



## Sonographic measurement of the inferior vena cava as a marker of blood loss

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**Abstract** Detecting and monitoring blood loss in trauma patients can often be challenging when an obvious source of hemorrhage is not readily seen.

**Objective:** To provide a noninvasive measurement of circulating blood volume and of drop therein by measuring the change in the inferior vena cava diameter (IVCd) in relationship to blood loss.

**Methods:** This was a prospective observational study on blood donors at a donation center. The IVCd, both during inspiration (IVCi) and during expiration (IVCe), was measured in volunteers both before and after blood donation of 450 mL. All actual blood donors aged 18 years and older were eligible for enrollment. Persons who were younger than 18 years, who declined to participate in the study, or who did not meet blood center criteria for blood donation were excluded. All examinations were performed in the supine position with the ultrasound transducer placed in a subxyphoid location. Sagittal sections of the IVC behind the liver were imaged and the maximal diameter of the IVCe and the minimal diameter of the IVCi were measured. Statistical analysis included test for normality, paired *t* test, and correlation analysis.

**Results:** A total of 31 volunteers (18 male) with a mean age of 49.5 years (range, 18-73) were studied. The mean IVCe before blood donation was 17.4 mm (95% CI, 15.2-19.7 mm) and after blood donation was 11.9 mm (95% CI, 10.3-13.6 mm). The mean IVCi before blood donation was 13.3 mm (95% CI, 11.3-15.3 mm), but after blood donation was 8.13 mm (95% CI, 6.7-9.6 mm). The difference between IVCe before and after blood donation (dIVCe) was 5.5 mm (95% CI, 4.3-6.3 mm) yielding a  $P < .0001$ . The difference between IVCi before and after donation (dIVCi) was 5.16 mm (95% CI, 4.2-5.9 mm) yielding a  $P < .0001$ . The dIVCe and the dIVCi were closely correlated ( $r = 0.83$ ). Similarly, the pre-IVCe correlated well to the post-IVCe ( $r = 0.74$ ) and the pre-IVCi correlated well to the post-IVCi ( $r = 0.75$ ).

**Conclusions:** Our data indicates that the measurement of the IVC diameter is a reliable indicator of blood loss, even in small amounts of 450 mL. On average, there was about a 5-mm decrease in both the IVCe and IVCi after donation of 450 mL of blood. The measurement of the IVCe may be an important addition to the ultrasonographic evaluation of trauma and other potentially volume-depleted patients.

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## 1. Introduction

Trauma is the fourth leading cause of death in America and the single greatest cause of death before the age of 45 years. In fact, trauma causes more deaths among children and adolescents than all other diseases combined [1]. Detecting, assessing significance, and monitoring ongoing blood loss may be easy in specific situations such as extremity wounds when blood-soaked towels or bandages can be counted. However, the emergency physician (EP) typically has no way to quantify the amount of volume lost by an exsanguinating patient. Physical examination, vital signs, and laboratory evaluation of trauma patients often are unreliable because of multiple factors [2]. The unreliability of physical and laboratory evaluation combined with a lack of history and patient cooperation due to serious injury or altered level of consciousness obscures the clinical assessment of acute blood loss as well as the assessment for ongoing hemorrhage. These uncertainties can potentially result in inappropriate resuscitation, either too little or too much [3].

Traditionally, diagnostic peritoneal lavage (DPL) has been the primary tool for assessing for intraabdominal blood loss in an unstable trauma patient in that it can be performed rapidly at the bedside. However, it is an invasive procedure that does not provide specific information on the cause of the hemoperitoneum, ongoing blood loss, or the quantity of blood present in the hemoperitoneum. In contrast to DPL, computed tomography (CT) evaluation of the trauma patient can yield information regarding organ-specific injury, intraperitoneal or intrathoracic blood, as well as the presence of retroperitoneal injury. However, CT evaluation usually occurs outside the monitored environment of the emergency department, may require intravenous contrast media, and thus is limited to the evaluation of hemodynamically stable trauma patients. In addition, CT is incapable of giving information concerning the amount of blood lost, the volume status of the trauma patient, or any ongoing hemorrhage.

Increasingly, ultrasonography (US) is being used for the evaluation of trauma patients, and in many centers, replacing DPL in the initial evaluation of unstable trauma patients.

Even though US does not reliably yield information regarding specific organ injury as does CT, it is a noninvasive bedside test that can detect hemoperitoneum, hemopericardium, and hemothorax.

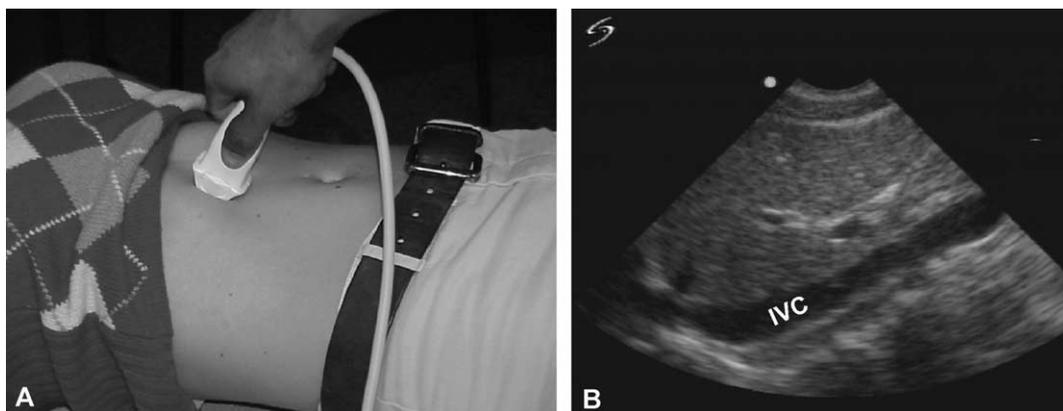
Despite the widespread use of CT, DPL, and US in the evaluation of trauma patients, there is no convenient noninvasive way to monitor for ongoing blood loss at the bedside. However, sonographic measurement of the inferior vena cava (IVC) has been shown to correlate with the circulating blood volume (CBV). Our objective was to determine whether acute blood loss in a potential trauma patient could be detected by sonographic measurement of the IVC, and if repeated measurements of the IVC can monitor for ongoing blood loss.

## 2. Methods

This was a prospective observational study of volunteers donating blood at a metropolitan blood donation center using a convenient sample over 4 data collection days. The study was approved by authors' human assurance committee as well as the medical director of the blood donation center. Written consent was obtained from each volunteer before enrollment into the study.

The study was conducted in a metropolitan blood donation center. All volunteers aged 18 years and older who were actually donating whole blood at the center were eligible for enrolment. Volunteers younger than 18 years old, those who declined to participate in the study, and those who met the center's exclusion criteria for blood donation were excluded from the study. No attempt was made to specifically control for medical condition, medication use, or hydration status.

The inferior vena cava diameter (IVCd), both during inspiration (IVCi) and during expiration (IVCe), was measured in subjects donating blood both immediately before and immediately after donation. A single emergency medicine senior resident from a local emergency medicine training program performed all ultrasound examinations. A

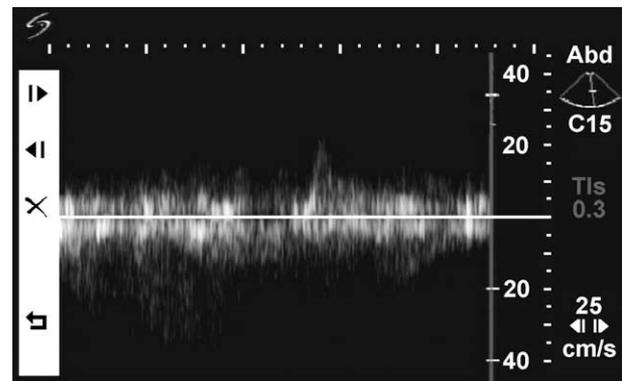


**Fig. 1** A, The transducer position is shown directly over the IVC. B, The IVC is seen near the bottom of the image, below the liver.

board-certified emergency medicine attending physician was present during all examinations. Each attending physician has hospital credentials for performance and interpretation of emergency US and is Registered Diagnostic Medical Sonographer (RDMS) certified. The emergency medicine residency has a structured ultrasound education program based at a level I trauma center.

All examinations were performed in the supine position using a Sonosite 180 plus portable ultrasound machine (Sonosite, Bothell, Wash). The C15 microconvex 2 to 4 MHz broadband transducer was used on the abdominal setting. The probe was placed in a subxyphoid location and the sagittal section of the IVC behind the liver was imaged (Fig. 1A, B). Because the IVC dilates in expiration and collapses in inspiration, the IVCe and the IVCi were measured 2 cm distal to the IVC-hepatic vein junction where the anterior and posterior walls of the IVC are well seen and parallel to each other (Fig. 2). Subjects were not instructed on how to breathe and imaging was performed during resting respiration. Inferior vena cava identification was confirmed using the spectral Doppler feature on the Sonosite 180 plus (Fig. 3). After visualization of the IVC, the image was frozen and a cine-loop was used to take IVC measurements after frame-by-frame analysis to determine the maximal and minimal diameter. Diameters were measured by calipers using the trailing edge to the leading edge technique. The maximal diameter on the IVCe and the minimal diameter on the IVCi were recorded both before and after blood donation. The sonographic measurements were repeated immediately after blood donation, before any rehydration. No correlation of the IVC diameter to the heart cycle was made. Only one author obtained the measurements from the cine-loop. Several measurements of the IVCe and IVCi were taken on each subject and averaged for the final value. There was no further confirmation of measurements.

Ultrasound examinations were performed using a Sonosite 180 plus with a C15 microconvex ultrasound transducer. The transducer is broadband with a range of 2 to 4 MHz. Inferior vena cava blood flow was confirmed using the spectral Doppler feature on the Sonosite. All data were recorded on standardized data sheets. Data were then



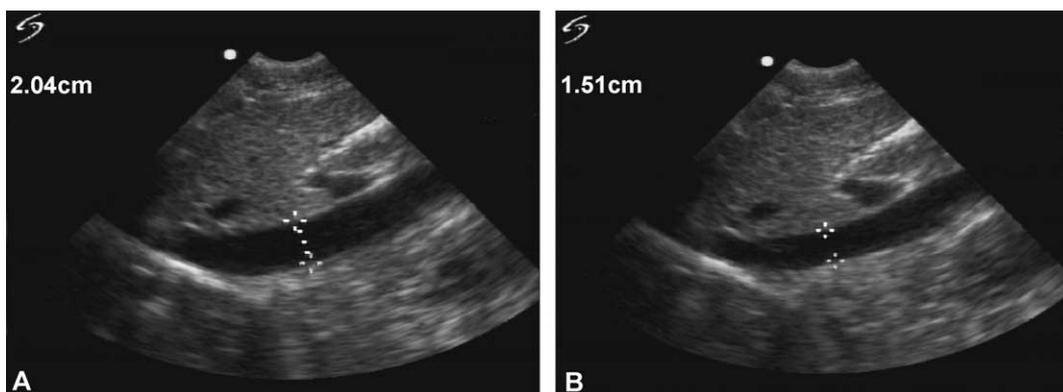
**Fig. 3** A spectral Doppler image is shown. This reading was taken from a vascular structure presumed to be the IVC. The low-speed waveform with little systolic and diastolic variation confirms the IVC vs the aorta as the subject of interest.

compiled into a database. Distances between IVC walls were measured in millimeters. Calipers were placed just inside both the near field and far field walls.

The null hypothesis was rejected at the 5% probability level. Mean values for IVCd were calculated with 95% confidence intervals (CIs). Normality was tested for and *t* test comparisons were made on the data using SAS statistical software by a professional statistical consultant.

### 3. Results

A total of 31 volunteers from the blood donation center were evaluated before and after blood donation. No volunteers donating blood were excluded from this study. There were 18 male volunteers and 13 female volunteers with a mean age of 49.5 years (range, 18-73). The mean IVCe before blood donation (pre-IVCe) was 17.4 mm (95% CI, 15.2-19.7 mm). The mean IVCe postblood donation (post-IVCe) was 11.9 mm (95% CI, 10.3-13.6 mm). The mean IVCi before blood donation was 13.3 mm (95% CI, 11.3-15.3 mm), but after blood donation was 8.13 mm (95% CI, 6.7-9.6 mm). The difference between IVCe before and after donation (dIVCe) was 5.5 mm (95% CI, 4.3-6.3 mm),



**Fig. 2** A, Expiratory IVC diameter before blood donation. B, Expiratory IVC diameter after blood donation.

whereas the difference between IVCi before and after donation (dIVCi) was 5.16 mm (95% CI, 4.2-5.9 mm).

The data were normally distributed on the basis of calculation of normality. Using the paired *t* test, there are statistically significant differences between pre- and post-blood loss for both the IVCe and IVCi with  $P < .0001$ . On average, there was about a 5-mm drop in both the IVCe and IVCi after donation of 450 mL of blood. The dIVCe and the dIVCi were closely correlated yielding an  $r = 0.83$ . Also, the pre-IVCe correlated well to the post-IVCe ( $r = 0.74$ ). Similarly, the pre-IVCi correlated well to the post-IVCi yielding an  $r = 0.75$ . Thus, those with a high pre-IVCi and pre-IVCe also had a high post-IVCi and post-IVCe.

There were 19 volunteers without hypertension and 12 with hypertension. All 12 volunteers with hypertension were on medical therapy for it. Using the *t* test, there were no statistically significant differences between these 2 groups in measurements of the IVC parameters ( $P < .05$ ). The mean duration of blood donation was 5 minutes 43 seconds. Three men and 2 women became symptomatic after blood donation. Symptoms included lightheadedness and weakness on standing. No detectable differences were found in the symptomatic donors. There were no serious complications.

#### 4. Discussion

Shock is the clinical condition that can arise from multiple etiologies but is characterized by the widespread failure of the circulatory system to oxygenate and nourish the body adequately [4]. Although the trauma patient is susceptible to shock from many different mechanisms, hemorrhagic shock emerges as the etiology in the overwhelming majority of cases and can be rapidly fatal. Hemorrhagic shock usually follows excessive and often rapid blood loss due to vessel or organ injury, leading to baroreceptor activation, vasoconstriction, increased cardiac conduction, and increased heart rate. This compensation for blood loss continues until these mechanisms are overwhelmed. Any further blood loss leads to sudden severe hypotension indicative of uncompensated shock [2].

Blood pressure (BP) measurements are generally regarded as the principal marker in evaluating emergency medical conditions as well as the adequacy of resuscitation. In fact, criteria for the severity of shock are frequently based on BP measurements [5]. However, Wo et al [2] have shown that BP is an unreliable indicator of blood loss unless the severity of shock is extreme. The cardiovascular response to shock can vary with underlying cardiopulmonary status, age, presence of medications or drugs, and other concomitant injuries such as intraabdominal hemorrhage [6,7]. As a result, the measurements of heart rate and BP, though noninvasive and readily available, are poor markers of acute blood loss and hence are poor indicators of the severity of the shock as well as response to treatment [2].

Other factors are present in the trauma patient that compound the problems of diagnosing ongoing blood loss.

Often, a critically injured trauma patient can give little or no history to direct the examination or provide the information concerning the adequacy or resuscitation. Second, physical examination is unreliable. The characteristic findings in hemoperitoneum, that is, abdominal tenderness, distension, or tympany, may not be present until patients have nearly exsanguinated [8]. Third, the evaluation of trauma patients is limited by the supine position. No information regarding orthostatic changes in BP or pulse can be obtained, and the assessment of jugular venous distension is limited to the evaluation for obstruction of superior vena cava flow to the heart. If used, laboratory evaluation for blood loss lags behind the clinical picture and is rarely useful in the initial evaluation of trauma patients. The hemoglobin level does not begin to decrease until after there is mobilization of extravascular fluid into blood vessels to compensate for blood loss [9]. Other laboratory values such as renin levels, atrial natriuretic peptide (ANP), arterial blood gas, and serum lactate are also inadequate for monitoring unstable trauma patients due to the delays in obtaining results as well as poor correlation to the amount of blood lost [10]. All of these difficulties in evaluating the amount of blood loss often results in either over- or under-resuscitation of the patient, potentially leading to increased morbidity and mortality [3].

Increasingly, ultrasound of the unstable trauma patient is being used by EPs as well as by trauma surgeons for the diagnosis of hemoperitoneum, hemopericardium, and hemothorax [11,12]. Its utility has been shown in the evaluation of single and multiple trauma patients. In the aftermath of the Armenian earthquake in 1988, sonography was used effectively as a primary screening procedure at the entry to a hospital in mass casualty patients with trauma [13]. Only an average of 4 minutes was required to study each patient with only 1% false negative rate and no false positive results for trauma-associated pathology of the abdomen and the retroperitoneal space [13]. However, the standard examination for trauma, the FAST, does not give any information about the hemodynamic status, amount of blood lost, ongoing blood loss, or response to resuscitation. In addition, the FAST examination cannot provide information about blood loss outside the peritoneum, such as the retroperitoneal space. Regrettably, there has been no reasonable noninvasive way to monitor for blood loss at the bedside, and any invasive methods are unlikely to find acceptance in most situations.

The IVC is a highly compliant vessel, whose size and dynamics vary with the changes in total body water and respirations [14]. During inspiration, negative intrapleural pressure develops, permitting increased venous return to the right side of the heart. Flow through the IVC increases causing a decrease in intraluminal pressure, which in turn leads to a decrease in the diameter of this highly compliant vessel [15]. Ultrasonographic imaging of the IVC was first reported by Weil and Maurat and demonstrated that the diameter of the IVC was dilated in the right-side cardiac failure and changed with respiration [16].

Using ultrasound, Natori et al [17] showed that the diameter of the IVC and the amount of inspiratory collapse, in patients lying in a supine position, correlated with the central venous pressure. Cheriex et al [18] demonstrated using an invasive central venous line that IVC dimensions correlated significantly with invasive measurements of mean right atrial pressure. Furthermore, this study showed that IVC indices could be used as parameters for both high- and low-filling pressures.

In studies on patients undergoing dialysis, Tetsuka et al [19] demonstrated that IVCd, CBV, and body weight are decreased by ultrafiltration. Most significantly, their data showed that there was a linear correlation between the IVCd at end expiration (IVCe) and CBV. This correlation was maintained even after hemodialysis. The authors concluded that IVCe reflects CBV rather than the amount of total body fluid and is a marker of CBV.

Kusaba et al [14] demonstrated, using hemodialysis patients, that there was a poor correlation between the amount of fluid removed and postdialysis systolic BP. However, the IVCe gradually decreased in accordance with the amount of fluid removed during dialysis and increased after reinfusing blood following hemodialysis. It was also demonstrated that the IVCi decreased in response to fluid removal. However, the change in the IVCe significantly exceeded that of the IVCi.

To validate the use of IVC measurements as a marker of CBV, Sakurai et al compared these measurements with plasma ANP, cardiothoracic ratio, systolic and diastolic BP, hematocrit, serum concentration of protein, blood urea nitrogen, and sodium. This study showed that the IVCd on both inspiration and expiration correlated significantly with cardiothoracic ratio and plasma ANP, indicating a correlation to CBV. In contrast, IVCd did not correlate with systolic or diastolic BP, hematocrit, or serum concentrations of protein, blood urea nitrogen, or sodium [20].

Using the correlation between IVCe diameter and CBV, unique information regarding acute blood loss, ongoing blood loss, and response to resuscitation can be gained on the trauma patient. This is an attractive tool for several reasons. First, it is a noninvasive bedside procedure and can be performed serially or when there is a change in the condition of the patient. The measurement of the IVCe is easily performed, and more importantly, this measurement is well suited to the trauma patient in that it is performed in the supine position and requires no patient cooperation. Furthermore, this measurement can be performed rapidly, on average, taking less than 1 minute, and can be added to the standard ultrasound examination for trauma (FAST).

We used volunteer blood donors as models for trauma patients because a known amount of blood was removed from the CBV in a controlled fashion. In addition, the blood removal occurred over a brief period simulating trauma. The amount of blood lost during donation is approximately 450 mL. This amount of blood loss falls into class 1 hemorrhage, up to 750 mL or 15% of the CBV. In a class 1 hemorrhage,

change in vital signs while in the supine position is not expected [5,21].

Our data indicate that there is a significant correlation between both the change in IVCi and the change in IVCe during blood donation of 450 mL. This change was approximately 5 mm in both the dIVCi and dIVCe and was consistent regardless of the initial diameter. This argues that a patient can be monitored for ongoing blood loss by serially measuring the IVCd. Implied is that the IVCd can be used as a measure of intravascular volume in response to resuscitation. Furthermore, it appears that we may be able to monitor relatively minor changes in blood volume. Consequently, the EP may not have to await large blood losses, which are easier to detect by clinical examination, but are more devastating.

The mean diameter of the IVCe of 17.4 mm before blood donation is similar to the mean value of 16.7 mm obtained in healthy volunteers as controls in a previous study by Ando et al [16]. In this study of normal volunteers, there was no statistical difference in the IVCd on the basis of sex, body surface area, or age. Even though these data were not specifically evaluated in our volunteer population, these conclusions appear applicable to our subjects as well. Similarly, in comparing the volunteers with no medical problems to those with hypertension on medication, there were no statistical differences between the 2 populations in our study.

The IVCe is the most appropriate measurement for trauma for evaluating for potential hemorrhage even though the data show that both the IVCi and IVCe are equally correlated. The IVCe in prior articles has been shown to have the highest correlation to CBV [19]. In addition, as the CBV decreases, the IVCi will become smaller and eventually collapse; thus, the IVCi value will approach a zero value. Collapse of the distal parts of the IVC was seen in symptomatic (lightheaded) volunteers after blood donation in this study (Fig. 4). Also, as a technical matter of measurement, the larger size of the IVCe is easier to measure and therefore is more accurate. Furthermore, it has been postulated that IVCe will be unaffected by patient respiration because the chest wall muscles are relaxed



**Fig. 4** The IVC is seen to collapse distally in this volunteer after blood donation (arrow).

during expiration. However, in certain pathological conditions found in trauma patients such as acid-base disturbances, pain, and anxiety, respirations can be forceful. The muscular effort required to cause this forceful inspiration may alter the IVCi [14]. This would indicate that the IVCi is a less reliable indicator than IVCe.

The clinical implication of this study is that IVCe may be a marker of CBV in trauma patients. However, serial measurements of IVCe can be used to assess for ongoing blood loss as well as a marker for response to treatment and prevention of overhydration. Direct measurement of the central venous pressure is unsuitable as a routine examination. In contrast, ultrasonographic measurement of the IVCd provides noninvasive real-time information of the CBV. Furthermore, sonographic measurement of the IVCd combined with the FAST examination may increase the specificity for the sonographic detection of intraabdominal hemorrhage.

A limitation of this technique is that it has not been validated in patients with right-sided cardiac disease or in patients with severe tricuspid insufficiency. In patients with severe valvular disease, the measurement of the IVCd may not correlate with the CBV due to the back pressure of the right ventricle through an incompetent valve. However, most trauma patients are young and are unlikely to have heart disease. Also, because only a relatively small amount of blood can be removed from a volunteer, this study does not establish an IVCe below which hypotension will regularly occur. In a study by Ando et al [16], in hemodialysis patients, the IVCe diameter below which hypotension would occur was found to be  $8 \pm 3$  mm. However, it is not known if this information can be generalized to whole blood loss. In fact, in this study, the IVCe was less than 8 mm in several subjects after blood donation, but no evidence of hypotension was found by the blood center staff. Furthermore, despite being performed on subjects with rapid blood loss, this study did not evaluate the uncontrolled environment of actual trauma-induced hemorrhage.

Areas of future study include the determination of the IVCe at which the average individual would be expected to become hypotensive due to whole blood loss. Also, if this technique was to be combined with the standard FAST examination, the sensitivity of the FAST in detecting abdominal trauma may be expected to be increased. Future studies will evaluate the efficacy of this combination of ultrasound techniques in trauma patients.

Our data indicate that the measurement of the IVC diameter is a reliable indicator of blood loss, even in small amounts of 450 mL. The measurement of the IVCe combined with the FAST examination is a powerful technique for evaluating for hypovolemia due to hemorrhage as well as a guide in resuscitation in trauma patients.

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