Al-Azhar International Medical Journal

Volume 4 | Issue 2 Article 26

2023

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How to Cite This Article

Maghraby, Hend Maghraby; Awad, Eman Aboelnasr; Mohammed, Rehab Abdelfattah; Abdelmaniem, Manal Fouad; Sherif, Hala Maghraby; and Sabry, Rabab (2023) "Inferior Vena Cava Diameter and Collapsibility Index measurements by Ultrasound and its Correlation with Central Venous Pressure in Critically Ill Patients," *Al-Azhar International Medical Journal*: Vol. 4: Iss. 2, Article 26.
DOI: https://doi.org/10.58675/2682-339X.1682

ORIGINAL ARTICLE

Inferior Vena Cava Diameter and Collapsibility Index Measurements by Ultrasound and its Correlation with Central Venous Pressure in Critically Ill Patients

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Abstract

Background: **The diagnosis and treatment of critically ill patients depend on an accurate evaluation of intravascular volume status. An intrusive tool used for this is central venous pressure (CVP).**

Aim: **In the present investigation, intravascular volume status of severely ill patients was evaluated using noninvasive inferior vena cava (IVC) diameter and collapsibility index (CI) measurements in ICU patients and its link with CVP.**

Patients and methods: **A total of 100 adult patients hospitalized to the medical ICU were included in this study. CVP was measured by an intrathoracic venous catheter in the right atrium. The IVC-CI was calculated by measurement of IVC diameter in expiration and inspiration by bedside ultrasound.**

Results: **The IVC dmin and IVC dmax decreased in hypovolemic patients compared with euvolemic and hypervolemic patients. However, IVC-CI showed a significant increase in hypovolemic patients. CVP showed a significant positive correlation with IVC diameter with expiration and inspiration but had a negative correlation with the IVC-CI.**

Conclusion: **IVC diameters and collapsibility index have a significant correlation with CVP. Its measurements by ultrasound are simple, noninvasive, safe methods for evaluation of volume status versus CVP in critical patients.**

Keywords: Central venous pressure, Critically ill, Intrathoracic venous catheter, Inferior vena cava diameter, IVF collapsibility Index

1. Introduction

Invasive hemodynamic testing is widely used by clinicians to begin a fluid managing strategy as a support for data gathering from the clinical evaluation and laboratory tests. A common hemodynamic measure is central venous pressure (CVP). The use of ultrasound in the ICU enables a noninvasive, cost-effective approach to the evaluation and treating of severely ill patients.[1] A beneficial noninvasive adjunct to evaluate the intravascular status is bedside ultrasound to measure inferior vena cava (IVC) diameter.[2]

The difficulty related to CVP insertion consists of subcutaneous hematoma, failure to region the catheter, catheter malposition, arterial puncture, a systolic cardiac arrest, pneumothorax, hemothorax, and catheter-associated infection[3]

In patients who breathe on their own, the IVC diameter and IVC collapsibility index (IVC−CI) were proven to correlate with CVP and the volume status.[4] Monitoring of collapsibility of the IVC is beneficial for the management of patients with acute heart failure as well as supporting current recovery by measuring CVP noninvasively.[5]

Accepted 4 January 2023.
Available online 15 May 2023

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https://doi.org/10.58675/2682-339X.1682

This study aimed to assess volume status by IVC diameter and collapsibility index (CI) in ICU patients and its correlation with CVP.

2. Patients and methods

2.1. Participants

A total of 100 adult patients admitted to medical ICUs from June 2021 to August 2021 were included in this research. Exclusion criteria included age below 18 years, pregnant, ventilated patients, chronic hemodialysis, patients with elevated intra-abdominal pressure or intrathoracic pressure, and patients with cardiac or liver disease.

Full clinical history was taken from patients or their relatives, and clinical examination was done with special emphasis on vital signs (blood pressure, pulse, and respiratory rate). Laboratory tests included complete blood picture, bleeding profile, liver function tests, serum urea, serum creatinine, and urine output. CVP was measured by an intrathoracic venous catheter ending in the right atrium. The IVC-CI was calculated by measurement of IVC diameter in expiration and inspiration by bedside ultrasound.

2.2. Sample size

According to the following calculation, the sample size for this research was 72 participants at a 5% significance level and 90% research power:

The typical normal deviation for $\alpha = Z_\alpha = 1.97$.

The typical normal deviation for $\beta = Z_\beta = 1.28$.

The expected correlation coefficient for CVP and maximum IVC diameter was ($r = 0.371$), $C = 0.5 \times \ln [(1+r)/(1-r)] = 0.3826$.

Overall sample size $= N = [(Z_\alpha + Z_\beta)/C]^2 + 3 = 72$

The sample size was increased to 100 participants to increase the power of the study and to compensate for incomplete data.

3. Methods

The patient lied supine, the gel was applied to the patient's abdomen at the subxiphoid region, and the transducer was applied at the longitudinal plane. The machine used was Phillips Affiniti 70 (Amsterdam, Netherlands) with Convex (transabdominal) probe 3.5 mHz. The intrahepatic segment of the IVC was scanned at its entry in the right atrium. IVC diameter was calculated at 3−4 cm from the intersection of IVC with the right atrium or 2 cm cauda to caudal hepatic veins-IVC junction. Measurement at this position was favored to avoid collapsibility of IVC by muscular diaphragm activity. The maximum diameter of IVC (IVC dmax) was determined at the end of expiration as the maximum anteroposterior dimension from the inner edge to the inner edge of the vessel wall. Moreover, the same technique was used for the minimum diameter (IVC dmin) but was determined at the end of inspiration. An image of the IVC was recorded for one respiratory cycle (Figs. 1 and 2). The IVC-CI was then determined by dividing the variation between the IVC dmax and IVC dmin by the greatest IVC diameter and then multiplying that result by 100% (IVC dmax−IVC dmin/IVC dmax). Informed written consent was acquired from each patient and controls. The Institutional Review Board (IRB) of Al-Azhar University approved this investigation, and it was conducted in conformity with the tenets of the Declaration of Helsinki (NO:202107929).

3.1. Statistical analysis

The Windows version of the SPSS application was used to examine data (Standard version 21; Chicago, Illinois, USA). A one-sample Kolmogorov−Smirnov test was used to check the data's normality. The χ^2-test was used to determine if categorical variables were associated. For nonparametric variables, qualitative data were reported as mean, SD, and median (Minimum−maximum). Qualitative data were described using numbers and percentages and compared with Student's t-test for normal data. Pearson correlation (parametric) and Spearman's correlation (nonparametric) were used to set the relation between the two variables. P value less than or equal to 0.05 was deemed significant.

4. Results

A total of 100 patients hospitalized to the medical ICU were recruited in this study. Of them, 53 (53.0%) were females and 47 (47.0%) were males, with a mean age of 50.55 ± 14.87 years. The CVP of the studied group ranged from 2 to 22, with a median of 8. Hypovolemic patients with CVP less than 7 cmH_2O were 46/100 (group I), whereas group II euvolemic patients with CVP between 7 and 12 cmH_20 were 39/100 and hypervolemic patients (group III) were 15/100 with CVP >12 cmH_2O. The mean IVC-CI of studied patients was 23.67 ± 11.71 and between 6.5 and 48.7% (Table 1). Our results revealed that IVC dmin and IVC dmax decreased in group I (hypovolemic patients) compared with group II (euvolemic patients) and group III (hypervolemic patients). However, IVC-

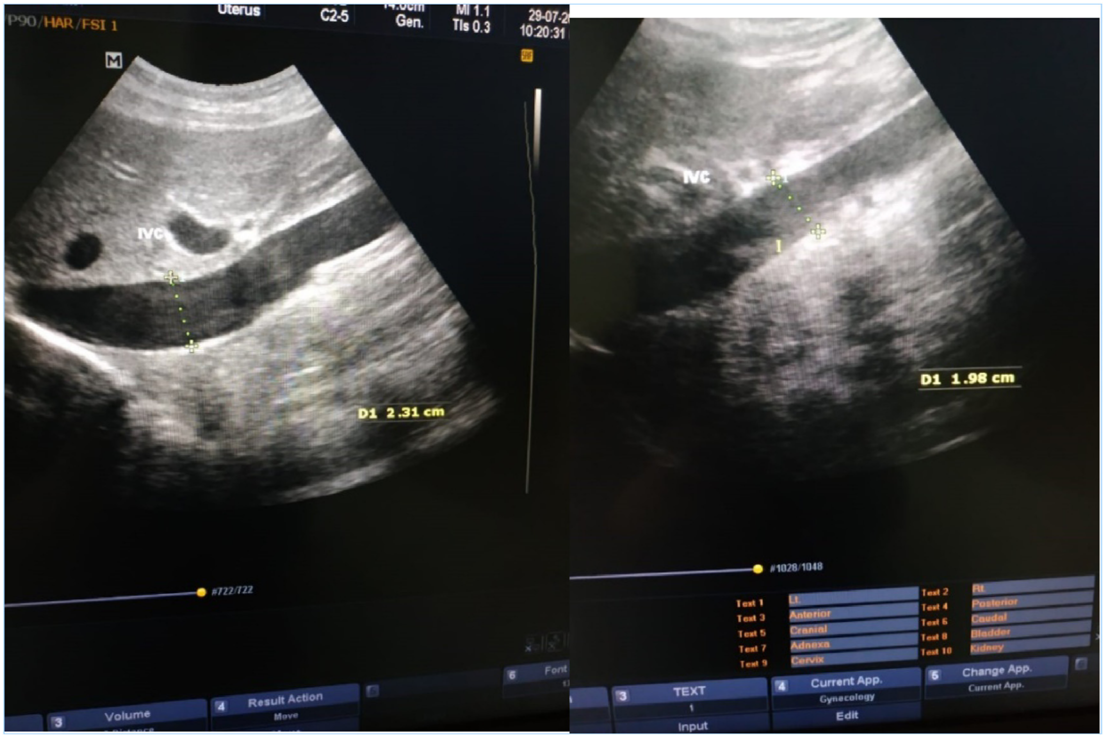

Fig. 1. M-Mode scanning of the hypovolemic patient's inferior vena cava inspiratory and expiratory diameters (close to the hepatic vein).

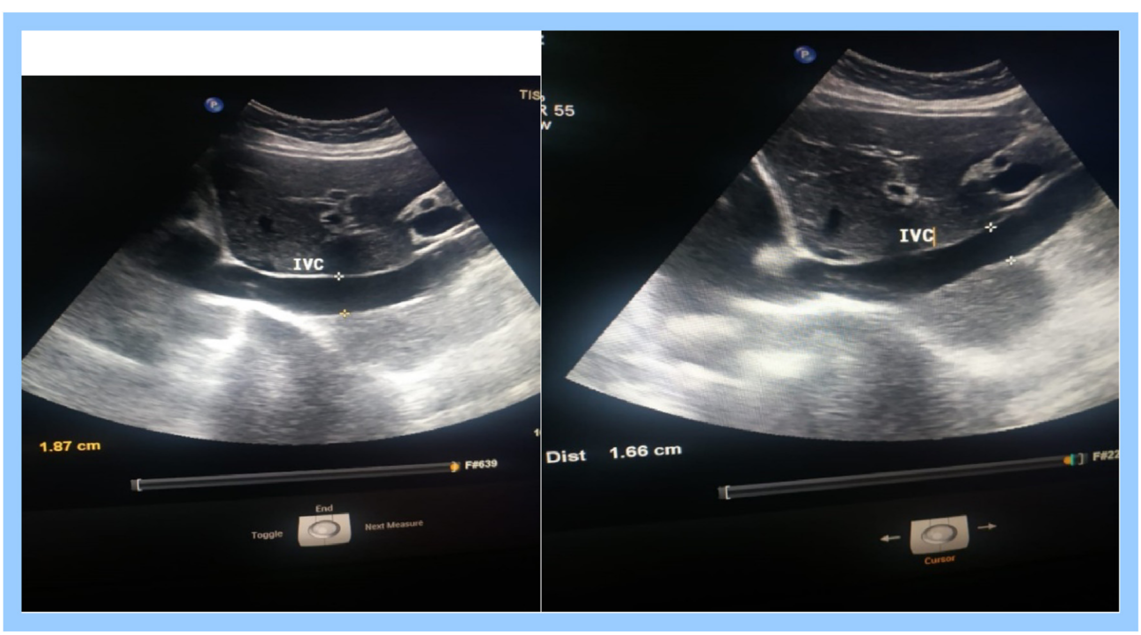

Fig. 2. Inferior vena cava inspiratory and expiratory diameters measured in M-Mode in a euvolemic patient close to the hepatic vein.

CI showed a substantial improvement in hypovolemic patients compared with patients with normal volume status and hypervolemic patients (Table 2).

The mean CVP was significantly correlated with IVC diameter at expiration (IVC dmax) and IVC diameter at inspiration (IVC dmin) ($r = 0.234$ and 0.800, respectively) (Figs. 3 and 4), whereas there

Table 1. Clinical data of the studied group.

Patients characteristics	The study group ($n = 100$)
Age (years)	
Mean ± SD	50.55 ± 14.87
Minimum–maximum	20–74
Sex [n (%)]	
Males	47 (47.0)
Females	53 (53.0)
Mean ABP	
Mean ± SD	80.16 ± 12.91
Minimum–maximum	60–120
HR	
Mean ± SD	103.51 ± 22.70
Minimum–maximum	75–140
Clinical diagnosis [n (%)]	
Sepsis	35 (35.0)
DK	22 (22.0)
Pneumonia	18 (18.0)
Heart failure	10 (10.0)
Hepatic encephalopathy	7 (7.0)
Autoimmune	5 (5.0)
Upper GIT bleeding	3 (3.0)
CVP (cmH_20)	
Median (minimum–maximum)	8 (2–22)
CVP <7 (group I) [n (%)]	46 (460%)
CVP 7–12 (group II) [n (%)]	39 (39.0%)
CVP >12 (group III) [n (%)]	15 (15.0%)
IVC diameter max (cm)	
Mean ± SD	3.03 ± 0.52
Minimum–maximum	2.3–4.2
IVC diameter min (cm)	
Mean ± SD	2.30 ± 0.51
Minimum–maximum	1.5–3.8
IVC-CI %	
Mean ± SD	23.67 ± 11.71
Minimum–maximum	6.5–48.7

CVP, central venous pressure; GIT, gastrointestinal tract; IVC-CI, inferior vena cava collapsibility index.

was an inverse significant relation with IVC-CI ($r = -0.800$) (Table 3, Fig. 5).

5. Discussion

Regarding volume status, the variety of IVC diameter, which tracks the respiratory cycle, is taken into consideration to be a treasured predictor of volume improvement in ventilated patients having circulatory failure[6] and patients with spontaneous breathing.[7]

In our study, we demonstrated that IVC dmin and IVC dmax decreased in hypovolemic patients compared with euvolemic and hypervolemic patient groups. IVC-CI showed a significant increase in hypovolemic patients compared with patients with normal volume status and hypervolemic patients. The same result was reported by Dipti et al.,[8] who also reported high sensitivity and specificity of IVC max for identifying low CVP levels, whereas the IVC

Table 2. Comparison between studied patient groups (group I, II, and III according to CVP level) regarding many parameters.

	CVP			Test of significance		
	Group I: CVP <7 ($n = 46$)	Group II: CVP 7–12 ($n = 39$)	Group III: CVP >12 ($n = 15$)	P_1	P_2	P_3
Mean ABP						
Mean ± SD	69.30 ± 6.91	86.05 ± 6.95	98.13 ± 8.01	$t = 11.1$ $P \leq 0.001$*	$t = 13.49$ $P \leq 0.001$*	$t = 5.48$ $P \leq 0.001$*
HR						
Mean ± SD	124.67 ± 12.17	87.21 ± 10.78	81.00 ± 9.85	$t = 14.89$ $P \leq 0.001$*	$t = 12.59$ $P \leq 0.001$*	$t = 1.94$ $P = 0.058$
IVC diameter max (cm)	2.96 ± 0.64	3.01 ± 0.38	3.28 ± 0.39	$t = 0.399$ $P = 0.691$	$t = 1.87$ $P = 0.066$	$t = 2.44$ $P = 0.018$*
IVC diameter min (cm)	1.95 ± 0.33	2.46 ± 0.38	2.98 ± 0.34	$t = 6.58$ $P \leq 0.001$*	$t = 10.42$ $P \leq 0.001$*	$t = 4.64$ $P \leq 0.001$*
IVC-CI %	32.84 ± 9.98	18.43 ± 4.42	9.21 ± 4.48	$t = 8.34$ $P \leq 0.001$*	$t = 8.83$ $P \leq 0.001$*	$t = 6.84$ $P \leq 0.001$*

CVP, central venous pressure; GIT, gastrointestinal tract; IVC-CI, inferior vena cava collapsibility index; P_1, comparing between group I and group II; P_2, comparing between group I and group III; P_3, comparing between group II and group III; t, Student t-test. * means significance.

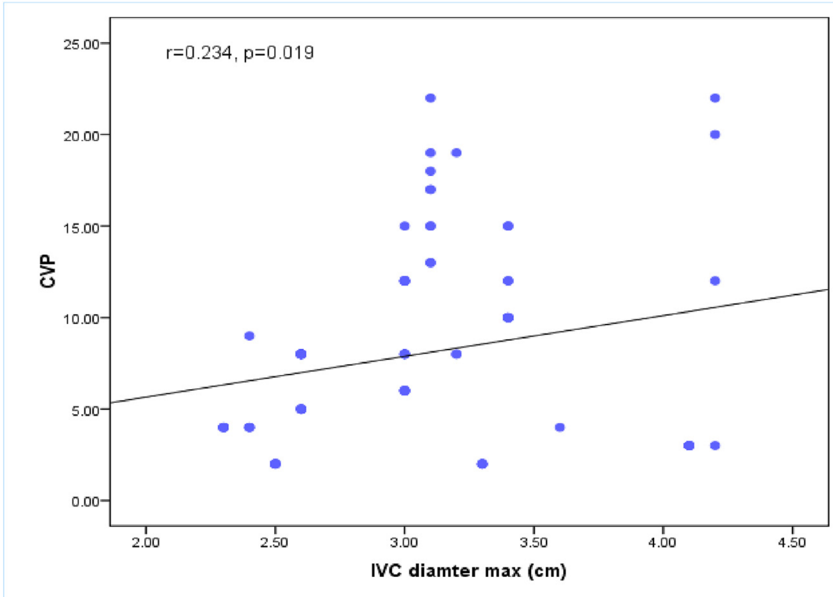

Fig. 3. Scatter plot for connection of inferior vena cava (IVC) diameter max (cm) and central venous pressure (CVP).

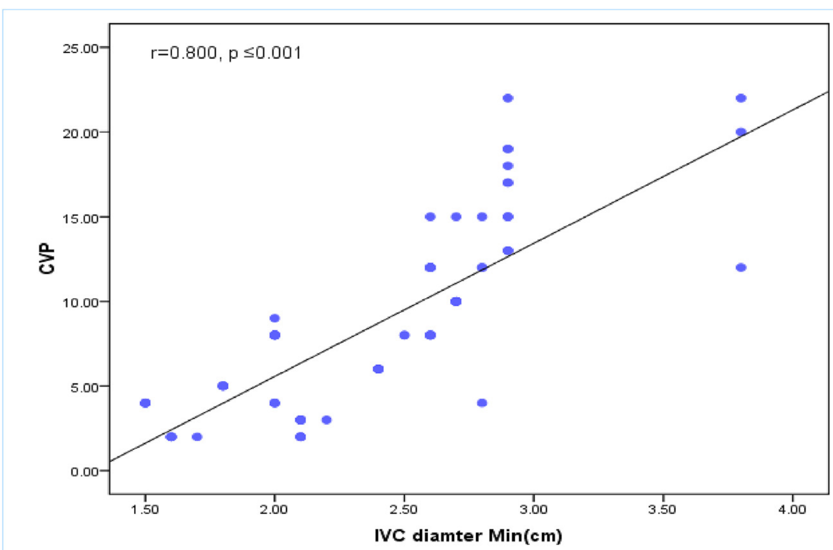

Fig. 4. Scatter plot for connection of inferior vena cava (IVC) diameter min (cm) and central venous pressure (CVP).

Table 3. CVP relationship with other factors.

	CVP	
	r	*P* value
Mean ABP	0.914	≤0.001*
HR	−0.789	≤0.001*
IVC diameter max (cm)	0.234	0.019*
IVC diameter min (cm)	0.800	≤0.001*
IVC-CI %	−0.803	≤0.001*

CVP, central venous pressure; IVC-CI, inferior vena cava collapsibility index. * means significance.

index significantly correlated more with high CVP levels. Moreover, other studies reported a significantly high IVC-CI with low CVP levels.[9,10]

In our study, the mean CVP was substantially connected with IVCaval diameter during expiration (IVC dmax) and IVCaval diameter during inspiration (IVC dmin). However, there was an inverse correlation with the IVC-CI. Brennan et al.[11] also reported a positive significant relation between the mean IVC diameter and CVP. Another study

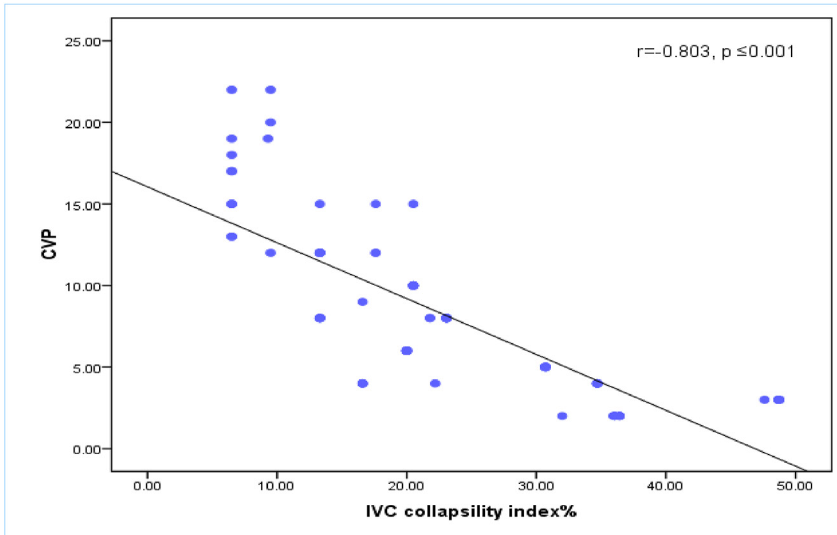

Fig. 5. Scatter plot for correlation of inferior vena cava collapsibility index (IVC–CI) % and central venous pressure (CVP).

showed that the end-expiratory vena caval index had significantly correlated with the CVP.[12] These findings were in line with what was found by Schefold et al.[13]

It was more linked with CVP in patients with spontaneous breathing than in patients receiving mechanical ventilation, and the IVC-CI had a strong negative relationship with CVP value. The IVC-CI was correlated better with CVP in patients with low CVP values (<10 cmH_2O) than in patients with higher CVP values (≥10 cmH_2O).[14] Wiryana et al.[15] also demonstrated that the CVP and IVC-CI had an adverse connection.

In a research conducted by Ilyas et al.[16] on 100 adult patients admitted to the medical ICU, they reported a strong inverse significant connection between the IVC-CI and CVP. Another study conducted on 83 patients in the critical care unit revealed that the IVC-CI inversely connected with CVP ($P < 0.01$).[17] Conversely, other studies found a significant connection of CVP with IVC-CI.[12,18] A total of 124 patients were enrolled by Stawicki and his colleagues in their study, where 56 (45.2%) of them were on mechanical ventilation. They reported a significant weak connection between IVC-CI and CVP values, and IVC-CI correlated well with CVP in the set of low (<20%) and great (>60%) collapsibility ranges.[19] The authors recommended that IVC-CI measurements by bedside ultrasound can afford noninvasive valuable monitoring of volume status evaluation in ICU patients. The correlation between volume status and IVC-CI is weakened by several factors such as the high frequency of elevated intra-abdominal pressure in patients and the risk of the presence of high pulmonary artery pressure, right ventricular dysfunction in an unknown number of cases, and tricuspid or pulmonic valve disease.[19] Conversely, Govender et al.[20] reported no statistically significant connection between CVP and IVC-CI with a weak positive nonsignificant correlation in males and a moderate negative nonsignificant correlation in females.

5.1. Conclusion

Ultrasound measurements of IVC diameter during inspiration, expiration and CI calculation are effective, economic, and easy noninvasive assessments of fluid status in critically ill patients in comparison to CVP.

Limitations of our trial were the exclusion of ventilated patients from this study and no selection of patients with low or high CVP to have strong conclusive data. Wide-scale studies are necessary to certify the usage of IVC ultrasound in different critically ill patients.

Disclosure

The authors were responsible for paying the article processing fee.

Authorship

Each author significantly contributes to the essay.

Conflict of interest

There are no conflicts of interest.

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