**Evaluation of ultrasonography measurement of superior vena cava diameter in comparison to central venous pressure in guiding of fluid therapy in patients with hypovolemic shock**

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**ABSTRACT**

**Background:** Central venous pressure (CVP) measurement is fundamental in perioperative medicine and is often achieved invasively with a central venous catheter (CVC). CVP can be estimated non-invasively by clinical examination of the jugular venous pressure. Echocardiography has been used to estimate CVP, with particular emphasis on the superior vena cava (SVC) diameter and collapsibility with respiration.  **Aim:** to evaluate the role of ultrasound measurements of SVC Diameter and collapsibility index in comparison to CVP measurements in guiding fluid therapy in patients with hypovolemic shock. **Methodology: o**n admission hemodynamic monitoring of intravascular volume by CVP measurement,non invasive blood pressure measurement, urine output calculation were done, together with SVC ultrasound for measurement of diameter and collapsibility. **Results:** Patients with CVP equal or more than 10 was significantly associated with higher SVC max and SVC min, lower SVC CI. CVP showed significant positive correlation with dSCV max, dSVC min, significant negative correlation with SVC-CI. The best cut-off point of the SVC-CI for discrimination between patients with CVP<10 and patients with CVP≥10was 36.8% with sensitivity of 27.6% and specificity of 87.5%. lower SVC-CI was considered independent predictors for CVP≥10, that help making decision to stop fluid infusion. **Conclusion:** The CVP remains the most frequently used variable to guide fluid resuscitation in critically ill patients. SVC diameter and collapsibility with positive pressure ventilation is a potentially attractive method of non-invasively estimating CVP. SVC-CI can be used as a predictor for high CVP measurement to make decision to stop fluid infusion.

**KEY WORDS**: Shock, hypovolemia,CVP, SVC, shock monitoring.

**Introduction**

Shock is a life-threatening manifestation of circulatory failure. ***(1).***  There are mainly four broad categories of shock: distributive, hypovolemic, cardiogenic, and obstructive. Undifferentiated shock means that the diagnosis of shock has been made; however,the underlying etiology has not been uncovered ***(2).*** Patients with hypovolemic shock have severe hypovolemia with decreased peripheral perfusion. If left untreated, these patients can develop ischemic injury of vital organs, leading to multi-system organ failure ***(3).*** Hypovolemic shock is the most common type of shock in children, most commonly due to diarrheal illness in the developing world. ***(4).*** Severe hypovolemic shock can result in mesenteric and coronary ischemia that can cause abdominal or chest pain. ***(5).*** Various laboratory values can be abnormal in hypovolemic shock. ***(6).*** Central venous pressure (CVP): is often used to assess volume status ***(5).***  CVP can be estimated by assessing the inferior vena cava or internal jugular vein diameter and collapsibility ***(7).*** For patients in hemorrhagic shock, early use of blood products over crystalloid resuscitation results in better outcomes. Anti-fibrinolytic administration to patients with severe bleed appears to decrease death ***(8).*** For patients in hypovolemic shock due to fluid losses, the exact fluid deficit cannot be determined. Therefore, it is prudent to start with 2 liters of isotonic crystalloid solution infused rapidly as an attempt to quickly restore tissue perfusion ***(9).*** The CVP can be measured using a central venous catheter advanced via the internal jugular vein and placed in the superior vena cava (SVC) near the right atrium ***(10).*** CVP was found to be a poor predictor of fluid responsiveness. Accurate measurements of the CVP were also challenged. (***11).*** Some factors that can decrease CVP are hypovolemia or vasodilation. Either of these would decrease venous return and thus decrease the central venous pressure. ***(12).*** Elevated CVP can occur in heart failure due to decreased contractility, valve abnormalities, and dysrhythmias. Any patients on ventilator assistance that have excessive positive end-expiratory pressure would have an increase in pulmonary arterial resistance which causes an increase in CVP ***(13).*** Clinical utility of the CVP can be seen in the assessment of cardiocirculatory status ***(14).*** The easy determination of the CVP makes it a clinically attractive, albeit non-specific, indicator of fluid status. As such, other indices, such as the inferior vena cava collapsibility index (IVC CI) must be used adjunctively for more accurate assessment of volume status ***(15).*** CVP can be indirectly measured by the clinical assessment of jugular venous pressure or on ultrasound evaluation of the inferior vena cava (IVC). It can be measured directly via a simple manometer attached to a central venous catheter. The transducer should be aligned with the patient’s mid chest at the mid-axillary line, at the level of the left atrium. A common pitfall in CVP measurement is not accounting for the effect of positive end expiratory pressure (PEEP) with positive pressure ventilation. PEEP may have direct effects on cardiac preload, afterload, and ventricular compliance. PEEP can falsely elevate CVP measurements depending on pulmonary compliance and intrathoracic cavity pressure swings by creating resistance to flow ***(16).*** The SVC is a commonly used site for central venous access ***(17).*** The latest multicentral retrospective study demonstrated that inappropriate fluid administration is correlated with increase in postoperative complications. Thus, excessive fluid infusion may increase the risk of pulmonary and peripheral tissue edema retarding the recovery of respiratory and intestinal function, while the conservative fluid therapy may induce an unstable hemodynamic profile, multiorgan hypoperfusion, and prolonged hospital stay ***(18).*** Traditional static hemodynamic parameters, such as CVP and pulmonary capillary wedge pressure, have shown little value in guiding volume expansion. In addition, although widely used and accepted as robust indicators to predict preload responsiveness in mechanically ventilated patients, the dynamic indices of stroke volume variation (SVV) ***(19),*** or pulse pressure variation (PPV) ***(20)*** require a costly sophisticated device or invasive catheterization With the increasing accessibility of ultrasound devices in perioperative settings, ultrasonography has been recommended for volume assessment due to its advantage in noninvasiveness, repeatability, and short learning curve ***(21).*** Among these echocardiographic variables, superior vena cava (SVC) collapsibility index (SVCCI), and SVC variation over the cardiac cycle (SVCV) have shown promising results in mechanically ventilated patients, but SVC measurements required transesophageal echocardiography (TEE) technique, which currently limited its routine clinical application ***(22).*** With the introduction of SVC acquisition through transthoracic echocardiography (TTE) approach, it is, therefore, possible to determine volume responsiveness by measuring SVC variation using a noninvasive approach ***(23).*** Evaluation of the CVP is a method that is widely accepted in assessing the intravascular volume status. Nevertheless, positive pressure ventilation can affect precision in assessments of the CVP. Recently, the stroke volume variation has been used as guide during intraoperative anesthesia care in the operating room ***(24).*** The SVC collapses partly or completely with positive pressure ventilation, depending on the transmural pressure difference between intrathoracic pressure and SVC pressure. In contrast, increased intrathoracic pressure causes dilation of the intraabdominal portion of the IVC. The collapsibility of the SVC has been used to estimate intravascular volume and fluid responsiveness in critically ill patients ***(25).*** Moreover, accurate estimation of the CVP is a key component of the non-invasive measurement of right ventricular systolic pressure (RVSP), with inaccuracies leading to both under- and overestimation of the RVSP. No data specifically comparing SVC indices with CVP. Nor is this mentioned in guideline statements from echocardiography societies, perhaps because of the difficulty imaging the SVC with transthoracic echocardiography in adult patients. With transesophageal echocardiography (TOE), the SVC is easy to visualize in almost all patients ***(26).*** So, we aim in the current study to evaluate the role of ultrasound measurements of SVC Diameter and collapsibility index in comparison to CVP measurements in guiding fluid therapy in patients with hypovolemic shock.

**Patients and methods**

**Study design**

An observational cross-sectional study was carried out in the intensive care unit (ICU), Benha University Hospital and approved by The Ethical Committee of Benha University.

**Study patients**

This study included 100 patients of both sex with hypovolemic shock admitted to the ICU in Benha University Hospital. A written informed consent was taken from patient’s relatives. All patients had a functioning central venous catheter inserted and SVC diameter using US was measured.

**Inclusion criteria:**

ASA I–III, ICU patients above 18 years old, non-intubated, non-ventilated with hypovolemic nonhemorrhagic shock (mean arterial BP <65 mmHg and tachycardia (defined as heart rate>100 beats/minute)

**Exclusion criteria:**

Patients under 18 years, patients with severe orthopnea, morbid obese BMI above 50kg/m2, suspected or diagnosed raised intraabdominal or intrathoracic pressures as known pregnancy, portal hypertension, or mediastinal mass, valvular heart disease , extended cervico facial cellulitis, venous thrombosis, ongoing hemodialysis on an internal jugular vein cathter, intracerebral hemorrhage or increased intracranial pressure, atrial fibrillation.

**Patients’ examination**

All patients were subjected to full assessment, as age, sex, body weight, and height. Mean age of studied cases was 51.2 years, ranged from 19 to 80 years. They were 74 males and 26 females. Full history was reported, past medical history including diseases as diabetes mellitus, hypertension, chronic kidney disease, chronic liver disease, cardiac history, cerebrovascular stroke, history of previous allergy, history of any drug or toxin intake, and in case of traumatized patient, mode and the time of trauma was taken in consideration. Past surgical history including any recent surgeries. Complete clinical examination was done. Measurement of the patient's hemodynamic parameters was evaluated by ABCDE

**Measurement of CVP and SVC diameter and CI by ultrasound:**  as all the readings of SVC diameter and CVP measurements were recorded concomitantly. All ultrasonographic examinations were performed with the patients in supine position by the same physician throughout the study. All the readings were taken by the researcher. As he sought specialized training in use of bed side ultrasonography by taking POCUS Course. Supine chest radiography and transthoracic echocardiography were done to exclude cardiogenic and obstructive shock.

**STATISTICAL ANALYSIS**

The collected data was analysed using Statistical package for Social Science (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.). Student T test was used to assess the statistical significance of the difference between two study groups. Correlation analysis was used to assess the strength of association between two quantitative variables. The ROC Curve (receiver operating characteristic) provides a useful way to evaluate the sensitivity and specificity for quantitative diagnostic measures that categorize cases into one of two groups. The optimum cut off point was defined as that which maximized the AUC value. Logistic regression analysis was used for prediction of risk factors. A p is significant if <0.05 at confidence interval 95%.

**Results:**

The present study was conducted on 100 cases who were admitted to the ICU with hypovolemic shock. Patients’ features are shown in **table 1**. Out of all studied cases, 49% received vasoactive drugs, while 51% did not., mean CVP was 6.9 cm H2O, ranged from 0 to 11 cmH2O; most of cases had CVP less than 10 cmH2O (76%), while only 24% had CVP equal or more than 10 cmH2O. Regarding the SVC diameters , the maximum diameter mean was 1.5 mm, while the minimum diameter mean was 1.1 mm and the SVC Collapsibility index mean was 28.9 and it ranged from 6.7% to 62% **(table 1).** High CVP was significantly associated with higher dSVC max, dSVC min, lower SVC-CI% **(table 2, figure 1).**

CVP showed significant positive correlation with age, BMI, SBP, DBP, MAP, dSCV max, dSVC min, significant negative correlation with HR, and SVC-CI. While, the SVC-CI% showed significant negative correlation with age, SBP, DBP, MAP, dSVC max, dSVC min, significant positive correlation with HR **(table 3, figure 2).**

Receiver operating characteristic (ROC) curve of SVC-CI was conducted for discrimination between patients with CVP<10 and patients with CVP≥10. The best cut-off point of the SVC-CI was 36.8% with (Sensitivity 27.6% and Specificity 87.5%). **Table 4** shows various sensitivities and specificities of different cut off values.

Logistic regression analysis was conducted to predict factors affecting CVP, using age, gender, BMI, SBP, DBP, MAP, HR and SVC-CI as covariates. Higher SBP, DBP, MAP, lower HR, SVC-CI were associated with prediction of high CVP in univariable analysis. While in multivariable analysis, only lower HR, SVC-CI were considered independent predictors for CVP≥10, in order to make decision to stop fluid infusion **(table 5).**

**Discussion**

Hypovolemic shock occurs when there is decreased intravascular volume to the point of cardiovascular compromise ***(3).*** Our study showed that mean CVP was 6.9 cm H2O, ranged from 0 to 11 cmH2O; most of cases had CVP less than 10 cmH2O (76%), while only 24% had CVP equal or more than 10 cmH2O, while Cowie et al found thatThe median CVP in their sample was 10 mmHg with a range of 2 to 19 mmHg ***(27).*** The present study found that, patients with high CVP was significantly associated with higher SBP, DBP, MAP and significantly lower HR. All cases with CVP equal or higher than 10 received vasoactive drugs. Rahim-Taleghani et al found that, among patients under mechanical ventilation, pH and anion gap showed significant negative correlation) with CVP, but HCO3 showed a significant positive correlation with CVP. Whereas in patients without mechanical ventilation, only pH had a significant negative correlation with CVP ***(28).*** The present study demonstrated that, patients with high CVP was significantly associated with higher SVC max and SVC min, lower SVC CI. Cowie et al found that, there was a weak, but statistically significant, correlation between CVP and SVC collapsibility index (***27***). The present study revealed that, CVP showed significant positive correlation with age, BMI, SBP, DBP, MAP, dSCV max, dSVC min, and significant negative correlation with HR, and SVC-CI. Cowie et al, found a lack of a relationship between the SVC diameter and CVP ***(27).*** Our results showed that, the SVC-CI% showed significant negative correlation with age, SBP, DBP, MAP, dSVC max, dSVC min, and significant positive correlation with HR. Before VE SVC collapsibility ranged from 0% to 100%, was weakly correlated with SVC maximum diameter, and was not correlated with central venous pressure. As well as Cowie et al found that, there was no statistically significant correlation between maximum SVC diameter and CVP Maximum SVC diameter was statistically significantly correlated with weight. There was no statistically significant correlation between CVP and age or body dimensions (***27).*** Charbonneau et al had revealed that, the best cutoff value of SVC diameter to predict fluid responsiveness was 29% with a sensitivity of 54%, and a specificity of 94%. A poor correlation between ΔSVC and ΔCI was found. A ΔSVC >36% used to discriminate between responders and non-responders with a sensitivity of 42%, a specificity of 100% (***29***). We conducted a ROC curve of SVC-CI for discrimination between patients with CVP<10 and patients with CVP≥10. The best cut-off point of the SVC-CI was 36.8% with (Sensitivity 27.6% and Specificity 87.5%) while Shalaby et al found in their study that, there was a significant correlation between CVP and the two studied ultrasound parameters, IVC CI and IVCdmax. Others found that the inferior vena cava collapsibility index (IVC CI) had the most favorable performance of the two ultrasound parameters in predicting CVP < 10 cm H2O.  As regards prediction of fluid responsiveness, a better diagnostic accuracy of IVC collapsibility index and IVC diameter was found for predicting fluid responsiveness (***30).*** In the present study, fluid infusion was stopped if CVP increased to a value≥12 cm, so logistic regression analysis was conducted to predict factors affecting CVP,using age, gender, BMI, SBP, DBP, MAP, HR and SVC-CI as covariates. Higher SBP, DBP, MAP, lower HR, SVC-CI were associated with prediction of CVP equal or more than 10 in univariable analysis. While in multivariable analysis, only lower HR, SVC-CI was considered predictors for CVP≥10, in order to make decision to stop fluid infusion. Cheng and his colleagues revealed that, ultrasound SVC measurements were predictive indicators of fluid responsiveness, and the minimal SVC diameter was a slightly more effective indicator than the SVC variation and maximal SVC diameter. The optimal cutoff value for the minimal SVC diameter, with sensitivity of 87.2% and specificity of 88.0%, was 1.135 cm. Furthermore, the AUC for the minimal SVC diameter was 0.929. The SVC variation decreased significantly after volume expansion. Meanwhile, the CVP had no statistically significant difference before and after the fluid challenge (***31).*** SVC-CI had a more significant correlation coefficient with cardiac output, a larger AUC, and a smaller gray zone than dIVC and SVCV, indicating that the respiratory variation of SVC is superior to dIVC and SVC cardiac variation in predicting volume responsiveness ***(32).*** Limitations of the present study is that its observational nature as well as lacking similar studies that compare measurements of SVC diameter as well as collapsibility index with CVP which made our results biased. In addition, recording data before and after fluid infusion is recommended in further studies.

In conclusions, the CVP remains the most frequently used variable to guide fluid resuscitation in critically ill patients. SVC diameter and collapsibility with positive pressure ventilation is a potentially attractive method of non-invasively estimating CVP. SVC-CI can be used as a predictor for CVP measurement.

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**Table (1). Vital signs , CVP, SVC assessment of all studied cases.**

|  |  |
| --- | --- |
|  | **Cases****N=100** |
| **SBP (mmHg)** | mean±SD (Minimum-maximum) | 98.4±16.3 (60-132) |
| **DBP (mmHg)** | mean±SD (Minimum-maximum) | 54.5±10.5 (37-75) |
| **MAP (mmHg)** | mean±SD (Minimum-maximum) | 68.7±11.7 (46-95) |
| **Pulse rate (bpm)** | mean±SD (Minimum-maximum) | 116.1±34.5 (66-183) |
| **CVP (cm H2O)** | mean±SD (Minimum-maximum) | 6.9±2.3 (0-11) |
| **CVP<10** | N, % | 76(76%) |
| **CVP≥10** | N, % | 24(24%) |
| **dSVC max (mm)** | mean±SD (Minimum-maximum) | 1.5±0.6 (0.5-2.60) |
| **dSVC min (mm)** | mean±SD (Minimum-maximum) | 1.1±0.5 (0.2-2.40) |
| **SVC-CI (%)** | mean±SD (Minimum-maximum) | 28.9±13.1 (7.6%-62%) |

**Table (2). Comparison of SVC among studied cases according to CVP.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **CVP<10** | **CVP≥10** | ***p*** |
| **N=76** | **N=24** |
| **dSVC max** | mean±SD (Minimum-maximum) | 1.3**±**0.4 (0.5-2.3) | 2.2**±**0.3 (1.7-2.6) | **<0.001** |
| **dSVC min** | mean±SD (Minimum-maximum) | 0.9**±**0.4 (0.2-1.7) | 1.6**±**0.3 (1.1-2.4) | **<0.001** |
| **SVC-CI%** | mean±SD (Minimum-maximum) | 29.8%**±**13.9% (9%-62%) | 26.3%**±**10% (7.6%-45%) | **0.025** |

**Table (3). Correlation of CVP and SVC-CI % with other studied parameters.**

|  |  |  |
| --- | --- | --- |
|  | **CVP** | **SVC-CI%** |
| ***coefficient*** | ***p*** | ***coefficient*** | ***p*** |
| **Age** | 0.324 | **0.001** | -0.232 | **0.020** |
| **BMI** | 0.273 | **0.006** | -0.009 | 0.927 |
| **SBP** | 0.804 | **<0.001** | -0.366 | **<0.001** |
| **DBP** | 0.830 | **<0.001** | -0.309 | **0.002** |
| **MAP** | 0.883 | **<0.001** | -0.356 | **<0.001** |
| **HR** | -0.927 | **<0.001** | 0.402 | **<0.001** |
| **dSVC max** | 0.891 | **<0.001** | -0.377 | **<0.001** |
| **dSVC min** | 0.848 | **<0.001** | -0.640 | **<0.001** |
| **SVC-CI%** | -0.431 | **<0.001** | **-** | **-** |

**Table (4). Validity of SVC-CI for prediction of CVP ≥10.**

|  |  |  |
| --- | --- | --- |
| **SVC-CI** | **Sensitivity** | **Specificity** |
| 27.8% | 50.0 | 54.2 |
| 28.8% | 44.7 | 54.2 |
| 29.5% | 43.4 | 54.2 |
| 30.4% | 38.2 | 58.3 |
| 30.9% | 38.2 | 66.7 |
| 31.3% | 36.8 | 66.7 |
| 32.3% | 36.8 | 70.8 |
| 34.0% | 30.3 | 83.3 |
| 35.5% | 28.9 | 83.3 |
| 36.8% | 27.6 | 87.5 |
| 37.8% | 26.3 | 87.5 |
| 39.0% | 25.0 | 87.5 |
| 40.5% | 21.1 | 91.7 |
| 41.9% | 19.7 | 91.7 |
| 42.9% | 18.4 | 91.7 |
| 44.0% | 18.4 | 95.8 |
| 45.5% | 14.5 | 100 |

**Table (5). Regression analysis for prediction of CVP≥10 in order to stop fluid infusion**.

|  |  |  |
| --- | --- | --- |
|  | **Univariable** | **Multivariable** |
| ***p*** | ***OR(95% CI)*** | ***p*** | ***OR(95% CI)*** |
| **Age**  | 0.133 | 1.018(0.9950.995-1.042) |   |  |
| **Gender** | 0.226 | 0.665(0.3440.344-1.287) |   |  |
| **BMI** | 0.066 | 1.067(0.9960.996-1.144) |   |  |
| **SBP** | **<0.001** | 1.064(1.0381.038-1.092) | 0.536 | 1.031(0.9350.935-1.138) |
| **DBP** | **<0.001** | 1.144(1.0821.082-1.21) | 0.488 | 1.072(0.8810.881-1.305) |
| **MAP** | **<0.001** | 1.123(1.0741.074-1.174) | 0.835 | 0.972(0.7420.742-1.272) |
| **HR** | **<0.001** | 0.935(0.9040.904-0.967) | **0.006** | 0.942(0.9030.903-0.983) |
| **SVC-CI%** | **0.023** | 0.987(0.9650.965-0.998) | **0.045** | 0.867(0.5980.598-0.945) |

OR, odds ratio; CI, confidence interval.

**Figure (1). The SVC CI among studied cases according to CVP.**



**Figure (2). Correlation of CVP with SVC CI.**