kg of IVFs administered should change the dCI by 0.86-1.00%. This anticipated change in IVC diameter can be used to gauge a patient's response to intravascular volume repletion.

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INTRODUCTION

Background

Bedside ultrasound of the inferior vena cava (IVC) is an important tool in the assessment and management of critically ill patients and can provide very useful information about a patient's intravascular volume status within a matter of minutes. Over the years, physicians in acute care settings have found that ultrasound measurements of the IVC can help guide intravenous fluid management and direct resuscitation options [1]. An evaluation of a patient's IVC can be performed quickly at the bedside, and serial examinations can be conducted in a non-invasive manner, with little to no risk to the patient.

There are currently a variety of methods available for assessing a patient's intravascular volume status. These methods include, but are not limited to, the use of pulmonary artery catheters, central venous pressure monitors, esophageal Doppler analysis, arterial waveform analysis, mitral valve inflow evaluation, and tissue Doppler studies [2].Many of these methods require invasive procedures that place the patient at risk for complications such as hemorrhage, infection, and accidental puncture or laceration of adjacent structures. It is also common for clinicians to evaluate physical exam findings such as skin turgor, mucous membrane appearance, and capillary refill to help gauge a patient's intravascular volume status. Studies have shown that these physical exam findings can be very subjective and are limited by the interpretation of the practitioner. Blood pressure, heart rate, and pulse pressures are also common measurements assessed in the evaluation of patient's in shock, but these parameters have been shown to be unreliable indicators of intravascular blood volume unless the severity of shock is extreme [3].

The idea of using bedside ultrasound to evaluate the IVC and its relationship to intravascular volume status has been met with great enthusiasm over the past decade. The application is portable, non-invasive, and the results have been shown to be highly reliable in various patient populations. Practitioners have found that the IVC can be easily visualized via

bedside ultrasound, and that measurements of the IVC correlate directly with pressures and readings obtained from more invasive monitoring devices [2,4].

When assessing the IVC with ultrasound, it is important to remember that the IVC is a highly compliant vessel, whose size varies with changes in total body water and the respiratory cycle [5]. During inspiration, negative intrapleural pressure develops, which results in increased venous return to the heart [6,7]. As flow increases through the IVC, intraluminal pressure decreases and the diameter of the highly compliant IVC decreases. The difference in diameter at inspiration (IVC_i) and expiration (IVC_e) is referred to the collapsibility index (also known as the caval index, CI) and is defined as:

$$\frac{IVCe - IVCi}{IVCe}$$

The CI has been shown to be higher in patients with shock, and can also be used to determine if a patient has low central venous pressures [8].

Impact

Assessing the IVC diameter can be easily performed at the bedside in a critical patient who is lying supine or sitting upright. Saul et al. demonstrated that the approach in the anterior midaxillary line using the liver as an acoustic window yields the most reliable measurements [9]. Taking measurements of the IVC requires little to no cooperation on behalf of the patient and the procedure is relatively painless. Capturing all the requisite measurements takes very little time, and the patient is not exposed to any unnecessary radiation or risks from the procedure. Data has shown that IVC measurements can be obtained with a high inter-rater reliability and while precise measurement using the caliper function can yield more precise calculations, some have proposed that clinicians can reliably estimate IVC collapse, and thus the caval index, by gross visual inspection alone [1].

Recent studies have shown that there are typically three common sites of measurement along the IVC: (1) at the diaphragmatic junction (DJ), (2) two centimeters distal to the hepatic vein inlet (2HVJ), and (3) at the left renal vein junction (LRVJ). Wallace *et al* studied the degree of variation in IVC collapsibility at these three sites and recommended recording measurements

at 2HVJ and LRVJ only [10]. The data from this study were collected in healthy volunteers and consisted of students and residents present in the emergency department (ED) at that time. While other studies have proposed which site is the best to measure the CI, none have established which location along the IVC is most accurate for measuring the changes before and after fluid resuscitation.

Aims and Goals

Although there is great interest in using IVC ultrasound to assess intravascular volume status and guide resuscitation, there are still many unanswered questions in regards to this relatively novel ultrasound application. Our study attempted to address some of these questions. In the first portion of our study, we attempted to identify whether the diaphragmatic juncture (DJ), two centimeters caudal to the hepatic vein juncture (2HVJ), or the left renal vein juncture (LRVJ) is the most accurate, dynamic, and reproducible spot for determining intravascular volume status. We then evaluated whether changes in IVC diameter can be predicted based on patient weight and amount of fluid administered.

MATERIALS AND METHODS

Study Design

      This was a prospective, observational study where bedside ultrasound was used to obtain serial IVC diameter measurements in emergency department (ED) patients. Bedside ultrasonography is used routinely in the department where data was collected, and the hospital's institutional review board approved the research study prior to its commencement.

Study Setting and Population

      This study was conducted at a Level 1 trauma center with an annual ED census of approximately 65,000 patients. Patients were eligible for enrollment if they were at least 16 years of age and the treating physician identified the patient as requiring intravenous fluid as part of the management plan. Patients were excluded if they were unable to give consent. Other exclusion criteria included positive-pressure ventilation, trauma, or pregnancy greater than 20 weeks of gestational age.

Study Protocol

      Emergency medicine residents, emergency ultrasound fellows, and emergency medicine attending physicians were trained on how to perform IVC measurements via bedside ultrasound prior to study commencement. All participants received both a didactic and hands-on instructional course, and were supervised by an ultrasound fellowship-trained and credentialed emergency physician. Prior to the transabdominal ultrasound of the IVC, patient blood pressure, height, and weight were recorded. Patients were placed in the supine position with the head at 0 degrees. Using a phased array transducer on a SonoSite M-Turbro (Bothell, WA), the IVC and aorta were identified in the transverse plane in the subxiphoid window and both vessels were confirmed using color or spectral Doppler. Once the IVC was identified in the transverse plane, the probe was rotated 90 degrees so that a long-axis view of the IVC was obtained. Measurements of the IVC were obtained in the long-axis view along the anterior to mid-axillary line on the right side of the patient, using the liver as an acoustic window or via the

subxiphoid approach. The practitioner performing the scan was advised to take measurements in the view that provided them with the best visualization of the walls of the IVC.

Initial measurements of the IVC diameter were taken at the DJ, 2HVJ, and LRVJ during the patient's standard inspiratory and expiratory cycle at baseline. Then, all three measurements were repeated with the patient actively sniffing to decrease intrapleural pressures. Intravenous fluids (IVFs), typically normal saline, were then administered per the individual treatment plans as pre-determined by the treating physician, and the same six measurements were taken after the fluid bolus was completed. The difference in caval index (dCI) was calculated for all six data sets. The Pearson correlation coefficient (r) with the mL/kg of IV fluids administered was then calculated for the dCI at each individual location.

RESULTS

A total of 117 patients were recruited for enrollment in the study based on the inclusion and exclusion criteria. The mean patient height was 65.45 inches with a mean weight of 73.62 Kg. All six measurements were successfully obtained in 100 of the 117 enrolled patients. Data was missing on 17 patients secondary to obstructing bowel gas limiting the view of the IVC during subsequent measurements, lack of patient cooperation with subsequent scans, or patients leaving the ED prior to the completion of data acquisition.

The mean difference in IVC collapse (dCI) was 0.97 cm at the DJ, 1.15 cm at 2HVJ, and 0.8 cm at LRVJ. Measurements at both the diaphragmatic juncture (DJ) and 2 cm caudal to the juncture of the hepatic vein (2HVJ) had the greatest correlation (DJ; $r = 0.334$, p value = 0.00002; 2HVJ; $r = 0.354$, p value = 0.0003).

There was a statistically significant correlation between mL/kg of IVFs administered and dCI at all three sites (DJ: $r = 0.334$, p value = 0.0002; 2HVJ: $r = 0.354$, p value = 0.0003; LRVJ: $r = 0.192$, p value = 0.03). Both the DJ and the 2HVJ measurements yielded a power of 98% and 96% while LRVJ had a power of 52%.

The largest average dCI was seen at the 2HVJ site. The smallest average dCI was seen at the DJ site. The average dCI/mL/kg of IVFs administered was 0.90% at the DJ site, 1.00% at the HVJ site, and 0.86% at the LRVJ site. There was a statistically significant correlation between mL/kg of IVFs administered and dCI at all three sites evaluated.

Figure 1: dIVC vs. mL/kg at the Diaphragmatic Juncture (DJ).
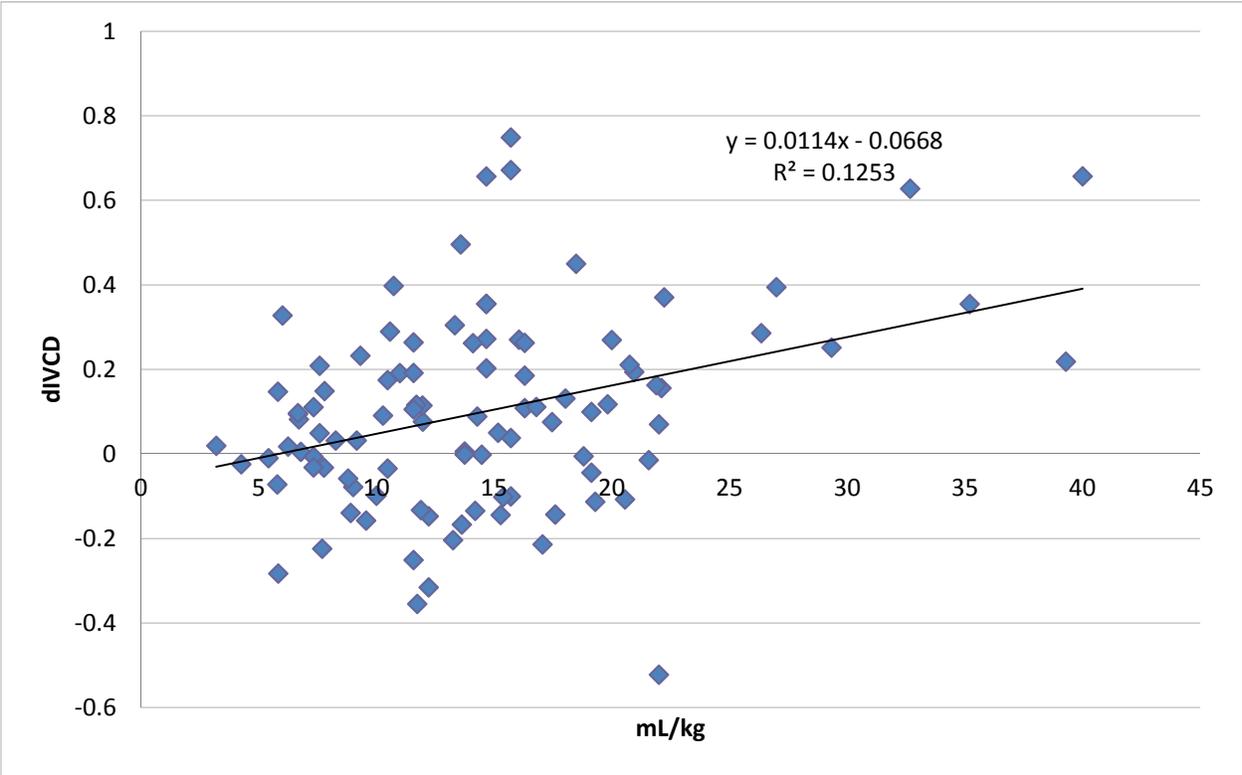
Figure 2: Diaphragmatic juncture of the IVC as measured by ultrasound

Figure 3: dIVC vs. mL/kg 2 cm distal to Hepatic Vein Junction (2HVJ).

$y = 0.0099x - 0.0278$
$R^2 = 0.1114$
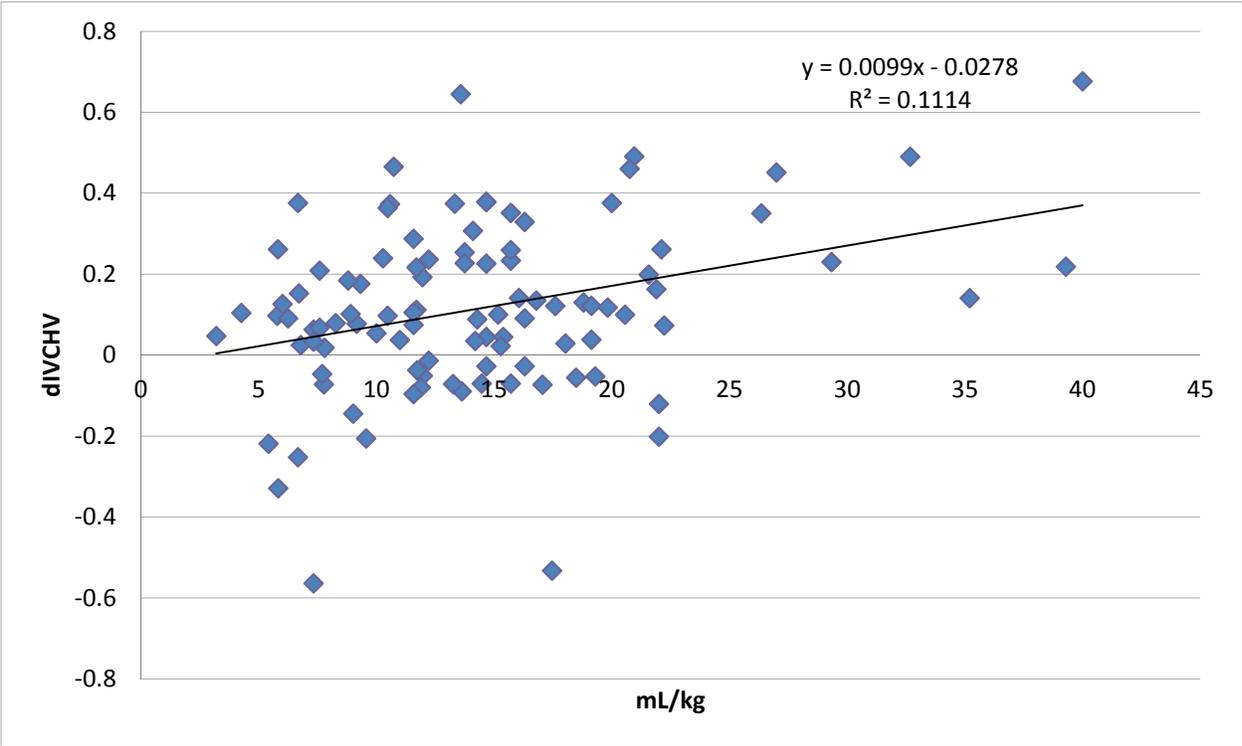
Figure 4: 2cm caudal to the hepatic vein juncture site as measured by ultrasound

Figure 5: dIVC vs. mL/kg at Left Renal Vein Junction (LRVJ).

$y = 0.0045x + 0.0153$
$R^2 = 0.0367$
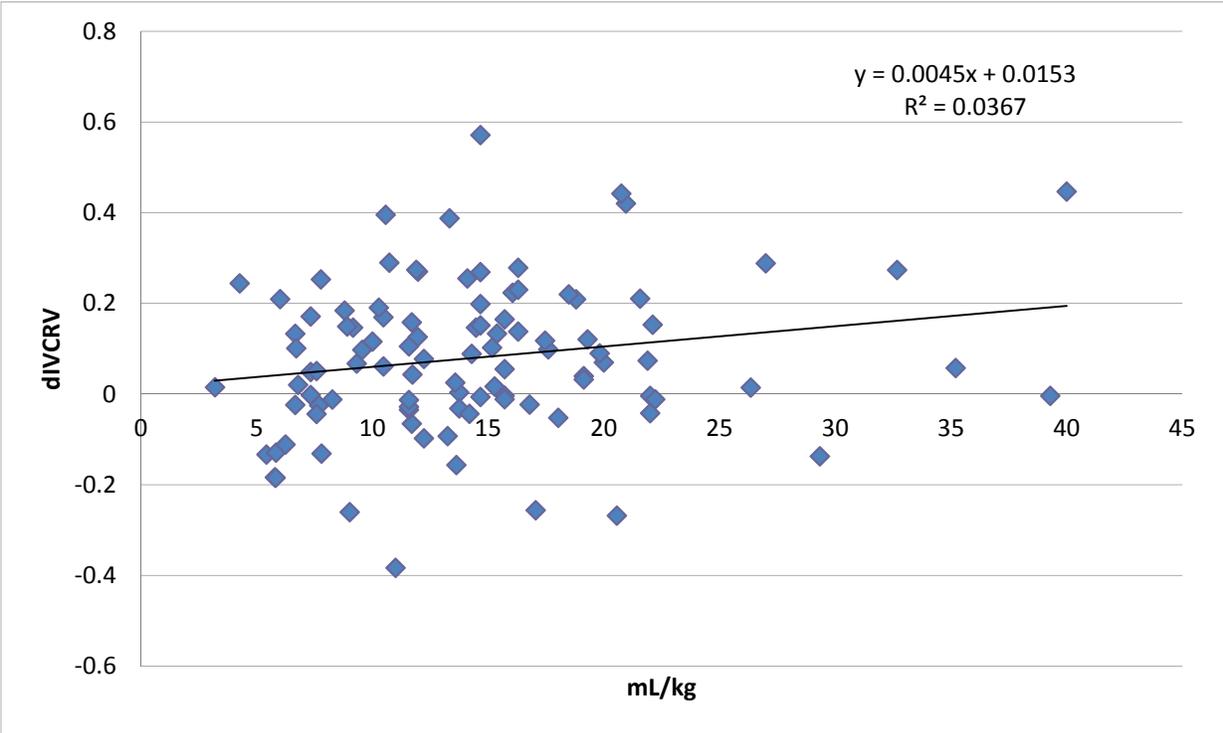
Figure 6: Left renal vein juncture on the IVC as measured by ultrasound

DISCUSSION

When measuring the IVC diameter during the assessment and resuscitation of patients requiring intravascular volume repletion, the three most common sites of measurement in recent literature are (1) at the diaphragmatic junction (DJ), (2) two centimeters distal to the hepatic vein inlet (2HVJ), and (3) at the left renal vein junction (LRVJ). These three points on the IVC are the most common sites for evaluation because they are the easiest sites to identify distinctly on bedside ultrasound. The retrohepatic and proximal IVC are most clearly seen on ultrasound when the liver is usually used as an acoustic window. Attempts to visualize the IVC distal to the confluence of the left renal vein is difficult because of overlying bowel gas and lack of an acoustic window. To date, most of the literature mentions analysis of the IVC diameter at one of the three aforementioned sites, but there is no consensus detailing which site provides the most accurate, dynamic, and reproducible measurements for IVC diameter assessment using bedside ultrasound.

The first goal of our study was to determine whether the diaphragmatic juncture (DJ), two centimeters caudal to the hepatic vein juncture (2HVJ), or the left renal vein juncture (LRVJ) demonstrates the most dynamic change during an assessment for intravascular volume status. During a resuscitation, it is important to know which part of the IVC demonstrates the greatest change in diameter during intravascular volume repletion. This appreciable change in diameter is what is being used to assess a patient's response to fluid administration during point-of-care ultrasound. If a practitioner performs serial measurements at a site on the IVC that does not normally fluctuate in size based on intravascular volume status, the sonographic data obtained will not be useful in gauging response to IV fluid administration.

Based on our data the greatest correlation between the amount of intravenous fluids administered and the dCI was seen along the IVC 2 cm caudal to the juncture of the hepatic veins (2HVJ). The data from our study makes sense in regards to what would be expected from an anatomical standpoint. In most patients, the walls of the IVC are tethered to walls of the diaphragm as it enters into the thoracic cavity at its foramen at T8 and joins the right atrium. Because of this tethering, ultrasound analysis of the IVC at this level may not demonstrate as

large of a difference in IVC diameter with changes in intrapleural pressures and during intravascular volume resuscitation. The hepatic veins typically join the IVC anywhere between 0.5 to 3.0 cm proximal to the ostium of the right atrium and this juncture can be easily visualized on ultrasound. The IVC 2 cm proximal to this juncture is very dynamic and variations with respiration are easily appreciated during sonographic evaluations of the IVC walls at this level. It stands to reason that this is the best site to evaluate the IVC for changes in diameter and to assess the change in caval index during intravascular volume resuscitation. At the level of the left renal vein juncture, the IVC is smaller in diameter and harder to visualize. Because the absolute diameter of the IVC at the LRVJ is smaller than cranial portions of the vessel, changes in diameter at this level are harder to appreciate and accurate measurements at this site are more difficult to reproduce.

The second aim of our study was to evaluate whether changes in the IVC diameter can be predicted based upon the patient's weight and amount of fluid administered. In our study, every mL/kg of IVFs administered was shown to change the dCI by 0.86-1.00%. This proved to be an interesting trend and can be very useful data in the clinical setting. If a patient is receiving intravascular volume repletion, it is useful to know if the IVC diameter is responding and increasing as predicted. If the dCI is not increasing by 0.86 to 1% for every mL/kg of IVFs administered, the patient may not be retaining the fluid intravascularly (ie. hemorrhaging) or the clinical situation may require vasopressor agents to help improve vascular resistance and appropriate distribution of the intravascular volume being administered. Knowing the dCI/mL/Kg can help guide the total volume of fluid resuscitation required based on the patient's weight and help gauge whether or not the patient is demonstrating the predicted response to the fluid administered.

LIMITATIONS

In evaluating the IVC via ultrasound, the major pitfalls encountered are usually secondary to large patient body habitus, obstructing bowel gas, subcutaneous emphysema, and provider experience level with ultrasound. In an attempt to minimize these pitfalls, most IVC ultrasounds are performed in the ED using the lateral approach where the IVC is imaged through the liver at the anterior axillary line. A long-axis view of the IVC can be obtained with this approach using the liver as an acoustic window. The long-axis view allows the practitioner to see the confluence between the IVC, the hepatic veins, and the left renal vein. In order to standardize our ultrasound scanning technique and measurement, we had our practitioners obtain all measurements of the IVC in the long-axis view so that they could easily identify the diaphragm, the hepatic vein joining the IVC, and the left renal vein.

It is important to note that the measured diameter of the IVC in this long-axis view can be smaller than the true diameter of the IVC if the measurements are taken just medial or lateral to the center of the IVC. On a long-axis view of a cylindrical structure, it is impossible to know if the sound waves are directed directly through the center of the structure or if they are tangentially off to one side or the other. Although the long-axis view provides practitioners with the clearest view of the IVC, it is important to note that this view may underestimate the true diameter of the IVC and the data should be interpreted accordingly. In our study, we minimized the tangential cylindrical effect by calculating the % of change in IVC diameter. Further studies are necessary to elucidate the differences between diameter measurements in the short-axis subxiphoid view of the IVC, long-axis subxiphoid view of the IVC, and lateral long-axis view of the IVC. Also, because the IVC is not a perfect cylinder and is typically more lenticular shaped in patients with a normal or sub-normal intravascular volume status, the normal transverse diameter is typically larger than the normal antero-posterior (AP) diameter. Larger studies should be aimed at determining the difference between the dCI when measurements are taken in the AP diameter versus the transverse diameter during resuscitation attempts.

Another limitation of this study is that we do not know whether or not any of our patients had any congenital or anatomical abnormalities that would have led to erroneous IVC diameter measurements. In situations where the diameter values are unexpected and falsely low or high, it may be prudent to take serial measurements at various sites along the IVC to ensure that there are not other confounding factors for the unexpected readings.

CONCLUSION

Our study demonstrated that the greatest correlation between the amount of intravenous fluids administered and the dCI was seen along the IVC 2 cm caudal to the juncture of the hepatic veins (2HVJ) and that this site is where the largest change in diameter can be appreciated on ultrasound during intravascular volume resuscitation. Our data also suggests that every mL/kg of IVFs administered should change the dCI by 0.86-1.00%. This anticipated change in IVC diameter can be used to gauge a patient's response to intravascular volume repletion.

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