Ultrasound in Emergency Medicine

DOES A SIMPLE BEDSIDE SONOGRAPHIC MEASUREMENT OF THE INFERIOR VENA CAVA CORRELATE TO CENTRAL VENOUS PRESSURE?

Robert A. De Lorenzo, MD, MSM,*†‡ Michael J. Morris, MD,‡§ Justin B. Williams, MD,† Timothy F. Haley, MD,*‡ Timothy M. Straight, MD,*† Victoria L. Holbrook-Emmons, MSN, RN,* and Juanita S. Medina, RMA*

*Department of Clinical Investigation, †Department of Emergency Medicine, Brooke Army Medical Center, Fort Sam Houston, Texas, ‡Masters Degree Program in Clinical Investigation, University of Texas Health Sciences Center at San Antonio, San Antonio, Texas, and §Department of Medicine, Brooke Army Medical Center, Fort Sam Houston, Texas

Corresponding Address: Col. Robert A. De Lorenzo, MD, MSM, Department of Clinical Investigation, MCHE-CI, Brooke Army Medical Center, 3851 Roger Brooke Dr., Fort Sam Houston, TX 78234-6200

Abstract—Background: Bedside ultrasound has been suggested as a non-invasive modality to estimate central venous pressure (CVP). Objective: Evaluate a simple bedside ultrasound technique to measure the diameter of the inferior vena cava (IVC) and correlate to simultaneously measured CVP. Secondary comparisons include anatomic location, probe orientation, and phase of respiration. Methods: An unblinded prospective observation study was performed in an emergency department and critical care unit. Subjects were a convenience sample of adult patients with a central line at the superior venocaval-atrial junction. Ultrasound measured transverse and longitudinal diameters of the IVC at the subxiphoid, suprailiac, and mid-abdomen, each measured at end-inspiration and end-expiration. Correlation and regression analysis were used to relate CVP and IVC diameters. Results: There were 72 subjects with a mean age of 67 years (range 21–94 years), 37 (53%) male, enrolled over 9 months. Seven subjects were excluded for tricuspid valvulopathy. Primary diagnoses were: respiratory failure 12 (18%), sepsis 11 (17%), and pancreatitis 3 (5%). There were 28 (43%) patients mechanically ventilated. Adequate measurements were obtainable in 57 (89%) using the subxiphoid, in 44 (68%) using the mid-abdomen, and in 28 (43%) using the suprailiac views. The correlation coefficients were statistically significant at 0.49 (95% confidence interval [CI] 0.26–0.66), 0.51 (95% CI 0.23–0.71), and 0.50 (95% CI 0.14–0.74) for end-inspiratory longitudinal subxiphoid, midpoint, and suprailiac views, respectively. Transverse values were statistically significant at 0.42 (95% CI 0.18–0.61), 0.38 (95% CI 0.09–0.61), and 0.67 (95% CI 0.40–0.84), respectively. End-expiratory measurements gave similar or slightly less significant values. Conclusion: The subxiphoid was the most reliably viewed of the three anatomic locations; however, the suprailiac view produced superior correlations to the CVP. Longitudinal views generally outperformed transverse views. A simple ultrasound measure of the IVC yields weak correlation to the CVP. Published by Elsevier Inc.

Keywords—central venous pressure; ultrasonography; bedside; inferior vena cava; shock; focused assessment by sonography for trauma

INTRODUCTION

Background

Central venous pressure (CVP) is a key physiologic estimate of preload, which in turn helps define the
intravascular fluid status. It is a particularly important parameter to measure in critically ill and injured patients who may require fluid resuscitation. Unfortunately, measurement of the CVP requires invasive central venous catheters that can be difficult or time-consuming to insert and are associated with complications. A non-invasive means of inferring the CVP would provide clinicians with an acceptable alternative. Gosink was among the first to fully describe a relationship between the imaged diameter of the inferior vena cava (IVC) and CVP (1). Since then, ultrasonography has emerged as a reliable means to measure internal body structures, including the vena cava. Previous studies have shown various correlations between CVP or right atrial pressure and measurements of the IVC (2–7).

Importance

There is considerable emergency and critical care relevance to non-invasive measurements of CVP. Care of emergency patients often requires resuscitation without the benefit of invasive monitoring. Ultrasound is a tool that potentially could provide a rapid and non-invasive means of gauging preload and the need for fluid resuscitation. Because ultrasound machines are relatively light and portable, and many clinicians are trained in their use (e.g., emergency physicians, anesthesiologists, intensivists, and surgeons), the ability to non-invasively measure CVPs could extend patient monitoring capabilities to a variety of settings where direct measurements of the CVP are unavailable or impractical.

Goals of this Investigation

This study examined the correlation between CVP and the IVC diameter as measured by a bedside ultrasonographic technique. In particular, this study evaluated several single-view images obtained at various abdominal locations using easily identified external and internal landmarks. The study used a focused bedside ultrasound examination that is simple to perform. In essence, images and measurements were made in real time and did not require elaborate or time-consuming procedures such as multiple views or complicated measurement techniques (e.g., review of cine images), the need for special equipment (e.g., transesophageal probes), or formal studies (e.g., echocardiography) that usually require a dedicated technician and specialist interpretation (8).

MATERIALS AND METHODS

Study Design

The study was a prospective, cross-sectional observation that utilized a one-time assessment of IVC diameter to determine any correlation with CVP. Our primary hypothesis was that a single view technique using bedside ultrasound measurement of the diameter of the IVC correlates to simultaneously measured CVP in a variety of critical patients. Our secondary objectives included determining which combination of anatomic parameters (probe location and orientation) would demonstrate the highest correlation with CVP, and the effects of mechanical ventilation.

Study Setting and Population

Subjects were recruited from the Brooke Army Medical Center Emergency Department (ED) and critical care units over a 9-month period in 2008–2009. Potential subjects were referred by physicians in the ED or screened on a daily basis from critical care units. Subjects were adults (18 years or older) who had a functioning CVP catheter that already had been placed for clinical indications. Excluded were patients younger than 18 years, and patients in whom the required ultrasound examination would not be appropriate: when the supine position was medically contraindicated or not tolerated (including spontaneously breathing patients with documented severe orthopnea, or documented severe elevations of intracerebral pressure). Subjects with moderate-to-severe tricuspid regurgitation (as determined by prior echocardiogram and documented in the medical record) were excluded because the condition can falsely elevate CVP.

Study Protocol and Measurements

Subjects were placed in the supine position and portable ultrasound images were obtained during end-inspiration and end-expiration. No attempt was made to coach the patient in breathing. We identified the IVC by using sonographically identified landmarks. The IVC was measured at three locations intended to provide a proximal, middle, and distal view of the inferior vena cava: 1.5 cm caudal to the diaphragm at the location of the xiphoid (subxiphoid), 2 cm proximal to the iliac bifurcation (suprailiac), and at a point midway between the two (approximately at the level of the celiac trunk). We chose these locations based on simplicity and reproducibility; previous studies have used similar anatomical locations (2–7).

Measurements were made by obtaining maximal transverse (cross-sectional) and longitudinal diameters using images frozen according to operator judgment (Figure 1). Diameters were measured to the nearest tenth of a millimeter using display calipers in a trailing edge to leading edge technique (9). If unable to obtain an adequate image, the data point was coded either as a result of poor image quality (i.e., gas-filled bowel or large body habitus) or clinical condition (i.e., dressing prevented...
probe contact). All four study sonographers were members of the study team (two emergency physicians, one intensivist, and one research emergency nurse) and were credentialed in bedside ultrasonography or received 3–4 h of specific training and practice in the technique led by the principal investigator before obtaining study measurements. The study institution has active bedside ultrasound training programs for residents in emergency medicine, critical care, and other specialties. We did not time the data acquisition in this study, although in most cases image collection and measurement was estimated to take < 90 s per view.

Data were simultaneously collected from the CVP (or right atrium in the case of a patient with a right heart catheter) monitor. A recalibration, if needed, and a leveling of the external pressure transducer to the subject’s heart (phlebostatic axis) was conducted before the imaging. Additional data were collected, such as vital signs (directly from the patient monitors at the time of imaging) and general medical diagnoses (from the chart). This latter information was used to provide a baseline of the subject population’s characteristics. Study ultrasonographers were independent of the care team (the care team did not have access to the research data). Study personnel performed their own measurements of the vena cava and were blinded to the patient’s condition, but we were unable to blind CVP values.

A Sonosite MicroMaxx® portable ultrasound machine (Bothell, WA) was used with either a 60-mm curved abdominal or 17-mm curved phased array probe. All CVP measurements were made using the institution’s standard clinical pressure monitoring instrumentation, either an M1006B (Philips Component Monitoring System, Philips, Andover, MA), or Hospira Vascular Monitoring System, (Lake Forest, IL). Consent was obtained from study subjects or their surrogates in a manner approved in advance by the governing institutional review board.

**Data Analysis**

Bedside ultrasound measurements of the IVC diameters were compared to CVP. Diameters were determined from frozen images taken at various locations, angles, and phases of respiration. Each subject had 12 measurements taken: three different locations, two diameters viewed in the transverse and longitudinal orientations, and each at the two moments of end-inspiration and end-expiration.

We analyzed the collected data for normality through inspection of scatter plots and histograms. Linear correlation coefficients were calculated to determine the combination providing the best resolution and the minimum standard error. Non-linear (quadratic) regression was also performed for all combinations. As this was a preliminary study, we did not select a pre-determined threshold for clinically significant correlations, preferring instead to explore the range of results that might point toward choices for future study. We did perform exploratory subgroup analysis for subjects receiving mechanical ventilation and those spontaneously breathing, because prior work suggests that positive pressure can affect CVP and clinicians do not often have the option of altering this intervention just to obtain clinical data. Missing values were handled by excluding the data point from the analysis. Sample size was estimated before the start of the study by following the general rule that for regression analysis there should be 30–100 subjects distributed across the range of interest. Data were collected on Microsoft Excel 2007 spreadsheet software (Microsoft Corporation, Redmond, WA) and imported into SPSS v11.5 (SPSS Inc., IBM, Armonk, NY) for statistical analysis.

**RESULTS**

Four operators enrolled 72 subjects with a mean age of 67.2 years (range 21–94 years), 37 (51%) male, over
Central venous pressure monitoring is a mainstay of estimating vascular fluid status and cardiac preload in critically ill and injured patients (10,11). It is the preferred method in the ED and in other situations when a pulmonary artery catheter is not practical (12). Recent criticisms of using CVP to estimate fluid responsiveness notwithstanding, CVP measurements remain the standard of care in shock management (13). The advent of goal-directed therapy in sepsis and permissive-hypotension resuscitation in trauma will likely ensure that the measurement of CVP remains integral in emergency and critical care for the foreseeable future (14,15). Unfortunately, CVP monitoring requires placement of a central venous catheter and attachment of a pressure transducer, which is often difficult in an urgent resuscitation, or even impossible if the clinician is inexperienced or in an austere environment.

Bedside ultrasonography is a commonly used technique that is readily available in the ED, intensive care unit, and elsewhere (16,17). It has even been used in prehospital and combat settings (18,19). Ultrasonography is safe,

Table 1. Vital Characteristics of Study Subjects, n = 65

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>Range</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>66</td>
<td>21–94</td>
<td>15.1</td>
</tr>
<tr>
<td>Percent male</td>
<td>49</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Systolic BP, mm Hg</td>
<td>119</td>
<td>76–180</td>
<td>22.4</td>
</tr>
<tr>
<td>Diastolic BP, mm Hg</td>
<td>61</td>
<td>30–98</td>
<td>13.5</td>
</tr>
<tr>
<td>Respiratory rate (breaths/min)</td>
<td>23</td>
<td>12–58</td>
<td>7.9</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>36.9</td>
<td>34.4–39.2</td>
<td>0.88</td>
</tr>
<tr>
<td>SaO₂, %</td>
<td>98</td>
<td>90–100</td>
<td>2.9</td>
</tr>
<tr>
<td>Mechanically ventilated</td>
<td>28</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Body mass index</td>
<td>30.3</td>
<td>13–54</td>
<td>8.3</td>
</tr>
<tr>
<td>CVP, cm H₂O</td>
<td>10.4</td>
<td>1–34</td>
<td>5.9</td>
</tr>
<tr>
<td>IVC diameter (Tran-end-insp), cm</td>
<td>1.89</td>
<td>1.98–3.93</td>
<td>0.51</td>
</tr>
</tbody>
</table>

BP = blood pressure; SaO₂ = oxygen saturation; CVP = central venous pressure; IVC = inferior vena cava.

Table 2. Summary of Linear Correlation Statistics

<table>
<thead>
<tr>
<th></th>
<th>Tran_End-Exp</th>
<th>Tran_End-insp</th>
<th>Long_End-Exp</th>
<th>Long_End-insp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subxiphoid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rₘean</td>
<td>0.341*</td>
<td>0.421*</td>
<td>0.468*</td>
<td>0.491*</td>
</tr>
<tr>
<td>r₁, Lower</td>
<td>0.089</td>
<td>0.181</td>
<td>0.237</td>
<td>0.265</td>
</tr>
<tr>
<td>r₁, Upper</td>
<td>0.552</td>
<td>0.614</td>
<td>0.649</td>
<td>0.666</td>
</tr>
<tr>
<td>p-value</td>
<td>0.009</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>n</td>
<td>57</td>
<td>57</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Midpoint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rₘean</td>
<td>0.380*</td>
<td>0.381*</td>
<td>0.390*</td>
<td>0.507*</td>
</tr>
<tr>
<td>r₁, Lower</td>
<td>0.094</td>
<td>0.095</td>
<td>0.09</td>
<td>0.233</td>
</tr>
<tr>
<td>r₁, Upper</td>
<td>0.608</td>
<td>0.608</td>
<td>0.625</td>
<td>0.706</td>
</tr>
<tr>
<td>p-value</td>
<td>0.011</td>
<td>0.011</td>
<td>0.013</td>
<td>0.001</td>
</tr>
<tr>
<td>n</td>
<td>44</td>
<td>44</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Suprailliac</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rₘean</td>
<td>0.565*</td>
<td>0.673*</td>
<td>0.469*</td>
<td>0.495*</td>
</tr>
<tr>
<td>r₁, Lower</td>
<td>0.231</td>
<td>0.401</td>
<td>0.109</td>
<td>0.142</td>
</tr>
<tr>
<td>r₁, Upper</td>
<td>0.769</td>
<td>0.836</td>
<td>0.72</td>
<td>0.736</td>
</tr>
<tr>
<td>p-value</td>
<td>0.002</td>
<td>0.001</td>
<td>0.014</td>
<td>0.009</td>
</tr>
<tr>
<td>n</td>
<td>28</td>
<td>28</td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

Long = longitudinal; Tran = transverse; r = Pearson correlation coefficient with significant values asterisked CI = 95% confidence interval; p-value = probability value based on two-tailed test; n = number of subjects.

a period of 9 months. Seven subjects were excluded for tricuspid valvulopathy but had similar demographics to the subject population; there were no other exclusions. An analysis was conducted on 65 subjects, and it showed the leading primary diagnoses were: respiratory failure including pneumonia and congestive heart failure, 12 (18%); sepsis, 11 (17%); pancreatitis, 3 (5%); renal failure, 3 (5%); and gastrointestinal (GI) bleed, 2 (3%). The majority of the secondary diagnoses included categories including pneumonia and congestive heart failure, 12 (18%); sepsis, 11 (17%); pancreatitis, 3 (5%); renal failure, 3 (5%); and gastrointestinal (GI) bleed, 2 (3%). The majority of the secondary diagnoses included categories from the former list as well as mesenteric ischemia, cancers, and a gunshot wound. Twenty-eight (43%) subjects were mechanically ventilated. Table 1 shows vital characteristics of the study subjects.

Adequate measurements were successfully obtained in 57 (89%) of the subjects using the subxiphoid view, in 44 (68%) using the mid-abdomen view, and in 28 (43%) using the suprailiac view. Subjects with one or more unobtainable view had CVP distributions similar to those of visualized subjects. Linear correlation coefficients (r-value) for ventilated and non-ventilated subjects combined were significant at all locations, and orientations with the best performance demonstrated with a longitudinal end-inspiratory view at the suprailiac level (Table 2). End-inspiratory measurements generally yielded slightly better r-values when compared to end-expiratory measurements at a given anatomic location. Longitudinal views generally yielded slightly better correlations than transverse probe orientations (except at the suprailiac level), and suprailiac views outperformed views obtained at the subxiphoid and midpoint locations. Figure 2 shows end-inspiratory linear models in transverse and longitudinal views; end-expiratory results were similar but generally demonstrated less significant regression fit.

Non-linear regression demonstrated a similar or only slightly improved fit in most cases, with r-values for longitudinal end-inspiratory measurements at subxiphoid (0.58, 95% confidence interval [CI] 0.38–0.73), midpoints (0.57, 95% CI 0.34–0.75), and iliac (0.50, 95% CI 0.15–0.74). Linear regression r-values of the subgroup of spontaneously breathing subjects (longitudinal end-inspiratory measurements) were subxiphoid (0.69, 95% CI 0.45–0.83), midpoints (0.66, 95% CI 0.20–0.80), and iliac (0.40, 95% CI 0.12–0.76); and of the subgroup of mechanically ventilated subjects, subxiphoid (0.26, 95% CI –0.17–0.60), midpoints (0.20, 95% CI –0.19–0.68), and iliac (0.47, 95% CI 0.22–0.83).

DISCUSSION
non-invasive, and portable, and images are readily interpreted by a broad variety of specialists (20). Accurate measurement of internal structures, especially blood vessels, is readily achieved with ultrasound (21).

This study demonstrates that a simple, single ultrasound view can yield a statistically significant, if weak, correlation between CVP and IVC diameter. For all subjects, the best correlations were obtained on suprailiac views. However, in more than half the cases, an image of the suprailiac IVC was not obtainable, usually because there was an inability to adequately visualize the IVC secondary to body habitus or bowel gas. Other investigators have reported on the use of ultrasound to estimate CVP or fluid status, with varying results (27–32). In summarizing the results of three studies, Vignon highlighted the potential value of this technique, but encouraged further study (30,31,33,34).

It is known that the distal IVC exhibits a greater dynamic range of diameter with the respiratory cycle, and thus may be more sensitive to CVP changes (9). Several authors measure both the inspiratory and expiratory diameters of the IVC and use it to calculate a so-called caval or collapsibility index (7,34). Gunst et al. examined patients in a surgical intensive care unit and used a four-component technique that included caval collapse along with a cardiac index, presence or absence of pericardial effusion, and a subjective assessment of cardiac function (22). Recently, Nagdev et al. reported a 50% collapse of the IVC diameter during a respiratory cycle as being strongly associated with a low CVP (35). Alternatively, a preliminary report by Gaspari et al. supports the conjecture that IVC respiratory collapse is not as good as diameter measurements in estimating fluid status (36).

Other factors can affect IVC diameter and its relationship to CVP. The liver or diaphragm may tend to tether the IVC in the “open” position in the most proximal portions (23). Valvular disease, particularly tricuspid dysfunction, and certain forms of right heart structural abnormalities are other important confounding conditions (37,38). Lastly, there is variation in the diameter of the IVC among normal patients (39,40). Whether any of these factors affects the ability to infer CVP from the IVC diameter has not been well elucidated (33).

Changes in intra-abdominal and intrathoracic pressures (e.g., during positive-pressure ventilation or
Valsalva maneuver) are also well known to alter the CVP and have some effect on IVC diameters (41–44). Our subject population was a mixture of patients receiving positive-pressure ventilation and those breathing spontaneously. In any case, depending on the ventilator settings, a given breath may be a combination of patient and machine breaths, with resulting ambiguous effects on airway pressure at the moment of measurement. Our data showed that correlations were less significant in subjects receiving ventilation; further study is necessary to fully account for the effects of airway pressure.

Limitations

There are a number of important limitations to this study. The number of subjects enrolled for this study was 72 (65 available for analysis), which is short of the total enrollment goal of 100. The range of subjects was less broad than expected, with fewer trauma patients enrolled than we had hoped. External validity was further limited by the single site, and the use of a convenience sampling methodology. Thus, investigations at other sites are necessary to confirm our findings. The internal validity of the study is limited by the selection bias from the inclusion and exclusion criteria, and the lack of complete operator blinding. These factors highlight the preliminary nature of these results.

All images were obtained contemporaneously and during a one-time assessment. That is, by design, this “on-the-fly” technique was without later review and subsequent revision of measurements; this is a potential source of error because bedside results were not checked against a standard. Averaging of multiple images, recording and reviewing the still images for the “best” view, or other techniques to improve operator precision were not performed. It is possible that circumferential (area) measurements of the IVC or two measurements in the perpendicular would result in greater accuracy of the IVC size measurement. However, a preliminary report by Fields et al. suggests that diameters outperform area measurements (45). This investigation used a simpler, single anterior-posterior diameter that better mimicked the likely bedside use of ultrasound during an acute resuscitation, and tended to maximize the generalizability to actual clinical use by ordinary clinicians. It is important to recognize that this study focuses on evaluating the correlation of a simple, single ultrasound view with the CVP and it is not a study of diagnostic accuracy or clinical outcome.

Whether a sonographically measured IVC accurately reflects CVP should be considered in the context of the limitations of imaging and measurement, the confounders of IVC correlation, and of course, whether CVP is a useful guide to fluid status in a given patient (13). Rather than inferring a discrete CVP, the IVC diameter provides a likely range of values and can form one of several clinical inputs for estimating fluid status. In situations where clinical assessment is limited due to time constraints (e.g., acute resuscitations), lack of monitoring capability (e.g., austere environments), or inability to assess a full complement of clinical signs (e.g., prehospital environment), a sonographically determined estimate of CVP may be valuable. Our study shows that a simple, single measurement can potentially inform this estimate.

CONCLUSION

The subxiphoid view was the most readily viewed of the three anatomic locations for obtaining adequate views of the IVC; however, the suprailiac view produced superior correlations to the CVP when compared to the subxiphoid and midpoint views. Longitudinal views generally outperformed transverse views at all levels except the suprailiac. Use of a single simple ultrasound measure of the IVC transverse diameter in end-inspiration yields weak correlation with the CVP.

Acknowledgment—The authors thank John Ward, PhD and Cristy Landt, MS for their biostatistical support.

REFERENCES

25. Arthur ME, Landolfi C, Wade M, Castresana MR. Inferior vena cava diameter (IVCD) measured with transesophageal echocardiography (TEE) can be used to derive the central venous pressure (CVP) in anesthetized ventilated patients. Echocardiography 2009;26:140–9.
ARTICLE SUMMARY

1. Why is this topic important?
   Bedside sonographic measurement of the inferior vena cava may estimate central venous pressure (CVP).

2. What does the study attempt to show?
   This study attempted to define the best sonographic views to correlate vena cava diameter and CVP in critical care patients.

3. What are the key findings?
   The subxiphoid view was most reliable while the suprariiac view produced superior correlations; overall, the study yielded weak correlations.

4. How is patient care impacted?
   Further research is needed to define the optimal views and correlations when attempting to estimate CVP from vena cava diameters.