The Effect of Weight-based Volume Loading on the Inferior Vena Cava in Fasting Subjects: A Prospective Randomized Double-blinded Trial

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Abstract

Objectives: Inferior vena cava ultrasound (IVC-US) assessment has been proposed as a noninvasive method of assessing volume status. Current literature is divided on its ability to do so. The primary objective was to compare IVC-US changes in healthy fasting subjects randomized to either 10 or 30 mL/kg of intravenous (IV) fluid administration versus a control group that received only 2 mL/kg.

Methods: This was a prospective randomized double-blinded trial set in emergency department (ED) clinical care rooms. Volunteer subjects with no history of cardiac disease or hypertension fasted for 12 hours. Subjects were randomly assigned to receive IV 0.9% saline bolus of 2 (control group), 10, or 30 mL/kg over 30 minutes. IVC-US was performed before and 15 minutes after each fluid bolus.

Results: Forty-two fasting subjects were enrolled. Analysis of variance (ANOVA) comparison showed that IVC-US was unable to detect any significant difference between the control group and those given either 10 or 30 mL/kg fluid, whether using maximum or minimum IVC diameter or caval index (IVC-CI). The groups receiving 10 and 30 mL/kg each had a statistically significant change in IVC-CI; however, the 30 mL/kg group had no significant change in either of the mean IVC diameters.

Conclusions: Overall, there were statistically significant differences in mean IVC-US measurements before and after fluid loading, but not between groups. Fasting asymptomatic subjects had a wide inter-subject variation in both baseline IVC-US measurements and fluid-related changes. The degree of IVC-US change in association with graded acute volume loading was not predictably proportional between our subjects.

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In the emergency department (ED), the etiology of hypotension is often unclear based on history and physical examination alone. Correctly identifying the volume state, in particular, is an area of ongoing research and controversy in the medical community.

Acute volume resuscitation is one of the main treatments for patients with undifferentiated shock. However, volume loading may have deleterious effects if the patient is in cardiogenic shock or is already volume overloaded. Other patients may receive insufficient fluids if severely volume depleted or vasodilated.

In the intensive care unit, volume status is often estimated with invasive monitoring such as central venous pressure (CVP) and pulmonary capillary wedge pressure. However, the time required to place, calibrate, and utilize these devices makes them impractical in most ED settings. Furthermore, the validity of these measurements and the associated procedural risks have been the subject of much debate.

As an alternative, bedside inferior vena cava ultrasound (IVC-US) evaluation has been considered to be an accessible, noninvasive estimate of CVP. The IVC-US examines the proximal IVC diameter, as well as...
the variation in diameter during a spontaneous respiratory cycle, known as the caval index (IVC-CI) or IVC collapsibility. However, the literature is divided on the accuracy of IVC-US, with some studies reporting a strong correlation and others reporting less accuracy between IVC-US and CVP. The CVP measurement, however, is an inaccurate measurement of volume status. Neither the single CVP value nor the dynamic CVP change in response to fluid boluses was able to predict the volume status or cardiac output increases in response to volume loading in healthy or critically ill subjects.

In a previous observational study, IVC-US changes occurred during acute volume loading interventions in symptomatic hypotensive ED patients. The varied fluid volumes and permutations of cardiopulmonary illness among subjects did not permit an evaluation of the use of IVC-US in determining volume status. For these reasons, this study begins to address the plausibility of using IVC-US as a marker of volume status by focusing on healthy subjects, will test their baseline IVC-US findings, and will measure IVC-US changes in response to controlled volume expansion interventions. Our hypothesis was that larger fluid boluses would lead to proportional IVC-US changes. Our primary objective was to compare IVC-US changes in healthy, fasting subjects randomized to either 10 or 30 mL/kg intravenous (IV) fluid administration versus a control group that received only 2 mL/kg. The secondary objective was to determine the intersubject variability in baseline IVC characteristics. A small subset was analyzed to assess for intra-subject temporal variance of IVC-US characteristics and fluid-associated changes.

METHODS

Study Design
This was a randomized, double-blinded, prospective study. The hospital’s institutional review board approved the study. All enrolled volunteer subjects provided informed consent before participation.

Study Setting and Population
We reserved ED clinical care rooms equipped with cardiac and oxygenation monitors. Advertisements were distributed within our health care center explaining recruitment and study goals. Interested candidates contacted the study coordinator and preenrollment forms were used to verify compliance with inclusion and exclusion criteria. Nine subjects were designated as “intrasubject” candidates based on willingness and ability to return for retesting with the same volume load in 1 to 2 weeks.

Inclusion criteria were 1) age ≥ 18 years; 2) 12 hours of food and fluid restriction prior to scheduled testing; 3) systolic blood pressure above 95 mm Hg; 4) consent to be randomized to receive IV 0.9% normal saline fluid boluses of 2, 10, or 30 mL/kg over 30 minutes; and 5) consent to have IVC-US performed before and after the assigned fluid challenge. Exclusion criteria consisted of age <18 years; systolic blood pressure below 95 mmHg; history of congestive heart failure; active cardiopulmonary disease; any fluid, nicotine, or caffeine intake within 12 hours prior to enrollment; strenuous physical exertion within 4 hours of enrollment; known pregnancy; and gel allergy or sensitivity.

Study Protocol
Subjects were assigned to Group 1 (2 mL/kg), Group 2 (10 mL/kg), or Group 3 (30 mL/kg) using computer-randomized, preprinted, and sealed envelopes. To maintain blinding, the only person viewing the contents of the envelope was the research nurse.

Prior to the start of the study, the US fellowship director provided a IVC-US didactic lecture, hands-on practical instruction, and training to the research team that consisted of a senior emergency medicine (EM) resident (ZK), the US fellow (ML), and the emergency US fellowship director (AW).

Each subject’s baseline weight (kg) and height (cm) were recorded. Blood pressure and heart rate were obtained before and after the fluid bolus. Each subject received continuous pulse oximetry monitoring throughout the study period. Research nurses inserted the peripheral IV catheters.

To ensure blinding, both sonologist and subject were blinded to the infusion volume. The sonologist performed baseline US measurements before the assignment group was determined. The research nurse administered the infusion over 30 minutes after the sonologist had performed the first US measurements. After infusion, the IV tubing and bags were discarded to maintain blinding. The second set of IVC-US measurements was performed by the same sonologist 15 minutes after the fluid bolus. Subjects enrolled for second testing in the intrasubject arm received the same protocol at the same time of day, 1 to 2 weeks later.

Image Acquisition. Images were acquired with a Philips CX50 (Philips Ultrasound, Andover, MA) US machine, and an S-5-1 phased-array probe. Two-dimensional views of the proximal IVC were obtained. Caliper measurements of the IVC diameter, using M mode, were taken approximately 1 cm caudal to the hepatic vein and perpendicular to the IVC long axis during the subject’s normal quiet spontaneous respiratory cycle. The IVC-CI was calculated using [maximum IVC diameter – minimum IVC diameter]/maximum IVC diameter during a spontaneous quiet breathing cycle. IVC-US measurements were performed before the volume load (time 0) and 15 minutes after the volume load (time 1). All subjects remained supine for 5 minutes before any baseline IVC-US measurements and remained supine for the duration of the study. All US studies had real-time supervision by two or more research investigators. The emergency US fellowship director was present for all scans and performed real-time supervision and peer review of adherence to the scan protocol. Digital US images were saved.

Data Analysis
Fourteen subjects were required in each of the three groups to detect an effect size of 1.25, with a = 0.05 and a power of 80%. We considered an effect size of 1.25 (a difference of 1.25 standard deviations [SD]) to be
clinically and biologically important. Descriptive statistics including means ± SDs or counts and percentages were calculated. Paired t-tests compared the differences between data measured at time 0 and time 1. This analysis was repeated separately for Groups 1, 2, and 3. One-way analysis of variance (ANOVA), followed by Tukey’s test when appropriate, was used to compare the differences between the means of the groups. Pearson’s correlation was used to test for linear relationships among the variables.

A paired t-test was used to test for differences between the two encounters for those subjects who were tested and measured on two different days. A two-tailed p-value of less than 0.05 was considered statistically significant.

RESULTS

Forty-two subjects were enrolled. Demographics and clinical characteristics are presented in Table 1. Nine subjects returned for repeat testing between 1 and 2 weeks. A total of 51 testing sessions occurred. The mean (±SD) time from baseline measurement to post-infusion measurement was 59.0 (±7.1) minutes. The mean (±SD) volume load for Group 1 was 150 (±29) mL, Group 2 was 748 (±122) mL, and Group 3 was 2,162 (±418) mL. None of the subjects had a decrease in pulse oximetry readings during the study. Three of the investigators (ZK, ML, AW) performed all of the US evaluations (both pre- and postbolus IVC-US) on 21, 18, and 13 subjects, respectively.

During the subject’s first visit, Pearson’s correlation coefficients were used to compare IVC measurements with weight, height, and body mass index. All Pearson’s correlation coefficients were between −0.12 and 0.15.

Analysis of variance testing was then performed for IVC minimum (IVC min) and maximum diameter (IVC max) and IVC-CI in response to fluid loading. Results for the mean change in IVC min for all three groups were p = 0.40, IVC max p = 0.33, and IVC-CI p = 0.53. Although Table 2 shows that there were several statistically significant changes within groups in response to fluids, there was not a significant change when the groups were compared to one another. Mean differences in IVC-US for each group and overall are shown in Table 3.

Another aim of the study was to determine how different volume loads affect the IVC diameter and IVC-CI. Mean results for measurements pre- and post-volume loading and paired t-test values are reported in Table 2. Both the IVC diameter and IVC-CI responses to fluid loading are depicted in Figure 1.

Table 2 shows the intersubject variation in baseline IVC-US characteristics. The range of maximum IVC diameter was 0.85 to 4.53 cm. Twenty-three of 42 (55%) subjects had an IVC max greater than 2.0 cm. The range of IVC min was 0.34 to 4.0 cm. The mean (±SD) baseline IVC-CI of the 42 subjects was 0.33 (±0.15) cm. Thirty-three of the 42 (78%) fasting subjects had baseline IVC-CI measurements of less than 0.4 cm.

The third aim of the study was to determine the intra-subject variance of a subset of the subjects. Nine subjects, three from each group, underwent repeated testing at 1 to 2 weeks using the same protocol and had similar times and volume loads. The mean (±SD) protocol time differences (minutes) between first and second visit were 12 (±2.6) minutes for Group 1, 4.3 (±4.9) minutes for Group 2, and 1.7 (±4.0) minutes for Group 3. The mean (±SD) volume differences for Groups 1–3 for different testing sessions were 0.2 (±1.8), 15 (±21), and 4.9 (±28) mL, respectively. Mean (±SD) intrasubject temporal differences in prefluid IVC max for Groups 1–3 were 0.42 (±0.35), 0.27 (±0.54), and 0.36 (±1.36), respectively. Mean (±SD) differences in IVC min for Groups 1–3 were 0.03 (±0.17), −0.58 (±0.70), and −0.64 (±1.29) cm and in IVC-CI were 0.10 (±0.06), 0.22 (±0.19), and 0.10 (±0.10) cm, respectively. There were some significant differences in baseline IVC characteristics on different testing days. Comparisons of fluid-associated mean IVC-US changes, by groups, on different days

Table 1

<table>
<thead>
<tr>
<th>Subject Characteristics</th>
<th>Group 1 (2 mL/kg Bolus), n = 14</th>
<th>Group 2 (10 mL/kg Bolus), n = 14</th>
<th>Group 3 (30 mL/kg Bolus), n = 14</th>
<th>All Subjects, N = 42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age distribution, yr</td>
<td>20–30</td>
<td>30–40</td>
<td>40–50</td>
<td>50–60</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Age, yr</td>
<td>32 (9)</td>
<td>35 (12)</td>
<td>32 (9)</td>
<td>33 (10)</td>
</tr>
<tr>
<td></td>
<td>10/4 (71%/29%)</td>
<td>6/8 (43%/57%)</td>
<td>7/7 (50%/50%)</td>
<td>23/19 (55%/45%)</td>
</tr>
<tr>
<td>Sex: male/female (percent distribution)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>75.45 (±14.69)</td>
<td>74.78 (±12.20)</td>
<td>72.07 (±13.93)</td>
<td>74.10 (±13.39)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>175.33 (±12.69)</td>
<td>168.73 (±9.23)</td>
<td>174.35 (±12.90)</td>
<td>172.80 (±11.81)</td>
</tr>
<tr>
<td>Body mass index</td>
<td>24.42 (±3.47)</td>
<td>23.52 (±3.36)</td>
<td>26.22 (±2.37)</td>
<td>24.72 (±3.23)</td>
</tr>
<tr>
<td>Blood pressure, mm Hg</td>
<td>123.07 (±75.07)</td>
<td>119.35 (±74.79)</td>
<td>116.71 (±73.36)</td>
<td>119.71 (±74.40)</td>
</tr>
<tr>
<td>(±14.38/9.99)</td>
<td>(±16.85/8.00)</td>
<td>(±6.33/5.17)</td>
<td>(±13.24/7.81)</td>
<td></td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>66.64 (±12.21)</td>
<td>69.71 (±7.22)</td>
<td>58.92 (±11.32)</td>
<td>65 (±11.20)</td>
</tr>
<tr>
<td>Pulse oximetry, %O₂ sat</td>
<td>98.14 (±1.41)</td>
<td>98.85 (±1.10)</td>
<td>98.71 (±1.54)</td>
<td>98.57 (±1.36)</td>
</tr>
</tbody>
</table>

Data are reported as mean (±SD).
DISCUSSION

An ideal tool for measurement of volume status should have an established normal reference range, it should be reproducible, and its intrasubject temporal variation should be less than its response to volume status changes or fluid intervention. One of the debatable aspects within emergency echocardiography, however, is the role of IVC-US in assessing the patient’s volume status. IVC measurements may potentially be used in clinical decision pathways to provide information on the adequacy of fluid resuscitation or as a guide to initiate volume loading. Some hospital centers now use IVC-US instead of CVP in modified early goal-directed therapy for sepsis protocols. However, the estimation of volume status based on a single IVC-US assessment should be less than its response to volume status changes within the spectrum of IVS-US values is also not reproducible, and its intrasubject temporal variation must be further elucidated. The sensitivity of IVC-US in detecting volume status changes or fluid intervention has also been reported. Lyon et al. reported a decrease in IVC diameter measured and an increase in IVC-CI after blood donation. However, Resnick et al. did not find differences in IVC-US values in subjects after 500 mL of blood loss. Reports on IVC-US assessments during acute volume loading are quite varied in study design and subjects studied. An objective evaluation of IVC-US as an indicator of volume status has not been fully explored in the EM literature. Intersubject variance in IVC-US, as well as the intrasubject variance, must be further elucidated. The sensitivity of IVC-US in detecting volume status changes within the spectrum of IVS-US values is also an important step in the evaluation of IVC-US as a diagnostic tool.

Although other studies in the EM literature have reported on the IVC-US findings in healthy subjects, our study was specifically designed to investigate the IVC-US dynamics of healthy subjects and their response to graded acute volume loading. We chose 2 mL/kg as a clinically negligible fluid volume load to serve as a minimal volume load control group and to facilitate double blinding in the study. Ten mL/kg was chosen as an intermediate fluid volume

Table 2
IVC Measurements With Weight-based Volume Loads

<table>
<thead>
<tr>
<th>IVC Measurement</th>
<th>Group 1 (2 mL/kg Bolus), n = 14</th>
<th>Group 2 (10 mL/kg Bolus), n = 14</th>
<th>Group 3 (30 mL/kg Bolus), n = 14</th>
<th>All Subjects, N = 42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVC max, cm</td>
<td>1.91 (±0.46)</td>
<td>1.97 (±0.42)</td>
<td>2.34 (±0.73)</td>
<td>2.07 (±0.57)</td>
</tr>
<tr>
<td>IVC min, cm</td>
<td>1.27 (±0.47)</td>
<td>1.34 (±0.45)</td>
<td>1.73 (±0.87)</td>
<td>1.4 (±0.64)</td>
</tr>
<tr>
<td>IVC-CI</td>
<td>0.35 (±0.13)</td>
<td>0.34 (±0.14)</td>
<td>0.29 (±0.18)</td>
<td>0.33 (±0.15)</td>
</tr>
<tr>
<td>Postbolus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVC max, cm</td>
<td>2.14 (±0.32)</td>
<td>2.24 (±0.16)</td>
<td>2.40 (±0.45)</td>
<td>2.26 (±0.34)</td>
</tr>
<tr>
<td>IVC min, cm</td>
<td>1.47 (±0.51)</td>
<td>1.77 (±0.27)</td>
<td>2.04 (±0.51)</td>
<td>1.76 (±0.50)</td>
</tr>
<tr>
<td>IVC-CI</td>
<td>0.33 (±0.19)</td>
<td>0.21 (±0.10)</td>
<td>0.15 (±0.11)</td>
<td>0.23 (±0.16)</td>
</tr>
</tbody>
</table>

Data are reported as mean (±SD).
IVC = inferior vena cava; IVC-CI = IVC caval index; IVC min = IVC minimum diameter; IVC max = IVC maximum diameter.

Table 3
Mean Differences in IVC Measurements With Weight-based Volume Loads

<table>
<thead>
<tr>
<th>Mean (±SD) Differences</th>
<th>Group 1 (2 mL/kg Bolus), n = 14</th>
<th>Group 2 (10 mL/kg Bolus), n = 14</th>
<th>Group 3 (30 mL/kg Bolus), n = 14</th>
<th>All Subjects, N = 42</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVC max, cm</td>
<td>0.23 (±0.28)</td>
<td>0.26 (±0.32)</td>
<td>0.05 (±0.55)</td>
<td>0.18 (±0.40)</td>
</tr>
<tr>
<td>95% CI, p value</td>
<td>0.07 to 0.39, 0.008</td>
<td>0.08 to 0.45, 0.008</td>
<td>−0.27 to 0.37, 0.73</td>
<td>0.06 to 0.31, 0.005</td>
</tr>
<tr>
<td>IVC min, cm</td>
<td>0.19 (±0.40)</td>
<td>0.43 (±0.34)</td>
<td>0.31 (±0.61)</td>
<td>0.31 (±0.46)</td>
</tr>
<tr>
<td>95% CI, p value</td>
<td>−0.03 to 0.42, 0.09</td>
<td>0.24 to 0.63, 0.0004</td>
<td>−0.05 to 0.66, 0.08</td>
<td>0.17 to 0.46, &lt;0.0001</td>
</tr>
<tr>
<td>IVC-CI</td>
<td>−0.02 (±0.17)</td>
<td>−0.13 (±0.12)</td>
<td>−0.13 (±0.11)</td>
<td>−0.09 (±0.14)</td>
</tr>
<tr>
<td>95% CI, p value</td>
<td>−0.12 to 0.08, 0.65</td>
<td>−0.19 to −0.06, 0.001</td>
<td>−0.20 to −0.07, 0.001</td>
<td>−0.14 to −0.05, &lt;0.0001</td>
</tr>
</tbody>
</table>

IVC = inferior vena cava; IVC-CI = IVC caval index; IVC min = IVC minimum diameter; IVC max = IVC maximum diameter.
bolus and 30 mL/kg as within the range of standard initial fluid boluses in symptomatic patients (20 to 40 mL/kg). The study not only reports IVC-US changes in response to different weight-based volume loading, but also demonstrates intersubject variations in IVC dimensions before any fluid loading intervention.

A wide range of individual IVC-US responses to volume loading was observed even with standard imaging technique and controlled volume loading conditions. This study did not investigate the changes of IVC-US in symptomatic patients or include patients with possible states of extreme volume depletion or volume overload. Other studies have employed IVC-US in clinical assessments of volume status assessments.\(^{15,29}\) The role of IVC-US in clinical decision-making with patients was not tested by our study design. We did not evaluate the IVC-US at any other time points after the fluid bolus completion. It is possible that delayed volume redistribution or changes to IVC-US may occur beyond the 15-minute post-fluid bolus time point that we used.

There were some changes in IVC-US in association with volume expansion that were not consistent or predictable. Two subjects assigned to Group 1 had greater decreases in IVC-CI than anticipated. Those same subjects also had greater increases in IVC diameter. One subject had a significant increase in IVC-CI after the 2 mL/kg fluid bolus as a result of decreases in both IVC max and IVC min. In Group 2, one subject of 14 had an increase in IVC-CI after the fluid bolus. In Group 3, two subjects had an IVC diameter greater than 2 SDs above the mean. Both had low initial IVC-CI and decreases in IVC diameter after the fluid bolus.

Subjects with larger baseline IVC diameters also had low IVC-CI values (closer to zero). The postfluid percentage change in IVC-CI was therefore limited in subjects with low baseline IVC-CI. The presence of two outliers in Group 3 may have affected the statistical significance of mean IVC-US changes for Group 3 following fluid intervention.

By ANOVA testing, we did not find statistically significant and proportional IVC-US changes in response to increased volume loading as hypothesized. Although there was an overall increase in IVC diameter and decrease in IVC-CI associated with volume loading, there was no statistically significant difference in mean IVC-US changes between the control group and the 10 and 30 mL/kg groups. Changes in IVC-CI were

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**Figure 1.** Graphs of individual IVC baseline diameters and IVC-CI changes for each volume loading group. IVC = inferior vena cava; IVC-CI = IVC caval index.
similar in Groups 2 and 3. We did not test whether the fluid bolus associated IVC-US changes were discernible by bedside visual estimates as was reported in earlier research.\textsuperscript{13}

Our subjects had a wide range of baseline IVC diameters and IVC-CI values. The mean IVC-US change associated with volume loading was greater in the Group 2 and 3 subjects than within the control group.

The subset of nine subjects who returned for repeat testing after the washout period received the same earlier volume load protocol with repeat measurements taken by the same sonologist. There were a few notable variations in the baseline IVC diameters, but baseline IVC-CI and postfluid directional changes were similar.

We suggest caution with employing the isolated IVC-US to clinically determine or interpret volume status. The majority of our fasting healthy subjects had IVC-US measurements that could categorize them as being within the “target” range (as a CVP surrogate) for adequate fluid resuscitation (Early Goal Directed Therapy in Sepsis guidelines\textsuperscript{30}); however, they also could erroneously suggest volume overload state based on current interpretations and references of recent IVC-US studies.

LIMITATIONS

Our study sample size of 42 subjects allowed for an evaluation of intersubject variation in baseline measurements, but 14 subjects per group is a small sample size for aggregate data on IVC-US response to each of the weight-based volume loading options. The analysis of differences per subject including those with repeat testing. The 45-minute duration of the protocol may not have been sufficient to demonstrate the natural course of IVC-US dynamics as a result of acute volume loading. Continued changes due to redistribution of intravascular volume may have been missed.

We chose to perform IVC-US measurements of subjects during natural quiet breathing. There are differences in IVC diameter and IVC-CI measurements associated with greater inspiratory efforts. We avoided instructed breathing efforts such as “sniff” testing to reduce the translational measurement errors of shifting the US beam along the long axis and off the short axis of the IVC.\textsuperscript{28}

Intraobserver and interobserver agreement and measurement variances were not tested. Variations could be due to sampling and measurement differences. We limited this by having close peer review of image acquisition and measurements and ensuring that the same sonologist did both pre- and postbolus IVC-US assessments per subject including those with repeat testing.

Intrasubject temporal variations and changes in response to volume loading were tested. A washout period of 1 week was used. We did not restrict or standardize the diet and fluid intake of the subjects except to require 12-hour fasting before research testing. Our study design and results do not report or predict the changes that may occur within a subject in response to acute volume loss or in response to acute illness such as sepsis. A study design with randomized crossover of different weight-based volumes per subject would offer better internal control than the study design we used.

Four subjects had technically difficult IVC imaging with unclear IVC borders at the preferred measurement site. In these cases, measurements were taken slightly more proximal or distal to what was defined by our protocol. Measurement variations in subjects with smaller IVC diameters were also more challenging and therefore susceptible to false variations due to caliper placement and shifting off axis. Outliers in direction and magnitude of IVC-US change were present in Group 3. This likely altered the estimation of the effect of a 30 mL/kg fluid bolus in this subgroup.

All of our study subjects were spontaneously breathing, and respiratory variations in the IVC were due to IVC collapsibility. This may not translate into the same effect or results in mechanically ventilated patients where insufflation results in IVC distensibility.

Finally, the clinical utility of IVC-US assessments was not investigated by our study design. However, because of the wide variation in baseline IVC-US findings and fluid responses in our asymptomatic healthy subjects, it is unclear how the single or dynamic IVC-US response to volume loading can provide clinical information on volume status, or the adequacy of volume resuscitation, or predict cardiac output improvements in patients without further investigation. This study only assessed IVC characteristics in fasting, asymptomatic subjects and did not associate these characteristics with a four-chamber evaluation of the heart.

CONCLUSIONS

Our findings suggest that inferior vena cava ultrasound has its limitations as a tool for the assessment of volume status or its changes, as healthy subjects displayed a great amount of intersubject variation in both baseline inferior vena cava characteristics and their response to 30-minute volume loading. It is unclear whether inferior vena cava ultrasound measurements can reliably describe, calibrate, and differentiate volume status changes in our group of relatively healthy volunteer subjects. Further studies of controlled volume adjustments of patients at either extreme of volume states should be done to determine the role of single and serial inferior vena cava ultrasound in volume status monitoring.

The authors acknowledge the assistance of the Philips organization, which provided a loan of the ultrasound machine and its transducers to the ultrasound division of our emergency department. No aspect of our research design or outcome was influenced by any of the organization’s personnel. We also acknowledge Sandra Roth, RN, MSN, and Heather Claremont for significant administrative support.

References


