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ORIGINAL ARTICLE

Sonographic measurement of the inferior vena cava as a predictor of shock in trauma patients

S. Sefidbakht · R. Assadsangabi · H. R. Abbasi · A. Nabavizadeh

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Abstract Detecting and monitoring blood loss is always a challenging dilemma in emergency settings. The diameter of the inferior vena cava (IVC) in trauma patients may be useful in this way. This has been classically done with computed tomography (CT); however, doing it with ultrasound as a bedside easily available modality is a relatively novel approach. Between January 2006 and March 2006, 88 injured patients referred to our center were investigated. The patients were divided in to two groups: a shock group (n=11, 12.5%) and a control group (n=77, 87.5%) who were trauma patients with normal blood pressure. The maximum anteroposteroir diameter of IVC was measured ultrasonographically both in inspiration (i) and expiration (e) by M-mode in the subxyphoid area. The difference between the diameters of IVCe and IVCi was regarded as collapsibility, and collapsibility index was defined as IVCe − IVCi/IVCe. Statistical analysis included Mann–Whitney U test and correlation analysis. The average diameters of IVCe and IVCi in the shock group at arrival were significantly smaller than in the control group (5.6±0.8 mm, 4.0±0.7 mm versus 11.9±2.2 mm, 9.6±2.0 mm; P<0.0001). The maximum diameter of IVC in the shock group was in a 30-year-old male patient with an IVCe and IVCi of 7.0 and 5.3 mm, respectively. Correlation analysis revealed a negative correlation between the diameter of IVCe (r=0.72) and IVCi (r=0.73) and the presence of shock. Regarding the collapsibility index, the mean collapsibility index of IVC was significantly higher in the shock group compared to patients in the control group (27% versus 20%; P<0.001). The diameter of IVC was found to correlate with shock in trauma patients. The measurement of the IVC may be an important addition to the ultrasonographic evaluation of trauma and other potentially volume-depleted patients and can be added to the focused assessment with sonography for trauma (FAST) of the trauma patient with minimum additional time.

Keywords Ultrasonography · Shock · Inferior vena cava

S. Sefidbakht · R. Assadsangabi · A. Nabavizadeh (✉)
Department of Radiology, Shiraz University of Medical Sciences, Shiraz, Iran
e-mail: nabavia@gmail.com

H. R. Abbasi
Department of Surgery, Shiraz University of Medical Sciences, Shiraz, Iran

Introduction

Shock is a clinical condition that can arise from multiple etiologies; however, in all cases, it is characterized by the widespread failure of the circulatory system to oxygenate and nourish the body adequately [1]. Although the trauma patient is susceptible to shock from many different etiologies, hemorrhagic shock is the leading etiology in most cases and can be rapidly fatal. Sonography has proved to be a suitable method to detect bleeding sources in trauma patients referred to as focused assessment with sonography for trauma (FAST) [2, 3].

Although sonography was used effectively as a primary screening procedure at the entry to a hospital in mass casualty patients with trauma, with an average of 4 min for each patient [4]; 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.

The relation between the diameter of the inferior vena cava (IVC) and the intravascular volume and right side cardiac function has been repeatedly investigated in hemodialysis patients and patients with cardiac disease [5–8]. The diameter and respiratory changes of IVC has also been shown to be useful as a guide to fluid therapy [9, 10]; however, the relation between the sonographic measurement of the diameter of IVC and the intravascular volume of trauma patients has been considered only recently [11, 12]. This study was conducted prospectively to determine the relationship between the diameter and respiratory variations of the IVC and the presence of shock in trauma patients.

Materials and methods

Between January 2006 and March 2006, 95 injured patients who were transferred to Namazi Hospital, a 1,000-bed general hospital in Shiraz, were investigated. All patients were transferred to the hospital within 1.5 h after injury without significant amount of infusion. All trauma patients aged 16 years and older were eligible for enrollment. Persons who were younger than 16 years were excluded.

Patients who developed cardiopulmonary arrest and patients who were not suitable for ultrasound visualization of IVC due to technical problems (severe obesity, severe gas distension, stab wound at the epigastrium, or other problems that prohibit optimal visualization of IVC) were also excluded from the study, and the remaining 88 patients were prospectively investigated during the first 18 h after admission. The patients were divided into two groups: a shock group (n=11, 12.5%) who were hypotensive and a control group (n=77, 87.5%) who were trauma patients with normal blood pressure. Hypotension was defined as systolic blood pressure of 90 mmHg either at arrival or within 18 h after admission. Normotesion was also defined as systolic blood pressure of 90 mmHg or higher throughout the study period.

The diameter of IVC both during inspiration (IVCi) and during expiration (IVCe) was measured by M-mode in trauma patients. The Logicbook (GE, USA) was used as an ultrasound device.

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. The difference between the diameters of IVCe and IVCi was regarded as collapsibility, and collapsibility index was defined as IVCe − IVCi/IVCe (Fig. 1). The upper part of the IVC was chosen because it was easily demonstrated in most patients [13]. Constant anatomic landmarks allowed about the same part of the IVC to be evaluated in each subject. To measure the IVC diameter, electronic calipers were used on the sonogram device screen at right angles to the axis of the vascular system (inner to inner diameter).

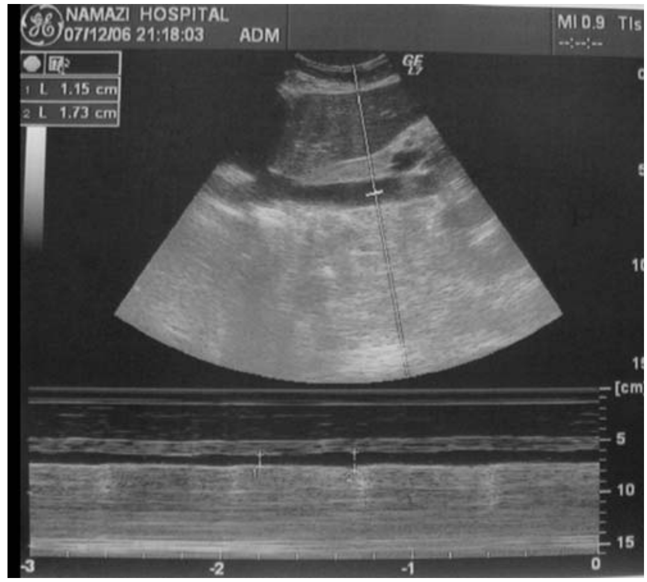

Fig. 1 Measurement of the inferior vena cava diameter in a patient in the control group using M-mode. As you see, the diameters of the IVCe and IVCi are 17.3 and 11.5 mm, respectively

Two radiologists independently measured the diameter, and the averages of the two measurements were considered for each patient.

Finally, various data regarding age, gender, vital signs, injury severity score, and the presence or absence of penetrating wound were recorded in each patient.

Statistical analysis included Mann–Whitney U test and correlation analysis. All data were expressed as mean± standard deviation. P values less than 0.05 were considered significant.

This study was approved by the bioethical committee of Shiraz Medical School.

Results

The demographic and clinical characteristics of patients at arrival to the hospital is summarized in Table 1. Four patients younger than 16 years and three patients who were unsuitable for ultrasound visualization of IVC due to technical difficulties were excluded from the study, and the remaining 88 patients were investigated. The age range was 16 to 80 years in the control group and 20 to 74 years in the shock group. The only parameter that was different between the two groups was systolic blood pressure (P< 0.001). There were not statistically significant differences in other parameters including age, sex, pulse rate, injury severity score, and presence of penetrating wound. One patient in the shock group initially showed normal blood pressure at arrival; however, his blood pressure deteriorated within 6 h after arrival. In the shock group, six patients received emergency laparotomy. The remaining five

Table 1 The demographic and clinical characteristics of patients in both groups at arrival to the hospital

Characteristics	Control (n=77)	Shock (n=11)	P value
Age	32.0±6.9	38.1±8.5	NS
Sex (M/F)	3.81	2.6	NS
Systolic blood pressure (mmHg)	114.7±11.1	77.7±5.6	<0.001
Pulse rate	91.6±4.5	95.4±6.8	NS
Injury severity score	9.5±1.3	11.2±1.8	NS
Penetrating wound	3	4	NS

NS: Not significant

patients were successfully managed conservatively for liver laceration and pelvic fractures. No patient in the control group received surgery during our study period.

The size of the IVC was maximal with the patient supine and at end expiration. The subhepatic IVC decreased in size at end inspiration. Regarding all patients, the mean IVCe and IVCi diameters were 11.9±2.2 mm and 9.6±2.0 mm, respectively.

The mean collapsibility of IVC in both groups was 2.2± 1.0 mm (collapsibility index=20%). The average diameters of IVCe and IVCi in the shock group at arrival were significantly smaller than in the control group (5.6± 0.8 mm, 4.0±0.7 mm versus 11.9±2.2 mm, 9.6±2.0 mm; $P<0.0001$). The maximum diameter of IVC in the shock group was in a 30-year-old male patient with IVCe and IVCi of 7.0 and 5.3 mm, respectively (Fig. 2). The

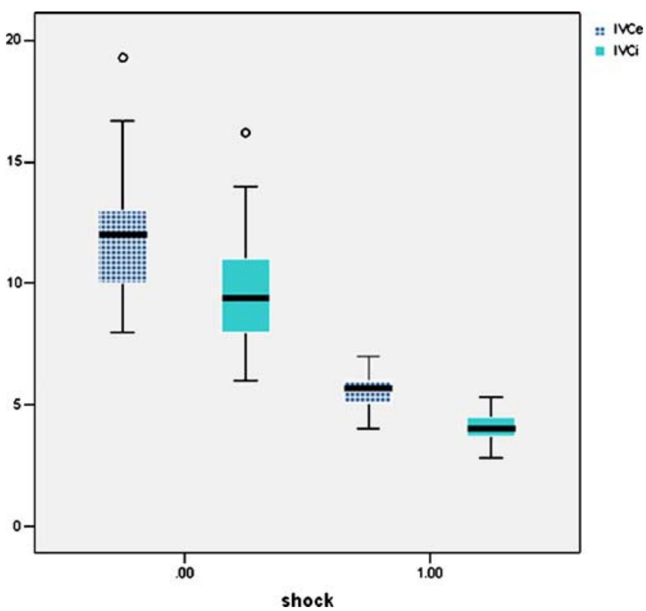

Fig. 2 The average diameters of the IVCe and IVCi in both groups (1=Shock group, 0=control group). As you see, the mean diameters were significantly smaller in the shock group than in the control group (5.6±0.8 mm, 4.0±0.7 mm versus 11.9±2.2 mm, 9.6±2.0 mm; $P<$ 0.0001)

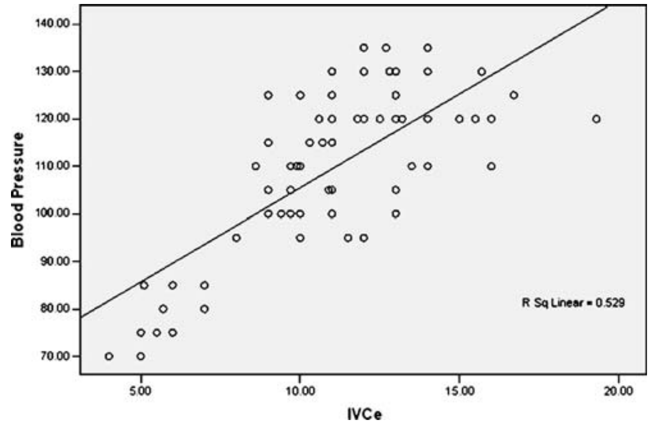

Fig. 3 The correlation analysis revealed a positive correlation between the diameter of the IVCe and the blood pressure

correlation analysis revealed a negative correlation between the diameter of the IVCe (r=0.72) and the IVCi (r=0.73) and the presence of shock, and a positive correlation between the diameter of IVCe and IVCi and the blood pressure (Figs. 3 and 4). Regarding the collapsibility index, the mean collapsibility index of IVC was significantly higher in the shock group compared to the patients in the control group (27 versus 20%; $P<0.001$).

Discussion

The IVC is a highly compliant vessel, whose size and dynamic vary with the changes in total body water and respirations [14, 15]. Although there are conflicting results about the respiratory variations in the sonographic appearance of the IVC [15–17], most authors feel that the normal IVC will diminish in caliber with inspiration and increase in caliber during expiration [5, 15]. Changes in the caliber of IVC are attributed to variations in blood flowing through the IVC in accordance with the respiratory and cardiac

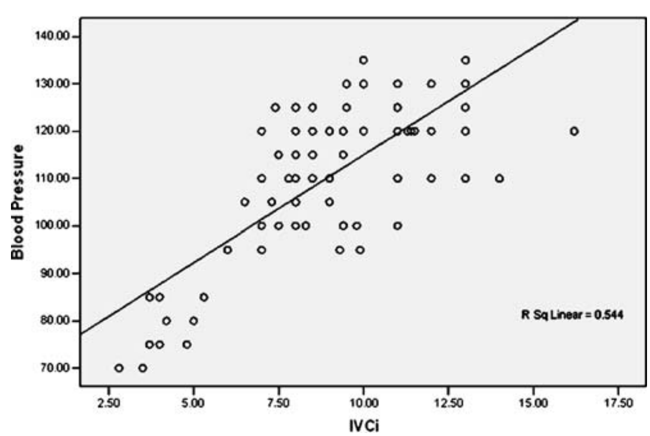

Fig. 4 The correlation analysis revealed a positive correlation between the diameter of the IVCi and the blood pressure

cycles. In inspiration, blood is literally sucked into the chest by negative pressure, causing the vessel to collapse, and these changes are reversed in expiration, causing ballooning of the IVC. Collapsibility of the IVC during inspiration has been shown to be a predictor of fluid therapy in mechanically ventilated patients with septic shock, and a 12% cut-off value allowed the identification of responders [18]. Decreased collapsibility of IVC may also be a feature of chronic congestive heart failure in association with dilated hepatic and renal veins [17].

Physical examination and vital signs of trauma patients often are unreliable because of multiple factors [19]. 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 makes the clinical assessment of blood loss in these patients a difficult task. These uncertainties can potentially result in inappropriate resuscitation, either too little or too much [20]. Measurement of IVC diameter, therefore, can be a very useful way to evaluate the patient's hemodynamic status. This is easily performed and is well suited in trauma patients because it can be performed in supine position and requires no patient cooperation. In addition, this can be performed rapidly and can be added to the FAST sonography of the trauma patient with minimum additional time. The use of M-mode is a very useful innovation to quickly measure IVCe and IVCi diameters and the collapsibility index.

Our study revealed that both IVCe and IVCi are significantly smaller in patients with shock, a finding that has also been reported in a recent study [11]. The maximum IVCe diameter in the shock group was 7 mm. In a study by Ando et al. [21], in hemodialysis patients, the IVCe diameter below which hypotension would occur was found to be 8±3 mm. Furthermore, Yanagava et al. [11] found that IVCe diameter of below 9 mm is associated with the presence of shock in trauma patients. Both IVCe and IVCi are equally correlated with shock in our patients, and this is in accordance with a recent study of sonographic measurement of IVC diameters on blood donors [12]; however, IVCe has been shown to have the highest correlation with circulating blood volume (CBV) in prior studies that have been performed in hemodialysis patients [22]. Another factor that should be mentioned is that, as CBV decreases, the IVCi will become smaller and more difficult to measure. Furthermore, it has been postulated that patient respiration has little effect on IVCe because chest wall muscles are usually relaxed during expiration. Conversely, in certain pathological conditions that are not uncommon in trauma patients, such as pain, anxiety, and acid-based disturbances, forceful inspiration can alter the diameter of the IVCi and make it unsuitable as a standard of CBV [14]. The above findings indicate that IVCi may be a less reliable indicator of CBV than IVCe. We found no significant difference between the age, sex, pulse rate, injury severity score, and the presence of penetrating wound between both groups. Our results are nearly the same as the study by Yanagawa et al. [11] except that they found more penetrating wounds in patients with shock. Logically, pulse rate and injury severity score should be higher in patients with shock. The reason why these two studies did not reach such an association may be due to the inadequate sample size in the shock group; however, it may also be indicative of the lack of sensitivity of these two factors in the prediction of shock.

The relation between the diameter of IVC and the intravascular volume of trauma patients has been retrospectively investigated using abdominal computed tomography (CT) scans. Jeffrey and Federle [23] reported that a collapsed IVC indicated hypovolemia secondary to major blood loss in six of seven trauma patients. They also reported that none of the trauma patients with normal IVC developed clinical hypovolemia in the immdediate period after CT scan. Mirvis et al. [24] noted a flattened IVC in 10 of 13 patients who were in shock after blunt abdominal trauma. However, a retrospective analysis by Eisenstat et al. [25] using abdominal CT for non-trauma patients showed that most (70%) patients with a flat cava sign do not have any evidence of hypotension or hypovolemia and concluded that the findings of flat cava sign should be closely correlated with clinical findings. Although correlation with clinical manifestations seems to be necessary in every patient, differences regarding both the subjects and the definition of collapsed IVC in the latter study and using more flexible criteria may have led to different results compared to the former studies.

This study has several clinical implications. Firstly, it shows that the measurement of IVC diameter is a reliable indicator of shock in trauma patients and may even predict it in patients who still have normal blood pressure due to sympathetic overactivity. In our study, one subject with a small IVC diameter in the shock group showed normal values for both blood pressure and pulse rate at arrival, but these values deteriorated within 12 h of arrival. Secondly, serial measurements of IVC diameter can be used to monitor ongoing blood loss and monitor fluid therapy and can even be used as an alternative to direct central venous pressure measurement, which is not suitable as a routine procedure.

A potential limitation of measurement of IVC diameter in trauma patients is that IVC diameter in patients with right-sided heart failure and severe tricuspid insufficiency may not correlate well with CBV due to the back pressure of the right ventricle through an incompetent valve. However, most trauma patients are young and unlikely to have heart disease. Measuring the collapsibility index can be very helpful in diagnosing patients with heart disease. Minutiello [26] revealed that a collapsibility index of ≥20% is associated with the absence of cardiac disease. Another potential limitation of IVC diameter measurement may be in patients with elevated intraabdominal pressure because narrowing of the upper abdominal IVC unrelated to CBV can occur in these patients [27]. Both groups in our study showed collapsibility indexes of ≥20%, and this index was higher in the shock group, which may be due to volume depletion and more strenuous cardiac activity in this group.

In the current study, the data for children were not investigated because there have been no previous data concerning the age-dependent normal range of IVC; however, the diameter of the IVC has been shown to be useful for determining the volume load in children with nephrotic syndrome [28]; so, the serial measurement of IVC diameter may also be a potentially useful parameter to evaluate the intravascular volume in traumatized children.

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