This edition of the Resident Journal reviews the utility of ultrasound in measuring the inferior vena cava (IVC) as a surrogate of intravascular volume status and then reviews the recent literature to determine how best to integrate ultrasound measurements of the IVC into your clinical practice.

**Introduction:**

In the 1980s cardiologists began using the size of the inferior vena cava (IVC) as seen on ultrasound (US) as a surrogate for the right sided filling pressures of the heart. Over time, this concept has been investigated in patients in a variety of settings such as hemodialysis clinics, cardiac units, intensive care units (ICU), and the emergency department (ED). The emergency medicine-based literature has looked at this modality for assessing volume status over the past 15 years. Despite this research, there are still many questions about the utility of US assessments of the IVC, such as determining a standard anatomical location to measure the IVC, determining the reproducibility of measurements among different providers, and the ability of IVC collapse (defined below) to assess volume status and to predict volume responsiveness.

**Measuring the IVC and Measurement Reliability**

The IVC can be measured using transabdominal US via a phased array or curvilinear abdominal probe. The IVC has been measured in both transverse and sagittal planes, and depending on the study, measurements have been done anywhere from the right atrial border, superiorly, to the renal veins, inferiorly. The IVC collapse index is also referred to as the caval index. The IVC collapse index is calculated during one respiratory cycle. It is the maximum diameter minus the minimum diameter of the IVC divided by the maximum diameter. It’s typically expressed as a percentage, also referred to as percent collapse.

The IVC collapse index (IVC-CI) = (IVC<sub>max</sub> diameter − IVC<sub>min</sub> diameter) / IVC<sub>max</sub> diameter.

The first article discussed below looks at whether measurement location affects the IVC collapse, and the second article investigates whether reproducible measurements of the IVC can be made by different providers.


This study examined the effect of the measurement location on IVC collapse. This was a sampling study of healthy volunteers performed at an academic emergency department by an experienced resident sonologist. The study was designed to look at three portions of the IVC. First, a view of the IVC at the level of the diaphragm was obtained in the sagittal plane, and the collapse of the IVC was measured where the IVC enters the right atrium. The second measurement was obtained 2cm caudal to the hepatic vein entering the IVC in the sagittal plane, and the final view was taken in the transverse orientation at the level of the renal veins.

Thirty-nine volunteers were enrolled, and the mean IVC collapse was calculated at each of the three measured sites. All images were reviewed by a fellowship-trained emergency sonologist. In these healthy volunteers, the measured values for IVC collapse were not significantly different when measured at the level of the hepatic vein or renal vein. Measurements obtained at the border of the right atrium had a significantly smaller percent collapse than at the other two sites.

This study suggests that measuring the IVC near the inlet of the hepatic vein or at the level of the renal veins provides more reliable results than measurements at the right atrial border. This is helpful, as about 10 percent of patients are unable to have the IVC visualized at all locations within the abdomen. This study is limited by its use of healthy volunteers. It is not clear whether there may be regional differences in IVC collapse in patients with hypovolemia, shock states, or those receiving vasoconstrictor infusions. Measurements of the IVC were made either in the transverse or sagittal (longitudinal) plane depending on the site of measurement. It is not clear whether different values may be found at the same site depending upon the orientation of measurement. Further studies would help define a standardized approach to the measurement of the IVC, and these results should be validated in hypotensive patients.


Prior to this study by Fields et al., the inter-rater reliability of IVC-US among emergency physicians (EPs) had not been studied. Fields et al. investigated whether emergency bedside ultrasound was a useful and repeatable modality for intravascular volume assessment. They also attempted to determine whether alternative methods of IVC-US, such as visual estimation and brightness mode (B-mode) diameter and area measurements, were as reliable as the traditionally used motion mode (M-mode) diameter measurements.

The authors performed a prospective observational study that used a small convenience sample of patients from an urban ED in April 2008. The enrolling EPs were comprised of four senior residents and one US fellow. All had met the training requirements for emergency ultrasonography as delineated by the American College of Emergency Physicians (ACEP) guidelines and had undergone
an additional standardized one-hour training session in IVC-US followed by 10 proctored and reviewed exams. Inclusion criteria included age over 18 years, non-pregnant, and the ability to tolerate supine positioning for the US examination. Separate IVC studies were performed on each patient by two different EPs fewer than 15 minutes apart. Each EP was blinded to the findings of the other and to the patient's clinical data. They all recorded a visual estimation of inspiratory IVC collapse (0% – 100%), then recorded a “gestalt” estimation of volume status by combining visually estimated collapse with the visual appearance of IVC size and shape (documented as either hypovolemic, lower range of normal, higher range of normal, or hypervolemic). Lastly, they each performed caliper measurements of the IVC using M-mode and B-mode. All studies were captured with video clips and still images for expert analysis. All studies were reviewed by a sonographer with more than 10 years of experience to determine correct vessel identification and caliper placement. Expert review found no studies to be inadequate.

Demographic and clinical information was obtained from 46 patients after the five EPs completed a total of 92 studies (two per patient). Inter-rater reliability was calculated for each US method using a one-way random effects model to estimate intraclass correlation coefficients (ICCs) for continuous variables and Cohen’s linear weighted kappa ($\kappa$) for categorical variables. In addition, the effects of the sonographer and patient characteristics on ICC values were analyzed. In summary, agreement for visually estimated IVC collapse (0.60, 95% CI = 0.36 to 0.76) was similar to agreement for calculated M-mode IVC collapse index (0.52, 95% CI = 0.27 to 0.71). Inter-rater agreement for gestalt assessment of volume status using visual estimation was substantial ($\kappa = 0.64, 95\% \text{ CI} = 0.46$ to 0.78). There were no statistically significant differences in IVC measurements by various caliper methods (B-mode diameter, B-mode area, and M-mode diameter). Analysis of M-mode diameter measurements revealed that IVC-US experience and the patients’ volume status were significantly associated with inter-rater reliability. There was significant improvement in inter-rater reliability when assessing hyper- and hypo-volemic patients and when EPs had performed at least five previous exams. Inter-rater reliability was not significantly associated with sonographer training level, patient respiratory rate, or body mass index.

This study showed strong agreement between EPs for M-mode IVC diameter measurements, and agreement for M-mode IVC-CI was moderate to good. Based on the study results, both measured and visually estimated IVC assessments seem similar and repeatable among different providers. Some potential sources of error in this study were recognized and included selection bias arising from convenience sampling and measurement bias that may have occurred if EPs tried to match measurements to their previously determined visual estimates. Also, study EPs may have enrolled patients they felt more confident about scanning. Finally, since clinicians were aware that their measurements were being studied, the Hawthorne effect may have been a factor. The expert review process was designed in an attempt to limit such bias by reviewing for inappropriate measurements, and no such measurements were identified.

Overall, this study shows that EP measurement of inferior vena cava diameter has a fairly high degree of inter-rater reliability. The use of the visual estimation technique should be considered by EPs who have learned to obtain measured parameters of inferior vena cava filling, since it seems equally reliable to traditional M-mode measurements and can be performed more rapidly.

### Qualitative Estimates of IVC Collapse

In the busy ED, quick assessments can lead to swift and appropriate therapies. Like the qualitative arm of the Fields study above, the next study looks at whether qualitative estimates of IVC collapse and left ventricular (LV) function can approximate measured values of IVC collapse or LV shortening.

### Comparison of Serial Qualitative and Quantitative Assessments of Caval Index and Left Ventricular Systolic Function During Early Fluid Resuscitation of Hypotensive Emergency Department Patients


This prospective, observational study investigated how visual estimates on bedside ultrasound of LV function and IVC respiratory dynamics correlated with more detailed, quantitative measurements. This study did not set out to determine if any of the measurements correlated with the patient’s fluid status or fluid responsiveness. The population for the study was patients older than 18 years arriving at the ED with systolic blood pressure (SBP) of <100mmHg or mean arterial pressure (MAP) <65mmHg, in sinus rhythm, and whose physician had the intent to give a fluid bolus of 20mL/kg or more. Exclusion criteria included unstable or absent cardiac rhythm at presentation, Advanced Cardiac Life Support (ACLS) in progress, suspected congested heart failure (CHF), inability to obtain adequate ultrasound images, pregnancy, trauma patients, inability to tolerate positioning for ultrasound, or predicted stay in the ED of fewer than 45 minutes.

All patients first had their IVC visualized in the longitudinal orientation 3cm caudal to the junction with the right atrium and its respiratory variation visually estimated using a three point scale: 1 = decreased (presumed to correlate with Caval Index (CI) of 0.0-0.3), 2 = normal (correlating to CI 0.31-0.69), or 3 = increased (correlating to CI 0.7-1.0). M-mode was then used to quantitatively measure the CI. The visual estimate score was then compared to the quantitative measurement.

Similarly, the left ventricle was visualized in the parasternal long axis. Using multiple visual indices of LV function (close approximation of anterior mitral leaflet to septal wall, significant thickening of the posterior LV wall in systole and significant movement of the septal and posterior walls toward each other), a visual estimate score of LV function was determined: 1 = severely depressed, 2 = moderately depressed, 3 = normal function, and 4 = increased function. The LV diameter was then measured at end-diastole (LVEDD) and end-systole (LVESD), and a quantitative measurement of the fractional shortening (FS) of the LV calculated (FS = (LVEDD - LVESD)/LVEDD).

Twenty-four patients underwent enrollment, and 72 videos of CI were obtained from a convenience sample of ED patients. Emergency US division physicians performed all studies and were trained in a
standard method of measuring CI and LV function. The main findings of this article were that visual estimates of IVC respiratory dynamics and of LV function correlated well with their respective quantitative measurements and that there was moderately good interobserver reliability in determining the visual estimate scores for a given patient. For the IVC collapse there was a Spearman correlation coefficient of \( r = 0.81 \) (\( p < 0.0001 \)) between visual estimates and measured indices. The main limitation to the study was that the same person performed the ultrasound evaluation for both the visual estimate and the quantitative measurements, which may have introduced an element of bias in determining the quantitative measurements. Though the authors comment on the changing size of the IVC over time, this study did not set out to measure the correlation of any of these measurements with the patient’s fluid status or responsiveness.

Visual estimates of IVC respiratory function and LV function are an acceptable estimation of more detailed quantitative measurements, and therefore likely useful as a quick, bedside measurement to help in decisions regarding a patient’s fluid management.

**Using IVC Collapse to Assess Volume Status**

In the ICU population, US measurements of IVC variation have been found to predict fluid responsiveness. Feissel and Barbier independently found that mechanically ventilated patients with an IVC variation of greater than 13 to 18 percent could have their cardiac output augmented with fluid boluses. These studies were designed to look for changes in the IVC patients on mechanical ventilation without any spontaneous respirations, with tidal volumes of at least 8ml/kg, and who had no arrhythmias. Extrapolating these results to the ED population is difficult, so some investigators have sought to correlate IVC collapse with measurements of central venous pressure (CVP). These results should be interpreted with caution. There has been an abundance of recent literature suggesting that CVP measurements do not accurately predict volume responsiveness. The next two articles discussed found a positive correlation between IVC measurements and CVP measurements.


The authors of this study looked at the correlation between CI and CVP measurements. They hypothesize that the two will be correlated, with a high CI being suggestive of a low CVP.

This is a prospective, observational study, looking at a convenience sample of patients within the critical care area of an academic ED. Eighty-two patients were initially enrolled, though nine were excluded due to the inability to obtain adequate US images. Inclusion criteria were the need for central venous catheter (CVC) placement and invasive hemodynamic monitoring as determined by the treating emergency physician. US measurements were performed with the patient in a supine position, and both inspiratory and expiratory IVC diameters were measured 2-3cm caudal to the right atrial border. Sonographers were blinded to the CVP measurements, which were obtained after the US examination. The sonographers were all experienced in bedside US. They were either US fellows or the US fellowship director of the institution’s EM US fellowship program.

Of the 73 patients included, 32 percent had a CVP of less than 8 mmHg. The correlation between CI and CVP was -0.74. The investigators looked at the ability of a CI of greater than 50 percent to predict a low CVP (<8mmHg), finding a sensitivity of 91 percent and a specificity of 94 percent.

There are multiple limitations to this study that should be addressed. Patient selection was not randomized and was taken from a convenience sample of patients with a mixture of different shock states, mechanically ventilated, and spontaneously breathing patients. Further, sonographers included US fellows and a fellowship director, raising questions as to the applicability to providers with less experience with bedside US. In addition, the time between US examinations and CVP measurements and the amount of intravenous fluid administered to patients was not standardized, though the investigators tried to limit the time between measurements. Finally, though a CI of greater than 50 percent was shown to strongly correlate with a CVP of less than 8mmHg, other critical care literature has cast doubt upon the reliability of CVP as an accurate surrogate for volume responsiveness. There are certain patients whose hemodynamic parameters and perfusion may improve with an intravenous fluid challenge despite having elevated CVPs. As a result, the CVP may not be the most useful clinical parameter to guide volume resuscitation.

Though this study supports the notion that the CI may accurately predict CVP, the failure to distinguish between volume status and volume responsiveness questions its clinical utility. However, US determination of the CI may serve as a reliable, non-invasive, and rapid bedside test to ascertain a general assessment of volume status prior to the availability of additional clinical parameters that require more time-consuming and invasive testing.


The purpose of this study was to assess whether IVC diameters correlated with invasive measurements of hemodynamic status and markers of pulmonary edema or acute lung injury.

This prospective study included 30 consecutively sedated patients with septic shock or severe sepsis at a tertiary care center in Germany with a 24-bed medical ICU and a 14-bed anesthesiological ICU. They defined “shock” as the presence of a SBP ≤90mmHg or MAP ≤70mmHg for at least one hour despite adequate fluid resuscitation, adequate volume status, or the use of vasopressors in an attempt to maintain a SBP ≥70mmHg. All patients were ventilated with a pressure control mode. All blood pressure measurements were obtained from an arterial line. Exclusion criteria included patients under 18 or over 90 years of age, structural liver disease (seen on ultrasound or known via history), or signs of increased intra-abdominal pressure.
Measurements were taken of the IVC diameter in a longitudinal axis in a blinded fashion by two independent ICU physicians at the end of inspiration and end of expiration in a subxiphoid location 2cm distal to the IVC-hepatic vein junction, where the anterior and posterior wall of the IVC were easily visualized. Calipers were used to take the measurements using the trailing edge to leading edge technique. At the time of the measurement, no patient was spontaneously breathing, and the CVP was measured in the supine position.

The results of this study showed significant correlation between expiratory IVC (eIVC) and inspiratory (iIVC) diameter and CVP. The authors also examined other surrogate hemodynamic markers for pulmonary edema and found correlation between both IVC diameters and extravascular lung water (EVLW), extravascular lung water index (EVLWI), intrathoracic blood volume (ITBV), intrathoracic blood volume index (ITBVI), intrathoracic thermal volume (ITTV) and PaO2/FiO2, with all p-values ≤0.05.

Although these results are thought-provoking and may lay some groundwork for additional areas of study, they did not provide sufficient data to delineate cutoffs for fluid responsiveness. The authors noted that the patients included in this study did not represent the majority of septic patients evaluated and treated in the ED, as these patients had already been volume resuscitated and were on mechanical ventilation at the time of their IVC measurements. This study did not detect a correlation between IVC diameter (delta-IVC) and CVP EVLW, EVLWI, ITBV, ITBVI, ITTV, or PaO2/FiO2. This data was not shown and is believed to be the result of a “well hydrated” study population. This study suffers from the same limitations as the Nagdev study in that it attempts to correlate IVC measurements with CVP, which may not be a useful surrogate for measuring volume responsiveness. There is insufficient data to change current clinical practice, and further studies on IVC collapse before and after volume resuscitation are needed.


A growing body of literature exists that has examined the correlation of IVC diameter with volume status; however, many of these studies have a limited sample size. To address this, Dipti et al. performed a meta-analysis on available studies of IVC assessment in the ED patient population. They specifically examined the usefulness of IVC measurements in patients not on mechanical ventilation.

Studies for their analysis were generated by a search of popular databases (EMBASE, EBM reviews, Ovid Medline, SCOPUS, and Web of Knowledge) in March and August of 2011. Search results were then filtered in two phases, the first using title and abstract and the second by a full review of the articles. Criteria for inclusion were prospective study design, use of adult ED patients, and report of IVC diameter measurements by US in both hypotensive and control patients. Criteria for exclusion were use of mechanically ventilated patient population, sample size less than 10, or reviews not based on original research. Application of these criteria reduced the database search population of 140 records to five eligible studies. Of these studies, three were done on hypotensive trauma patients, one on trauma and GI bleed patients, and the last on hypotensive patients presenting to the ED. Three of the studies employed a case-control design, and two employed a before-and-after study design, comparing IVC diameter in each patient before and after fluid challenge.

In all five studies, (1) patients were selected without bias, (2) initial judgment of patient volume status was made without knowledge of the IVC diameter, (3) control groups were clearly defined, (4) identical techniques were used to measure IVC diameter in both the hypotensive (or before-fluids) group and control (normotensive or after-fluids) group, and (5) ultrasonography personnel were judged by the study authors to be adequately trained.

The authors extracted from each study measurements of the IVC diameter at the hepatic segment during expiration (the point in the respiratory cycle at which IVC size is maximized). There was a trend toward smaller IVC diameters in hypotensive patients relative to normotensive controls with a mean difference of 6.3mm (95% CI: 6.0mm – 6.5mm), supporting the notion that IVC diameter varies with volume status. It should be noted though, that inter-study variability of IVC diameter measurements in both the hypotensive and control groups was quite large. In the hypotensive group, measurements ranged from 5.6mm to 15.5mm, and in the control group there was similar variability from 10.7mm to 29mm, depending on the study. The source of this variability is unclear, as measurements were consistently made in the expiratory phase of the respiratory cycle and at the hepatic segment of the IVC. The authors suggest that ethnic differences between study populations may account for this variability. Inter-operator variability or subtle differences in study protocols may also contribute. Regardless of the reason, the fact that the IVC diameter for hypotensive patients in some studies is actually greater than that for normotensive patients in other studies indicates that careful efforts must be made to standardize measurements before IVC diameter can be used to judge volume status.

This meta-analysis of studies comparing IVC diameter in hypotensive versus normotensive individuals demonstrates a trend towards a decreased IVC size in the hypotensive group relative to the control group. There are many limitations inherent to this study. The authors include Weekes’ study in the analysis, even though Weekes states his study was designed to correlate visual estimates of CI with quantitative measurements, and attempts to correlate CI with fluid resuscitation was “not the primary goal of [their] study.” This meta-analysis finds that after fluid resuscitation the IVC diameter changes, which is not surprising. An increase in the size of the IVC does not mean a patient is fluid or volume responsive. Measures such as cardiac output, stroke volume variation, or even blood pressure were not reliably or consistently examined to see if patients clinically changed when their IVC diameter increased. The significant heterogenity of measurements between studies in both the control and hypotensive groups suggests that additional research and standardization is needed. The conclusions by the study authors should be interpreted with caution.

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Take Home Points:
1. Measurements of the IVC can be taken at the level of the hepatic vein or the renal veins.
2. Visual estimates of IVC collapse are likely an acceptable estimation of more detailed quantitative measurements.
3. Providers with experience in IVC-US can reliably measure the IVC.
4. The IVC collapse index correlates with measurements of CVP, but must be interpreted carefully.
5. VC collapse has never been shown to predict fluid responsiveness in spontaneously breathing patients.

References: