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Comparative Analysis of Central Venous Pressure Estimation via Ultrasonography Versus Central Venous Line in Emergency Department Patients

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Abstract

Background: Central venous pressure (CVP) is currently one of the most widely used parameters for assessing the volume status in critically ill patients. However, CVP measurement using a central venous catheter is an invasive process. Recognizing the importance of noninvasive methods for CVP measurement, this study aimed to conduct a comparative analysis of CVP estimation using ultrasonography versus measurement through a central venous line (CV line) in patients in the emergency department. **Methods:** This cross-sectional study was conducted on patients referred to the emergency room of Imam Khomeini Hospital in Sari, Iran in 2023 using the available sampling method. Patients for whom CVP was measured using one of the two methods of ultrasonography and the CV line were included in the study. Vital signs including blood pressure, heart rate, urinary output, and arterial blood gas analysis were checked and documented for each patient. All statistical analyses were performed using SPSS software (version 22, Chicago, IL, USA), and statistical significance was defined as a p-value less than 0.05. **Results:** In this study, 116 patients were recruited: 57 women (49%) and 59 men (51%). Among the patients, 59% were under 60 years of age, while 41% were over 60 years of age. There was a significant difference between the mean CVP estimated using ultrasonography and that measured using the CV line method ($P = 0.000$, $t = 15.4$). Additionally, the results revealed a significant difference in the mean CVP estimated via ultrasound and that measured using the CV line method, based on symptoms of shock, volume overload, and patient age ($P < 0.05$). **Conclusion:** The study results indicated that the CVP estimated via ultrasound is consistent with the CVP measured using the CV line method. Ultrasonography for CVP measurement is a simple, noninvasive, and safe technique that avoids many complications associated with central venous access.

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Introduction

Central venous pressure (CVP) serves as an essential physiological measure indicative of the volume of blood returned to the heart and the subsequent efficacy of the heart in propelling this blood into the arterial circuit (1). Assessing CVP is a critical diagnostic technique that yields significant information regarding cardiovascular health, with a specific focus on evaluating the function of the right heart and overall fluid balance within the body. This process involves measuring pressure levels in the central venous system, particularly near the right atrium of the heart (2). Clinicians frequently rely on CVP to

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gauge both cardiac function and venous return, particularly in critically ill patients. CVP is conventionally measured within the thoracic vena cava proximal to the right atrium, with normal values falling within a range of 3–8 mmHg (3).

The acquisition of CVP data is commonly performed by inserting a central venous catheter into a major vein, typically the internal jugular or subclavian vein, ensuring that the catheter end is situated in the upper portion of the right atrium. The resulting CVP measurement is instrumental in informing clinical decisions related to fluid management, particularly in critically ill patients or those undergoing significant surgical procedures (4). Consequently, measuring CVP necessitates invasive procedures, such as catheterization, which can lead to complications, including venous thrombosis and infection. Furthermore, in situations in which a patient experiences significant fluid loss and is in shock, the time required to place a central venous catheter may delay critical resuscitation efforts (5). Alternatively, central vein cannulation carries risks, such as hemothorax, pneumothorax, vessel perforation (particularly of the carotid artery), cardiac tamponade, and tracheal perforation. Typically, the subclavian or internal jugular vein is selected for central venous catheter placement (6). Moreover, there are circumstances in which central vein catheter placement is not feasible, such as in cases of neck and clavicle fractures or anatomical alterations at the cannulation site due to heart surgery or radiotherapy (7).

Therefore, the implementation of a noninvasive technique for estimating CVP is crucial, particularly for patients in emergency settings. Evidence suggests that ultrasonography is an invaluable alternative in this regard (8). Advancements in nephrology, cardiology, and emergency medicine have enhanced our capacity to gauge CVP using ultrasonography, which involves measuring the diameter of the inferior vena cava as the starting point (9). The accuracy of CVP assessment using ultrasound is influenced by various factors, including patient-specific conditions and the ultrasound criteria applied (10). For example, a study demonstrated that an inferior vena cava diameter < 2 cm was indicative of a CVP < 10 mmHg, with an 85% sensitivity rate and an 81% specificity rate (11). Additionally, research has indicated that a CVP < 8 mmHg correlated with fluid responsiveness, yielding a pooled specificity of 76% and a sensitivity of 62% (12). Owing to the significance of employing noninvasive methods for measuring CVP, this study aimed to conduct a comparative analysis of CVP estimation using ultrasonography versus measurement through a central venous line (CV line) in emergency department patients.

Material and Methods

Study population

This cross-sectional study included 116 patients selected through convenience sampling from those presenting to the Emergency Department of Imam Khomeini Hospital, Sari, Iran, during 2023. The inclusion criteria were as follows: both intubated and non-intubated patients hospitalized in the acute and subacute units of the emergency department who had a central venous catheter placed in one of the neck veins for precise intravascular volume assessment. Conversely, patients were excluded if they had excessive obesity; a history of intrathoracic or abdominal surgery, intestinal hypergasemia that precluded accurate measurement of the inferior vena cava diameter, or if they experienced complications such as hemothorax, pneumothorax, or venous thrombosis following central venous line insertion.

Study protocol

In this study, demographic information such as age, gender, and BMI was initially recorded for each patient. Subsequently, vital signs, including blood pressure, heart rate, urinary output, and arterial blood gas analysis, were checked and documented. A portable ultrasound machine equipped with a 2-4 MHz curvilinear probe was used to measure CVP. The probe was positioned in the subxiphoid long axis, approximately 2 cm proximal to the entry site and inferior to the right atrium. Employing the M-mode method and freezing the image with framing, we measured the diameter of the inferior vena cava (IVC) during both inspiratory and expiratory phases. For non-intubated patients, measurements were taken during a normal respiratory cycle, whereas for intubated patients, measurements were obtained during forced inspiration. The estimated values were then referenced against the CVP (Table 1). Two emergency department physicians trained in ultrasonography conducted the measurements.

Next, the right atrial pressure was assessed using a central venous catheter in the supine position. This measurement is based on the water level inside the tube, corresponding to the fourth intercostal space, and is expressed in centimeters of water (cm H_2O) using the central venous line method. After at least two hours, following administration of the appropriate fluid volume, each patient underwent reassessment. This evaluation included vital signs, urinary output, CVP estimation via sonography and venous line method, and analysis of arterial blood gas (ABG) findings. The results were then documented.

Table 1. The estimated values of central venous pressure

CVP (mmHg)	Inspiratory collapse	IVC diameter
0-5	> 50%	< 15
6-10	50%	15-25
11-15	50%	15-25
16-20	50%	> 25
> 20	None	> 25

IVC, inferior vena cava; CVP, central venous pressure

Table 2. The clinical symptoms of the patients

Variable		N	Percentage
Measurement turns	1	79	68.10
	2	19	16.37
	3	13	11.20
	4	4	3.44
	5	1	0.86
Received serum (CC)	0-500	26	22.41
	501-1000	32	27.58
	1001-2000	49	42.24
	≥2001	9	7.75
Systolic blood pressure (mmHg)	<90	9	7.75
	90-180	98	84.48
	>180	9	7.75
Heart rate (beats per minute)	<90	64	55.17
	≥90	52	44.83
Urinary output (cc/kg/hour)	<50	37	31.90
	≥50	79	68.10
Arterial blood gases (ABG)	Metabolic	50	43.10
	Respiratory	4	3.44
	Mixed disorders	8	6.90
	Normal	54	46.55
Obesity	Morbid obesity	31	26.72
	Normal	85	73.27

Statistical analysis

Descriptive statistics including means, standard deviations, and percentages were used to summarize the data. Prior to analysis, the normality of the data was assessed using the Shapiro-Wilk test. For continuous quantitative variables with normal distributions, both Student's t-test and the Wilcoxon test were used. All statistical analyses were performed using SPSS software (version 22, Chicago, IL, USA), and statistical significance was defined as a p-value less than 0.05.

Ethical considerations

The Ethics Committee of Mazandaran University of Medical Sciences reviewed and approved the study protocol as part of its review and approval of the research project (No: …….).

Results

In this study, 116 patients were recruited, comprising 57 (49%) females and 59 (51%) males. Among the patients, 59% (68 individuals) were under 60 years old, while 41% (48 individuals) were over 60 years old. Based on the clinical symptoms, CVP was measured in more than half of the patients (68.10%) at the first turn. Additionally, 42.24% of the patients received 1001–2000 cc of serum. Furthermore, 84.48% of the patients exhibited systolic blood pressure within the range of 90 to 180 mmHg, 55.17% had a heart rate less than 90, and 60.10% had urinary output exceeding 50. Among the patients, 73.27% were classified as having normal weight, 46.55% had normal arterial blood gases, and 43.10% had metabolic acidosis (Table 2).

Based on the results obtained, the mean CVP measured using the ultrasonography method was 6.52 ± 4.47, while that measured using the CV line method was 5.14 ± 3.15. Based on statistical analysis, there was significant difference between the mean CVP estimated by ultrasonography and that measured using the CV-line method (P = 0.000, t = 15.4). Consequently, the mean CVP estimated using the ultrasonography method aligns with that measured using the CV-line.

The results revealed a significant difference between the mean CVP estimated via ultrasonography and that measured using the CV line method, based on symptoms

of shock, volume overload, and patient age ($P < 0.05$). In conclusion, the mean CVP estimated by ultrasonography aligns with the CVP measured by the CV line in patients exhibiting symptoms of shock, volume overload, and across different age groups (Table 3).

Table 3. The comparison of central venous pressure means based on clinical symptom

Method		Ultrasonography	CV-line	t*	P-value
Symptoms of shock		10.33 ± 3.19	9.33 ± 3.15	5.12	0.00
Volume overload		2.33 ± 3.52	3.04 ± 2.56	2.33	0.029
Age	<60	7.44 ± 4.32	6.02 ± 3.90	3.17	0.008
	≥60	5.22± 4.41	3.85 ± 3.01		

* t-test

Discussion

CVP is commonly used in clinical practice to monitor patient hemodynamics for diagnostic and treatment purposes. However, routine CVP measurement involves a central venous line, which carries a risk of complications. A novel noninvasive method using peripheral compression ultrasonography has demonstrated reliable and reproducible CVP measurement, making it a potential first-line approach in emergency situations (8). Therefore, in this study, we compared the results of CVP estimation using ultrasonography and CV line in emergency department patients. The results of this study indicate a significant difference between the mean CVP estimated by ultrasonography and that measured using the CV line method. Additionally, a significant difference was observed between the means of CVP estimated by the two methods, based on symptoms of shock, volume overload, and patient age. Consequently, the mean CVP estimated using the ultrasonography method aligns with the CV line, and the CVP estimated by both methods aligns with patients exhibiting symptoms of shock and volume overload across different age groups.

CVP monitoring using a central venous catheter, commonly known as the central line, is a valuable tool in critical care settings. However, the CV line method can result in numerous complications. These include mechanical issues (such as injury to the blood vessels, blood clots, lung injury, and accidental removal) and hemodynamic complications (such as heart rhythm abnormalities, nerve injury, and infection) (13). The incidence of mechanical complications during central venous catheter insertion is primarily influenced by operator skill. Notably, complications, such as pneumothorax, are often identified during catheter insertion. Thrombotic and infectious complications tend to manifest at a later stage than mechanical issues (14). According to Selby et al., cannulation complication rates vary according to anatomical site, with a reported incidence of 15% (15). In another study, Parienti et al. found that among the patient population, 2.1% experienced mechanical complications during catheter insertion, 0.5% to 1.4% encountered bloodstream infections, and a similar percentage developed deep vein thrombosis associated with the central venous catheter (16).

Currently, the most precise method for determining a person's fluid requirements is the calculation of CVP, which is an invasive procedure. But there is an alternative approach that has been suggested, that is, measuring the diameter of the IVC using ultrasound. This straightforward and accessible method allows for the estimation of intravascular fluid volume (17). The IVC serves as an ideal noninvasive surrogate for estimating CVP because it is an extremely adaptable vessel that distinctively does not constrict in reply to hypovolemia (18). Christophe et al. investigated the utility of respiratory changes in the IVC diameter for predicting fluid responsiveness in patients with sepsis. They discovered a robust positive correlation ($r=0.9$) between the baseline IVC diameter and subsequent increase in the cardiac index following blood volume expansion (19). The meta-analysis by Zhang et al. (20) and Alavi-Moghaddam et al. (21) reported that IVC evaluation by ultrasonography is an appropriate surrogate variable for determination of CVP. Sasai et al. investigated the estimation of CVP using noninvasive methods such as ultrasonography and echocardiography. These methods yielded acceptable and comparable results when compared with conventional CVP determination using a CV line (22). Our findings from the current research align with those of previous studies, which also demonstrated a significant difference between the mean CVP estimated using ultrasonography and that measured using the CV line method. Hence, in patients without other indications for CV line insertion and with an appropriate peripheral vein for adequate therapeutic fluid administration, it is advisable to avoid subjecting them to the invasive procedure of central venous catheter insertion and associated complications. Instead, periodic sonography was suggested to assess the IVC diameter and estimate the CVP based on the patient's hemodynamic status.

In this study, the patients were divided into two distinct groups based on their hemodynamic status and

clinical condition. The first group consisted of patients with unstable hemodynamics, including hypotension, tachycardia, and metabolic acidosis. These patients were in shock (such as hypovolemic, septic, or cardiogenic shock) or had liver and heart failure with volume overload. In this group, aggressive fluid administration was necessary to stabilize the hemodynamic status. Given that many patients in this category are elderly and have unknown cardiovascular and coagulation status, precise monitoring of circulating blood volume through CVP measurement is crucial for effective treatment. In contrast, the second group faced limitations in fluid administration owing to volume overload. Knowing CVP in this context greatly assists attending physicians in preventing exacerbations. Overall, the study revealed a significant difference in CVP means estimated by the two methods based on symptoms related to shock and volume overload. During the initial hours, when the doctor lacks information about the patient's coagulation status, heart function, kidney function, and liver function, inserting a CV line can be risky and may lead to serious complications. Therefore, the use of non-invasive alternative methods, such as ultrasonography, to determine CVP in patients represents a significant advancement in treatment and clinical management (23).

The primary limitation of our study is the small number of patients included in the subgroup analysis. Future research would benefit from a larger sample size and longer follow-up period. Future studies should be prospective and multicenter, preferably through comparative or clinical trials. Further studies should examine patient symptoms, quality of life, and treatment side effects in more detail.

Conclusion

In this study, the comparison between the ultrasonography and CV line results demonstrated consistency in the estimated CVP obtained using both methods. Furthermore, the CVP estimates from both approaches align with patients exhibiting symptoms of shock and volume overload across various age groups. Ultrasonography for CVP measurement is a simple, noninvasive, and safe technique that avoids many complications associated with central venous access. However, further studies are needed to validate its applicability in diverse patient populations.

Code of Ethics

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