Emergency Department Bedside Ultrasonographic Measurement of the Caval Index for Noninvasive Determination of Low Central Venous Pressure

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Study objective: Among adult emergency department (ED) patients undergoing central venous catheterization, we determine whether a greater than or equal to 50% decrease in inferior vena cava diameter is associated with a central venous pressure of less than 8 mm Hg.

Methods: Adult patients undergoing central venous catheterization were enrolled in a prospective, observational study. Inferior vena cava inspiratory and expiratory diameters were measured by 2-dimensional bedside ultrasonography. The caval index was calculated as the relative decrease in inferior vena cava diameter during 1 respiratory cycle. The correlation of central venous pressure and caval index was calculated. The sensitivity, specificity, and positive and negative predictive values of a caval index greater than or equal to 50% that was associated with a central venous pressure less than 8 mm Hg were estimated.

Results: Of 73 patients, the median age was 63 years and 60% were women. Mean time and fluid administered from ultrasonographic measurement to central venous pressure determination were 6.5 minutes and 45 mL, respectively. Of the 73 participants, 32% had a central venous pressure less than 8 mm Hg. The correlation between caval index and central venous pressure was −0.74 (95% confidence interval [CI] −0.82 to −0.63). The sensitivity of caval index greater than or equal to 50% to predict a central venous pressure less than 8 mm Hg was 91% (95% CI 71% to 99%), the specificity was 94% (95% CI 84% to 99%), the positive predictive value was 87% (95% CI 66% to 97%), and the negative predictive value was 96% (95% CI 86% to 99%).

Conclusion: Bedside ultrasonographic measurement of caval index greater than or equal to 50% is strongly associated with a low central venous pressure. Bedside measurements of caval index could be a useful noninvasive tool to determine central venous pressure during the initial evaluation of the ED patient. [Ann Emerg Med. 2010;55:290-295.]

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INTRODUCTION

Background

Determination of intravascular volume status can sometimes be challenging in the emergency department (ED) patient. Recent research indicates that invasive hemodynamic monitoring of central venous pressure is a useful guide in directing early resuscitative efforts and assists in reducing the morbidity and mortality of ED patients with severe sepsis/septic shock.[1,2] Specifically, in patients with severe sepsis/septic shock, a central venous pressure less than 8 mm Hg is considered an indicator for aggressive intravenous fluid replacement. Unfortunately, obtaining invasive hemodynamic monitoring can lead to complications (arterial puncture, venous thrombosis, infection, etc), may be time consuming, and is typically begun after increased lactate measurements are obtained or intravenous fluid boluses fail to improve blood pressure. There are some practical limitations to using invasive methods to monitor central venous pressure in the ED, including the need for special monitoring equipment, supportive resources, and trained personnel who can devote themselves solely to conducting monitoring.[3,4] Perhaps because of these limitations and the lack of broad-based campaigns about early severe sepsis interventions, a survey in 2004

Editor's Capsule Summary

What is already known on this topic

Studies in other settings and disciplines have suggested that ultrasonographic measurement of the inferior vena caval index can provide a noninvasive estimation of central venous pressure.

What question this study addressed

Whether emergency physician-performed bedside measurement of the caval index could predict a central venous pressure of less than 8 mm Hg in emergency department patients.

What this study adds to our knowledge

The investigators were able to obtain adequate images in 73 of 82 study patients. A greater than or equal to 50% respirophasic change in the width of the inferior vena cava had a sensitivity of 91% and a specificity of 94% for a central venous pressure of less than 8 mm Hg.

How this might change clinical practice

If confirmed in further studies, this bedside technique may provide emergency physicians a noninvasive adjunct in quickly estimating volume status.

indicated that only 7% of academic EDs have initiated protocols for invasive hemodynamic monitoring.[5]

Using bedside ultrasonography as a noninvasive method for hemodynamic monitoring might be a useful adjunct for the ED clinician. In conjunction with other more common clinical characteristics (urine output, pulse rate, blood pressure, etc), a noninvasive determination of central venous pressure could be a useful aid. Research from cardiology, nephrology, and critical care medicine has evaluated the ability of ultrasonography to evaluate central venous pressure among selected patients in the non–acute care setting by measuring inferior vena cava diameter and inferior vena cava collapsibility, termed the caval index.[6-8] These studies found strong correlations between central venous pressure and inferior vena cava diameter and with inferior vena cava and cavel index. A study by Brennan et al[9] among hemodynamically stable patients undergoing right-sided heart catheterization found that an inferior vena cava and caval index of 40% was predictive of a central venous pressure of 10 mm Hg.[9] As a demonstration of the potential use of ultrasonography for intravascular volume status determinations in the ED, Randazzo et al[10] evaluated the ability of ED clinicians to estimate central venous pressure with ultrasonographically-measured inferior vena cava collapsibility among stable patients undergoing echocardiography. However, the criterion standard used in the study was not central venous pressure, but rather a visual estimation of inferior vena cava collapsibility, as estimated by a cardiologist. To our knowledge, there have been no published studies evaluating correlation between bedside ultrasonographic inferior vena cava measurements performed by emergency physicians and measured central venous pressure. A noninvasive method of assessing volume status among ED patients may be a useful adjunct in the care of those with suspected hypovolemia, thereby allowing the clinician to initiate rapid fluid resuscitation before other objective and invasive measurements are determined.

Importance

Bedside ultrasonographic evaluation of the inferior vena cava could be a noninvasive marker of low volume status for the emergency physician, thereby aiding the clinician in fluid management early in the course of resuscitation before more invasive measurements are undertaken.

Goals of This Investigation

The objective of this study was to determine whether noninvasive bedside ultrasonographic measurement of the inferior vena cava and caval index could identify a low central venous pressure among ED patients who require central venous catheterization. Specifically, we hypothesized that a caval index of greater than or equal to 50% was associated with a central venous pressure less than 8 mm Hg. We also examined the relationship between inferior vena cava and caval index and central venous pressure and investigated whether clinical factors (patient characteristics, vital signs, lactate level, time elapsed from ultrasonographic measurement to central venous pressure measurement, and amount of normal saline solution infused between measurements) influenced this relationship.

MATERIALS AND METHODS

Study Design and Setting

This prospective, observational study was conducted at an urban, academic, adult medical center ED in New England. This ED serves more than 98,000 adult patients annually and has an overall 25% admission rate. Approximately 8.5% of all patients are evaluated in the critical care area of the ED. The hospital institutional review board approved the study.

Selection of Participants

A convenience sample of ED patients undergoing evaluation in the critical care area of the ED and who had a central venous catheter placed was recruited for this study.

Patients were study candidates if they needed central venous access and invasive hemodynamic monitoring, according to the discretion of the treating physician. Patients were ineligible if they were unable to consent for the procedure or if an ultrasonographic measurement of the inferior vena cava could not be performed because of technical limitations. Written, informed consent for participation was obtained before ultrasonographic examination. For intubated patients, consent was obtained from the patient's health care proxy.

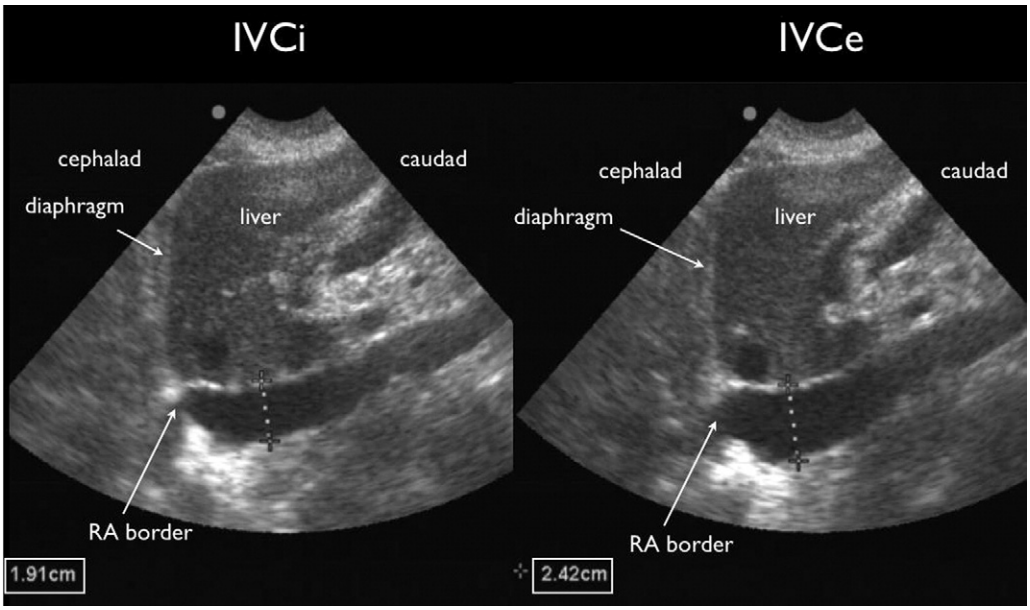

Figure. Ultrasonographic determination of inspiratory inferior vena cava (IVCi) and expiratory inferior vena cava (IVCe).

Methods of Measurements and Outcome Measures

While patients were supine, inspiratory inferior vena cava and expiratory inferior vena cava diameters were measured 2 to 3 cm from the right atrial border in a long-axis/subxiphoid view with a 2-4 MHZ curvilinear probe (Sonosite Titan; Sonosite Inc., Bothell, WA). Measurements were taken during a normal respiratory cycle for patients who were not intubated. For intubated patients, inspiratory inferior vena cava was the maximal diameter during forced inspiration, whereas expiratory inferior vena cava was the minimal diameter at the end of forced inspiration. Images were frozen on the ultrasonographic machine, and frame-by-frame analysis was performed to determine both expiratory inferior vena cava and inspiratory inferior vena cava values (Figure). Of the 4 ED physicians obtaining the measurements for the study, one was an ultrasonographic fellowship director and the remaining investigators were ultrasonographic fellows. Each investigator met the American College of Emergency Physicians standards for competency in ED clinician sonography.[11] To standardize measurements before enrollment of patients for the study, all 4 physicians performed 5 ultrasonographic examinations of the inferior vena cava with the lead author among patients undergoing central venous pressure monitoring.

During the data collection phase, physicians performing the measurements were blinded to the central venous pressure determination, which was obtained by nursing staff after completion of the ultrasonographic examination. Central venous pressure measurements were obtained by digital transduction of the pressure tracing of the distal port off the central line after confirmation from a supine chest radiograph that the catheter tip was at the distal aspect of the innominate vein. The numeric value was recorded after the measurement demonstrated lack of variability. Treating physicians were not informed of the results of the ultrasonographic examination, and clinical care was not interrupted for the ultrasonographic measurements. Research technicians blinded to the study results noted the time and amount of fluid administered between ultrasonographic measurement and central venous pressure transduction. The inferior vena cava and caval index was calculated as the relative decrease in inferior vena cava diameter during 1 normal respiratory cycle (expiratory inferior vena cava–inspiratory inferior vena cava/expiratory vena cava) and was also expressed as the inferior vena cava and caval index percentage (inferior vena cava and caval index$\times$100%).

Primary Data Analysis

Summary statistics were generated for the participants' characteristics (age, sex, intubation status), vital signs (pulse rate, systolic blood pressure, diastolic blood pressure), lactate level, and primary study measurements (central venous pressure, inspiratory inferior vena cava diameter, expiratory inferior vena cava diameter, inferior vena cava and caval index percentage, elapsed time from ultrasonographic measurement to central venous pressure measurement, and amount of saline solution administered). Participants were stratified by their central venous pressure measurement (low [$<$8 mm Hg] and high [$\geq$8 mm Hg]). Their characteristics, vital signs, lactate level, and primary study measurements were compared by calculating the difference in mean values or proportions between those in low minus high central venous pressure measurements. Corresponding 95% confidence intervals (CIs) of the differences were calculated. Differences were considered significant at the α=0.05 level for these and all other analyses, unless otherwise specified.

Pearson's correlation coefficients of central venous pressure with inspiratory inferior vena cava diameter, expiratory inferior vena cava diameter, and inferior vena cava and caval index,

Table 1. Comparison of participants by central venous pressure.

Participant Characteristics	All Participants n=73, Median (IQR)	CVP <8 mm Hg n=23, Median (IQR)	CVP ≥8 mm Hg n=50, Median (IQR)	Δ (95% CI)* n=73
Age, y	63 (52-76)	64 (49-76)	63 (52-76)	1.0 (–7.8 to 9.7)
Sex, % (95% CI)				
Female (n=44)	60.3 (48.1-71.5)	47.8 (24.4-68.2)	66 (52.3-79.1)	–18.2 (–42.5 to 6.0)
Male (n=29)	39.7 (28.5-51.9)	52.2 (31.8-72.6)	34.0 (20.9-47.1)	18.2 (–6.0 to 42.5)
Intubated	19.2 (10.9-30.1)	4.3 (0-12.7)	26.0 (13.9-38.2)	–21.7 (–36.4 to –7.0)
Vital signs/laboratory tests, μ (95% CI)				
Pulse rate, beats/min	95.3 (90.8-99.9)	91.7 (82.4-100.9)	97.0 (91.7-102.3)	5.3 (–5.1 to 15.8)
Systolic blood pressure, mm Hg	97.7 (93.4-102.1)	101.8 (95.6-108.0)	95.9 (90.1-101.6)	5.9 (–14.2 to 2.3)
Diastolic blood pressure, mm Hg	55.9 (53.1-58.7)	57.4 (52.9-61.9)	55.1 (51.5-58.7)	14.2 (-7.9 to 3.3)
Lactate level	4.5 (3.7-5.2)	4.3 (3.4-5.1)	4.6 (3.6-5.6)	–0.3 (–1.0 to 1.6)
Measurements, μ (95% CI)				
CVP, mm Hg	10.5 (9.3-11.6)	4.6 (3.9-5.3)	13.1 (12.2-14.0)	–8.5 (–9.6 to –7.4)
IVCi diameter, cm	1.1 (0.9-1.3)	0.4 (0.2-0.5)	1.5 (1.4-1.6)	–1.1 (–1.3 to –0.9)
IVCe diameter, cm	1.6 (1.5-1.7)	1.1 (0.9-1.3)	1.9 (1.7-2.0)	–0.8 (–1.0 to –0.5)
IVCCI	35.6 (29.0-42.1)	68.1 (59.1-77.1)	20.6 (16.3-24.9)	47.5 (37.7 to 57.3)
Elapsed time, min	6.5 (4.6-8.3)	8.3 (4.6-12.0)	5.6 (7.7-7.8)	2.6 (–6.9 to 6.9)
IV saline solution administered, mL	45.2 (0-101.7)	17.4 (0-34.2)	58 (0-140.8)	–40.6 (–43.6 to 124.8)

CVP, Central venous pressure.
*Calculated as CVP <8 mm Hg values minus CVP ≥8 mm Hg values.

respectively, were calculated along with corresponding 95% CIs. The association between inferior vena cava and caval index and central venous pressure was evaluated with simple linear regression. In addition, the following covariates were evaluated in simple linear regression models using central venous pressure as the outcome and as possible additional covariates in linear regression models with inferior vena cava and caval index and central venous pressure: age, sex, intubation status, pulse rate, blood pressure, lactate level, elapsed time from ultrasonographic to central venous pressure measurement, and amount of saline solution administered. Covariates considered significant at the $\alpha=0.10$ level were considered further in model construction. β-Coefficients with corresponding 95% CIs were estimated.

Performance characteristics (sensitivity, specificity, predictive value, likelihood ratios, and receiver operator characteristic curve area) of the ability of an inferior vena cava and caval index percentage greater than or equal to 50% to predict central venous pressure less than 8 mm Hg were calculated, along with corresponding 95% CIs. Receiver operator characteristic curves were generated for cutoff values other than 50% to evaluate their ability to predict low central venous pressure. The maximum values of the receiver operator characteristic curve were identified.

Table 2. Performance parameters of inferior vena cava and caval index greater than 50% as a predictor of central venous pressure less than 8 mm Hg.

Performance Parameters	Estimate (95% CI)
Sensitivity	90.9 (70.8-98.9)
Specificity	94.1 (83.8-98.8)
PVP	87 (66.4-97.2)
PVN	96 (86.3-99.5)
LR+	15.5 (5.12-46.7)
LR–	0.1 (0.03-0.36)
Receiver operator characteristic curve area	0.93 (0.86-0.99)

PVP, Predictive value positive; *PVN,* predictive value negative; *LR+*, likelihood ratio positive; *LR–*, likelihood ratio negative.

RESULTS

Eighty-two patients were initially enrolled in the study. Inferior vena cava measurements could not be obtained in 9 (11%) patients. Table 1 provides a description of the 73 study participants and a comparison of the participants by their central venous pressure measurements (central venous pressure <8 mm Hg versus central venous pressure ≥8 mm Hg). Each emergency physician enrolled at least 12 patients. There were no differences in central venous pressure measurements by age and sex, but there was a greater percentage of intubated patients in the higher central venous pressure group. The vital sign and laboratory measurements, elapsed time from ultrasonographic measurement to central venous pressure measurement, and amount of intravenous saline solution administered were similar between the 2 groups. The mean inspiratory inferior vena cava diameter and expiratory inferior vena cava diameter were significantly lower and the inferior vena cava and caval index percentage was significantly higher in the low central venous pressure group.

The correlations of central venous pressure measurement with the ultrasonographic measurements were, respectively, inspiratory inferior vena cava diameter (0.78; 95% CI 0.67 to 0.86), expiratory inferior vena cava diameter (0.66; 95% CI 0.51 to 0.77), and inferior vena cava and caval index (–0.74;

95% CI −0.82 to −0.63). The relationship between inferior vena cava and caval index and central venous pressure in an unadjusted linear regression model was β −0.125 (95% CI −0.153 to −0.098), adjusted R^2 0.54. In other words, each 12.5% increase in inferior vena cava and caval index was predictive of a 1–mm Hg decrease in central venous pressure. Age, sex, intubation status, pulse rate, blood pressure, lactate level, elapsed time from ultrasonographic to central venous pressure measurement, and amount of saline solution administered were not associated with central venous pressure alone or when added to linear regression models of inferior vena cava and caval index and central venous pressure (data not shown).

Table 2 shows the performance characteristics of a caval index percentage greater than or equal to 50% in ability to predict central venous pressure less than 8 mm Hg. As shown, inferior vena cava and caval index percentage was a strong predictor of low central venous pressure and was particularly strong in determining which patients did not have a low central venous pressure. Receiver operator characteristic curve analyses indicated that the maximum value for the receiver operator characteristic curve was 0.925 and corresponded to inferior vena cava and caval index percentage between 47% and 50%.

LIMITATIONS

There are several limitations to this study. The selection of study participants was not random; therefore, unintended factors in choosing the convenience sample of participants, such as when the investigators were available to conduct the study, might have influenced the results. However, the participants were enrolled without regard to category or severity of illness, hour of the day, or day of the week, so we believe this influence was small.

The ultrasonographic measurements of the inferior vena cava were not repeated by another physician or reviewed for precision. As a result, interrater reliability was not measured. We hope to examine interrater reliability of caval index determinations by emergency physicians in future studies. We also did not formally measure the time required to perform the bedside evaluation of the inferior vena cava. However, our anecdotal experience was that the bedside measurement time was approximately 3 minutes.

We were also not able to standardize the time between the ultrasonographic measurements and central venous pressure measurements, as well as the amount of fluid administered to patients. However, the analyses indicated that these factors did not influence the results of the study. In addition, it might be difficult to generalize the procedures and results of this investigation to other study sites, given that the investigators were experienced in bedside ultrasonography. As bedside ultrasonography becomes even more integrated in the practice of emergency medicine, future investigations can help determine the facility at which emergency physicians can measure caval index.

Finally, we could not visualize the inferior vena cava in 12% of ED patients, which limits who can receive this procedure. Like most bedside ultrasonograms, a small proportion of scans will be inadequate. Previous studies have also shown that inferior vena cava measurements are not possible in 10% to 15% of patients, usually because of large body habitus, excessive intra-abdominal bowel gas, or large amounts of intrathoracic air.[9,12]

DISCUSSION

Our study examined the association of inferior vena cava measured by bedside ultrasonography with direct invasive measurement of central venous pressure. We found that an inferior vena cava and caval index greater than or equal to 50% was strongly associated with a central venous pressure less than 8 mm Hg. We believe that ED clinicians can use ultrasonography as an accurate tool to aid in determining the need for aggressive fluid replacement before initiating central venous catheterization and accompanying invasive hemodynamic monitoring. Because determination of intravascular depletion can be difficult at the bedside during the initial evaluation of an ED patient and measurement of the inferior vena cava can be useful, a noninvasive measurement could aid a clinician in confirming signs of hypovolemia before more objective clinical markers are obtained.

We believe that using a binary estimator of central venous pressure, a caval index greater than or equal to 50%, provides ED clinicians with a simple decision point of when to begin aggressive fluid treatment. Although this study included patients with and without severe sepsis/septic shock, there were no other clinical factors in the regression analyses that refined the relationship between inferior vena cava and caval index and central venous pressure or better predicted a low central venous pressure, including lactate levels. In addition, the high negative predictive value of an inferior vena cava and caval index less than 50% indicates that this method performs even better in showing which patients do not have a low central venous pressure.

The ability of central venous pressure to be an absolute marker of intravascular volume has come into contention as of late. A recent meta-analysis discussed the inability of central venous pressure, over its entire range, to predict intravascular volume and the lack of correlation between a fluid challenge and resultant increase stroke volume/cardiac output.[13] Central venous pressure represents the interaction of cardiac function and the other function that determines the blood return to the heart, and thus by itself does not give an indication of the adequacy of vascular volume or the adequacy of cardiac preload. High central venous pressure can be caused from upstream cardiac dysfunction, and aggressive fluid resuscitation may not increase myocardial fiber recruitment and further increased cardiac output. On the other hand, a low central venous pressure (generally defined as less than 8 to 10 mm Hg) may be a good marker that the patient will be fluid responsive. In a recent study by Madger and Bafaqeeh,[14] researchers attempted to determine a threshold central venous pressure at which there would be a low probability that volume infusion will cause an increase in cardiac output. Those with a central venous pressure less than 10 mm Hg had the greatest probability of responding to a fluid challenge with an increase in cardiac output. This finding also suggests the utility of a bedside test that could

inform the clinician of a high probability of fluid responsiveness when the inferior vena cava and caval index is greater than 50%.

In summary, we believe that bedside evaluation of the inferior vena cava may be a useful bedside tool for the clinician. By determining collapsibility (greater than 50%) of the inferior vena cava during normal respiration, the clinician may be able to obtain a bedside marker of intravascular volume. In conjunction with common clinical markers, bedside ultrasonography of the inferior vena cava may be a useful adjunct in the evaluation of the ED patient.

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