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Is the inferior vena cava diameter measured by bedside ultrasonography valuable in estimating the intravascular volume in patients with septic shock?

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ABSTRACT

Introduction: Resuscitation should be initiated immediately in shock. Early goal-directed therapy is an established algorithm for the resuscitation in septic shock. The first step is to maintain cardiac preload. Central venous pressure (CVP) plays an important role in goal-directed therapy. Central venous catheterization is invasive and time-consuming in emergency conditions. There are some alternative and noninvasive methods for estimating the intravascular volume such as measuring the inferior vena cava (IVC) diameter by ultrasonography.
Methods: We searched PubMed, Google scholar, and Scopus databases with keywords (central venous pressure OR venous pressure OR CVP) AND (ultrasonography OR sonography) AND (sepsis OR septic shock) AND (inferior vena cava OR IVC).
Result: The search resulted in 2550 articles. The articles were appraised regarding the relevance, type of article, and statistical methods. Finally, 12 articles were selected. The number of patients was between 30 and 83 cases (mean age=57-67 years), intubated and non-intubated in each study. The IVC diameter was measured in respiratory cycle by bedside ultrasonography in longitudinal subxiphoid view and caval index was calculated, then they were compared with the CVP measured by central venous catheter.
Discussion: CVP is an indicator of intravascular fluid status and right heart function. CVP measurement is an invasive method and of course with some complications. The IVC is the biggest vein of venous system with low-pressure; expansion of the vein reflects intravascular volume.
Conclusion: It seems that IVC diameter measured by ultrasonography could be used as an alternative method for the determination of CVP in the emergency or critical patients.

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Introduction

Many patients in emergency department with pale appearance, sweating, tachypnea, tachycardia, and weak pulse are in shock (1). Shock may occur due to various etiologies. Resuscitation should be initiated immediately in all patients with shock, according to the etiology. Early goal-directed therapy is an established algorithm for the resuscitation in septic shock (2). In this approach, patients are resuscitated within the first 6 hours to reach standards of adequate preload, central venous pressure

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(CVP), perfusion, mean blood pressure (BP), and normalization of oxygen delivery (central venous oxygen saturation ($ScvO_2$) of 70% or lactate clearance of 10%). The first step in goal-directed therapy is to maintain the cardiac preload. It is difficult to estimate cardiac preload in an emergency situation. Heart rate, BP, capillary refill, and adequate urine output could be used to estimate intravascular volume in not severely ill patients, but in critically ill patients, CVP plays an important role in goal-directed therapy (1).

Central venous catheterization insertion is an invasive and time-consuming emergency procedure with various complications such as hematoma, hemothorax, pneumothorax, infection, and vascular injuries. Besides, catheter could not be inserted in patients with coagulopathy, insertion site infection, and unsuitable anatomy (2). There are some alternative and noninvasive methods for estimating the intravascular volume such as measuring the IVC diameter by ultrasonography (1). Thus, we decided to review the studies that utilized the bedside ultrasonography technique, its accuracy, and reliability for estimating the intravascular volume.

Methods

The question of this study is considered in a systematic review of literature which is prepared based on preferred reporting items for systematic reviews and meta-analyses, PRISMA statement (3).

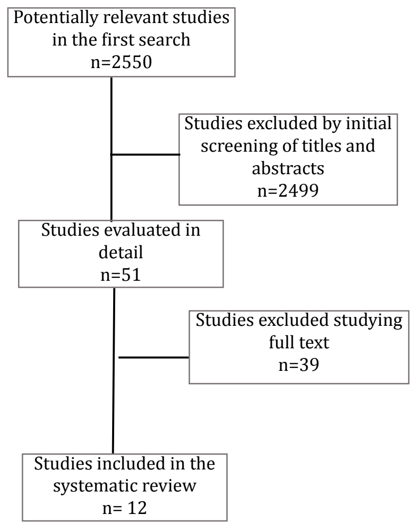
Google Scholar, PubMed, and Scopus were used as the main databases to search the most relevant articles related to the aim of this review. No time limitation were posed to the literature search (since 1st January 2015), except a definite search strategy with special keywords which were as follows: (central venous pressure OR venous pressure OR CVP) AND (ultrasonography OR sonography) AND (sepsis OR septic shock) AND (inferior vena cava OR IVC). The non-published articles, non-indexed journals, and non-English resources were not reviewed.

Relevant articles were searched based on inclusion and exclusion criteria to prevent any bias and irrelevant issues. All the articles which studied the comparison of IVC diameter by ultrasonography with CVP were eligible to be included in this review. The studies in trauma or children patients were excluded. Those which applied computed tomography scan or other methods for IVC diameter estimation and case reports were not included. Studies were first extracted based on the title and abstract obtained through initial search. Eventually, the full texts of the articles were studied to limit the results to the most relevant articles. References of the extracted articles were also studied to prevent missing any additional article.

Results

The search resulted in 2550 articles, 230 cases were selected based on the title, and then abstracts were reviewed. Fifty-one articles were found relevant and full texts were appraised for the study design. Finally, 12 articles were selected (Figure 1).

Figure 1. Flowchart of the selection process of articles



In these 12 studies, evaluation was performed in patients admitted to the emergency department and intensive care unit. The number of patients was between 30 and 83 cases in each study. The mean age was 57 to 67 years. Some patients were intubated and some were non-intubated. The underlying diseases were mostly associated with hypovolemia, sepsis, or other non-traumatic medical illnesses. Table 1 shows the characteristic data of included articles.

IVC diameter in inspiration and expiration, and IVC collapse were compared with the CVP measured by central venous catheter. In one study, IVC diameter of patients was compared with healthy volunteers (4).

Technically, the IVC diameter was measured in inspiration and expiration by bedside ultrasonography in longitudinal subxiphoid view and then caval index [CI = dIVCe (Inferior vena cava diameter in expiration)−dIVCi (inferior vena cava diameter in inspiration)/dIVCe] was calculated. In one study, IVC diameter was compared in the mid-abdomen, supra iliac, and subxiphoid views (5). The best view for the IVC diameter measurement was longitudinal subxiphoid (5). Measurement of the IVC caval index had a higher association with CVP compared to the measurement of the IVC diameter alone (6). In intubated patients, a significant relationship was not found between caval index and CVP (7).

In one study, the sensitivity and specificity of IVC diameter for the determination of CVP<10 cmH_2O

Table 1. Characteristic data of the included studies.

Author Year Reference	Number of patients	Mean age	Ward	Disease	Condition	Technique	Result
De Lorenzo 2012 (5)	72	67	ED[1] ICU[2]	Respiratory failure sepsis pancreatitis	43% under mechanical ventilated	IVC[3] diameter measurement in subxiphoid, mid-abdomen, supra iliac views	From the anatomical views, the subxiphoid was the most reliable view. Longitudinal views generally were better than transverse views.
Suat Zenign 2013 (4)	50	57.1±16.8	ED	Hypovolemia patients compared with healthy volunteers	spontaneous respiration	IVC diameter measurement during inspiration and expiration by M-mode in the subxiphoid view	In hypovolemic patients compared to healthy volunteers the ultrasonographic measurement of IVC diameter in inspiration and expiration and RV[4] diameter was significantly lower (p= 0.001).
Serenat Citilcioglu 2014 (7)	45	N/A[5]	ED	malignancy sepsis pneumonia, asthma, COPD	(24.4%) under mechanical ventilation (75.6%) spontaneous respiration	IVC diameter measurement during inspiration and expiration in the subxiphoid area.	In patients with spontaneous respiration, the ultrasonographic measurement of IVC diameter in expiratory and inspiratory phases was significantly related to CVP[6] values (respectively p=0.002, p=0.001). In mechanically ventilated patients no statistically significant association between IVC diameters and CVP values were found.
Wiwatworapan 2012 (8)	47	60±16	ED	N/A	N/A	IVC diameter measurement on end-expiration in subxiphoid view	There is a correlation between CVP and end-expiration IVC diameter (r=0.75)
Thanakitcharua 2013 (6)	70	63.8±1.9	ICU	Sepsis with hemodynamic instability (80.0%)	64.3% under mechanical ventilation	IVC diameters measurement in inspiration and expiration and IVC collapse index calculated	The CVP had the most significant correlation with IVC-CI[7] (r=-0.612, p<0.001).
Nagdev 2010 (10)	73	63	ED	sepsis	N/A	IVC diameters measurement in inspiration and expiration and caval index calculated	There was a correlation of -0.74 between caval index and CVP. If the caval index was equal or more than 50%, it could predict a CVP less than 8 mm Hg with a sensitivity of 91%, and specificity of 94%, (95% CI of 84% to 99%), the PPV [8] of 87% , and the NPV[9] of 96%.
Schefold 2007 (14)	30	60±15	ICU	severe sepsis or septic shock	Under mechanical ventilation	IVC diameters measurement in respiration	There was a great correlation between inspiratory and expiratory diameter of IVC with CVP.
Stawicki 2009 (12)	83	58.3	ICU	Admit surgery ICU	N/A	IVC collapse index measured	There was a significant correlation between IVC-CI ranges and mean CVP.
Minutiello 1993 (13)	65	N/A	ED	N/A	spontaneous respiration	The caval index was measured in subcostal views within 2 cm of the right atrium origin of IVC	A caval index> or =20% indicate normal CVP, a caval index < 20% is related to an elevated value of CVP.

Author Year Reference	Number of patients	Mean age	Ward	Disease	Condition	Technique	Result
Worapratya 2014 (11)	30	59.90±21.81	ED	shock	spontaneous respiration	Caval index was calculated as a relative decrease in the IVC diameter during the normal respiratory cycle by M mode	The caval index were of 30%, 20%, and 10% were respectively correlated with CVP levels <10 cm H2O, 10–15 cm H_2O, and >15 cm H_2O. [2]
Stawick 2014 (21)	79	55.8	ICU	N/A	under mechanical ventilation	Sonographic inferior vena cava collapsibility index measured	IVC-CI has an inverse correlation with CVP. Each 1 mm Hg increase in CVP was correlated with 3.3% decrease in median IVC-CI. If IVC-CI was less than <25%, euvolemia/hypervolemia existed, while IVC-CI was greater than 75% suggested hypovolemia.
Prekker 2013 (9)	67	N/A	ICU	Medical disease	spontaneous respiration	Measurement of the internal jugular vein height to width ratio (aspect ratio), the inferior vena cava diameter, and the percent collapse of the inferior vena cava with inspiration (collapsibility index) by ultrasound	In patients with no mechanical ventilation or vasopressor support, the maximal IVC diameter has the best correlation with CVP (R2=0.58). An IVC diameter<2 cm predicted a CVP<10 mm Hg with a sensitivity of 85%, specificity of 81%, and PPV of 87%.

[1]ED: Emergency department; [2]ICU: Intensive care unit; [3]IVC: Inferior vena cava diameter; [4]RV: Right ventricle; [5]N/A: Not available; [6]CVP: Central venous pressure; [7]IVC-CI: Inferior vena cava caval index; [8]PPV: Positive predictive value; [9]NPV: Negative predictive value

were 77% and 91%, and 90% and 89% for CVP>10 cmH_2O, respectively (8). In another study, IVC diameter<2 cm estimated a CVP of <10 mmHg with a sensitivity of 85%, specificity of 81%, and positive predictive value (PPV) of 87% (95% confidence interval (CI) 71% to 95%) (9). Relationship between caval index and CVP was 0.63 to 0.82. The sensitivity of caval index greater than 50% to predict the CVP less than 8 mmHg was 91%, and the specificity was 94% (10). In another study, cut-off points of the caval index were 30, 20, and 10 at CVP levels<10 cmH_2O, 10–15 cmH_2O, and >15 cmH2O, respectively (11). Low IVC-CI (<25%) was consistent with euvolemia/hypervolemia, while IVC-CI greater than 75% represented intravascular volume depletion (12). In one study, PPV and negative predictive values (NPV) were calculated as 87% and 96%, respectively) (10). In this study, caval index ≥20% indicated normal CVP and caval index <20% was related to the elevated CVP (13). In another study, extravascular lung water index, intrathoracic blood volume index, the intrathoracic thermal volume, and the PaO_2/FiO_2 (ratio of partial pressure arterial oxygen and fraction of inspired oxygen), oxygenation index were calculated (14). The diameter of IVC, IVC collapsibility index, and the internal jugular vein aspect ratio were compared in spontaneously breathing patients and it was shown that maximal IVC diameter was a more robust estimate of CVP (R2 = 0.58) compared to IVC collapsibility index and internal jugular vein aspect ratio, R2= 0.16 and 0.21, respectively (9).

Discussion

CVP monitoring is applied in emergency department in the patients who are in shock, heart failure and the patient who may need resuscitation with massive amount of fluid or blood with or without existing heart problems (15). CVP shows the right atrial or ventricular filling pressure. Thus, central venous catheter are applied to have an estimation of right heart function and intravascular volume. In normal physiology, CVP is a reflection of filling pressure of left ventricle. CVP is influenced by many conditions such as heart function, vasopressor therapy, increased pressure of thoracic and abdominal cavities. Therefore, a catheter should be invisibly placed in central veins (16). Any invasive procedure has its own complications and the risk of 15% is noted for CV line placement. Thus, it is preferred to substitute it by a reliable noninvasive method (17). IVC delivers the blood of subdiaphragmatic organs and lower extremities to the heart and has the largest amount of blood in comparison with other veins. The expansion of this vein is affected by the blood volume. Thus, IVC diameter could be a good reflection of intravascular volume. Respiration could also affect the size and diameter of thin-walled IVC. During inspiration the IVC diameter decreases due to the negative intrathoracic pressure, and it increases in expiration, valsalva maneuver, and positive pressure ventilation. The evaluation of IVC diameter changes during the respiratory cycle may lead to a more exact estimation of intravascular volume and predicting CVP (18).

Shock state is a clinical situation in which the tissue perfusion is less than cellular metabolic needs. Shock may happen as the result of hypovolemic, mechanical, distributive, or cardiac causes. During the sepsis, a combination of hypovolemia, vasodilation, cardiac and circulatory depressions and microcirculatory dysregulation happens.

In the emergency department, bedside ultrasonographic evaluation of IVC diameter could provide valuable information besides clinical context to determine the cause of shock (19). Moreover, the IVC diameter could be measured frequently during the process of resuscitation and it could provide an estimation of CVP noninvasively. In trauma patients, many different mechanisms result in shock and this technique could be very valuable in these patients to differentiate the shock etiology. In hemorrhagic shock, acute blood loss compensates by sympathetic activation, vasoconstriction, and an increase in cardiac contractility and rate. Serially measuring the IVC diameter in a patient with ongoing blood loss could be valuable (20).

Conclusion

It could not be stated with certainty but it seems that IVC diameter measured by ultrasonography is a reliable indicator for the determination of intravascular volume. It could be used as an alternative method in critically ill patients when there is no possibility of central venous catheter insertion, with acceptable sensitivity, specificity, PPV, and NPV.

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Conflict of Interest

The authors declare no conflict of interest.

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