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ORIGINAL RESEARCH

Measurement of the diameter and area of the inferior vena cava using computed tomography and its relationship with intravascular volume

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Abstract

Background: Accurate assessment of intravascular volume status is critical in intensive care management. Conventional methods may have limitations in precision and availability. Computed tomography (CT) offers the opportunity to measure the diameter and cross-sectional area of the inferior vena cava (IVC), potentially providing an alternative tool for fluid evaluation. **Methods**: This diagnostic investigation was conducted in the Internal Medicine Intensive Care Unit between 2022 and 2023. A total of 105 patients diagnosed with pneumonia were enrolled. Standardized CT imaging was performed for each participant, with measurements obtained at predetermined thoracic anatomical levels. Clinical indicators of fluid status, including pleural effusion and brain natriuretic peptide (BNP) levels, were recorded for comparison. **Results**: CT-based measurements of IVC diameter and area demonstrated statistically significant correlations with conventional indicators of intravascular volume status. Both pleural effusion and BNP levels were closely associated with the imaging parameters, thereby confirming their clinical relevance. **Conclusions**: CT measurements of the IVC provide a reliable, non-invasive approach to assessing intravascular volume in critically ill patients. This method holds promise for improving fluid management strategies in intensive care practice, offering an effective adjunct to traditional evaluation techniques.

Keywords

Inferior vena cava; Computed tomography; Intravascular volume; Pleural effusion; B type natriuretic peptide

1. Introduction

Precise regulation of fluid balance is a critical aspect of care for patients in intensive care units (ICU). Traditional methods for assessing intravascular volume often provide limited insights into the patient's fluid status, however, advanced imaging modalities offer the potential for more accurate and reliable evaluations. In recent years, the diameter and dynamic changes of the inferior vena cava (IVC) have emerged as sensitive indicators for assessing volume status. Notably, variations in the IVC cross-sectional area during inspiration have been shown to correlate significantly with right heart filling pressures and central venous pressure. These measurements are commonly preferred in critically ill patients due to their non-invasive nature, bedside applicability, and reproducibility [1]. Supporting this, a study by Lee *et al*. [2] demonstrated that CT-based measurements of IVC and aortic diameters can effectively predict hemorrhagic shock.

The present study, therefore, aims to propose a novel alternative to traditional methods of volume assessment by evaluating IVC diameter using thoracic CT scans. This approach allows for the rapid and accurate determination of volume status, potentially even before ICU admission, thereby supporting timely clinical decision-making and optimizing critically ill patient management.

Despite the increasing interest in non-invasive volume assessment, limited research has explored the direct relationship between CT-based IVC diameter measurements and conditions, such as pulmonary edema or hypervolemia. In this regard, our study seeks to provide a significant contribution to the existing knowledge and represents one of the most comprehensive investigations in this field.

2. Materials and methods

This study included patients who presented to the emergency department with a preliminary diagnosis of pneumonia and underwent thoracic CT scans between 2022 and 2023. A total of 105 patients were enrolled, excluding those without thoracic CT and available measurements of Brain Natriuretic Peptide (BNP). All patient information was obtained anonymously from the hospital information system.

IVC measurements were taken at two anatomical levels. The first measurement was taken from the axial CT slice at the level

of seventh or eighth thoracic vertebra (T7–T8). The second measurement was obtained from the segment of IVC immediately after it merges with the hepatic veins, corresponding to the level of the ninth or tenth thoracic vertebra (T9–T10) (Fig. 1).

Patients with pleural effusion were assessed for three radiological signs during visual evaluation: bilateral ground glass opacity, interlobular septal thickening, and pleural effusion. Those presenting with at least two of these signs were classified as pleural effusion positive. The extent of pleural effusion was assessed separately by measuring the thickness of the effusion (in centimeters) at the thickest transverse section of each lung and were summed to score the total fluid thickness. The accuracy of the measurements was verified by an expert radiologist (20 years of experience) unaware of the patients' clinical status. In case of discrepancy, the radiologist's measurement was considered definitive. Data were anonymized and stored in compliance with patient confidentiality.

Measurements were obtained using two different methods; direct cross-sectional area measurement (mm^2) performed by automatic area calculation from CT images, and derived area measurement (mm^2), calculated by multiplying the anteroposterior (APD) and transverse diameters (TSD)., including the Inferior Vena Cava Upper Cross-Sectional Area (IVCU.CSA), Inferior Vena Cava Upper Anteroposterior Diameter (IVCU.APD), Inferior Vena Cava Lower Cross-Sectional Area (IVCL.CSA), and Inferior Vena Cava Lower Anteroposterior Diameter (IVCL.APD). BNP levels were categorized according to the National Institute for Health and Care Excellence (NICE) Chronic Heart Failure Guidelines into three groups: >400 pg/mL, 400–100 pg/mL, and <100 pg/mL [3].

The diagnosis of Acute Respiratory Distress Syndrome (ARDS) was made according to the Berlin Criteria [4]. The relationship between laboratory parameters and IVC measurements was examined by considering BNP levels, sodium, blood urea nitrogen (BUN), and creatinine values.

Statistical analyses were performed using SPSS v26 (IBM

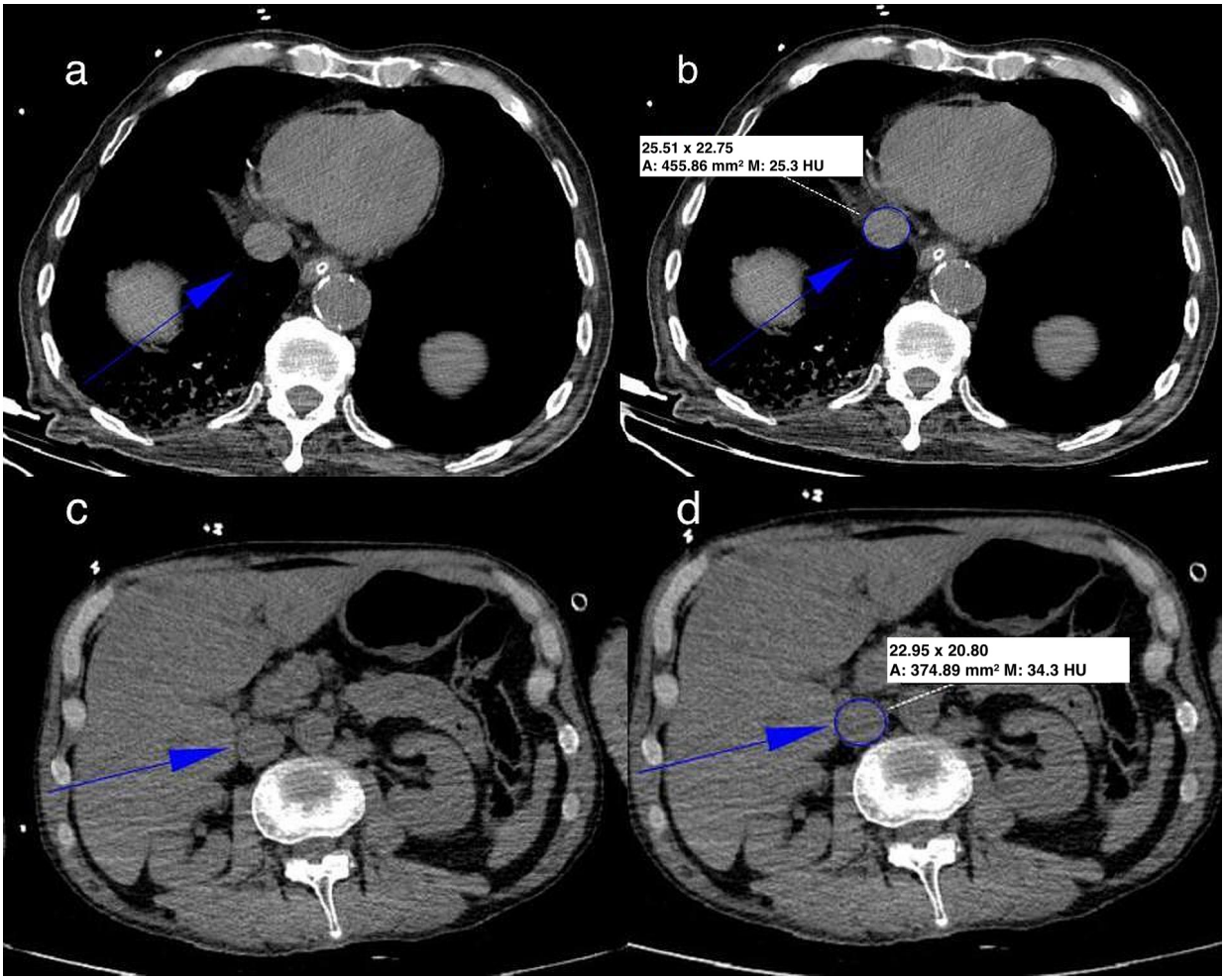

FIGURE 1. Computed tomography measurement examples of the inferior vena cava. Description: Measurement techniques for the Inferior Vena Cava (IVC) on coronal Computed Tomography (CT) images. (a) The upper measurement point of the IVC at the eighth thoracic vertebra (T8) level is indicated by a blue arrow. (b) Corresponding automated measurement results for the upper section. The parameters shown include the area (A), defined as the cross-sectional area (CSA; mm^2), and the mean attenuation (M) in Hounsfield Units (HU). (c) The lower measurement point of the IVC at the tenth thoracic vertebra (T10) level. (d) Corresponding automated measurement results for the lower section. These CT-based measurements provide objective data on IVC lumen size and density at two distinct thoracic levels.

Corp., Armonk, NY, USA). Continuous and categorical variables were presented using appropriate statistical methods, and the relationship between IVC measurements and laboratory values was assessed with correlation analysis. Differences in the degrees of pleural effusion among groups were evaluated with *t*-tests or Mann-Whitney U tests, depending on the normality of data distribution. The effectiveness of IVC measurements in predicting intravascular volume was analysed using receiver operating characteristic curve (ROC) analysis, with calculated sensitivity, specificity, and Area Under the Curve (AUC) values. Based on the ROC analysis, the optimal cutoff value for IVCU.APD in the diagnosis of pleural effusion was determined to be 616 mm^2, with a sensitivity of 79.4% and specificity of 83.3%. Logistic regression was subsequently performed with pleural effusion as the dependent variable, incorporating all measured variables. No correction for multiple comparisons was performed, as the analyses were exploratory in nature.

3. Results

The demographic and clinical characteristics of the 105 patients enrolled in this study showed the average age to be 70, years, with 45% male and 55% female. The disease spectrum included hypertension (67% prevalence), diabetes mellitus (34% prevalence), coronary artery disease (21% prevalence), diagnosed heart failure (10% prevalence), ARDS (15% prevalence), and pleural effusion (63% prevalence). The average Pleural Effusion Score (PES) was found to be 3.5, and the average Acute Physiology and Chronic Health Evaluation (APACHE) score was 23. The clinical findings of laboratory parameters, including hemoglobin, platelet, lymphocyte, leukocyte, albumin, BUN, sodium, alanine aminotransferase (ALT), and average BNP levels, are summarized in detail in Table 1. Detailed IVC measurements were recorded as follows: the average IVCU.CSA was 600 mm^2, average IVCU.APD was 688 mm^2, average IVCL.CSA was 401 mm^2, and average IVCL.APD was 494 mm^2.

The heat map analysis revealed significant correlations between BNP and the IVCL.CSA and the IVCL.APD. These results suggest that elevated BNP levels are associated with the expansion of the lower cross-sectional area and anteroposterior diameter of the IVC (Fig. 2). These findings are consistent with an increase in venous return in patients with heart failure, leading to the expansion of the IVC. High BNP levels, as an indicator of fluid retention and heart failure, are expectedly associated with these changes in IVC measurements, further supporting the utility of IVC parameters as indicators of intravascular volume status.

Significant correlations were obtained between PES and Pleural Effusion with BNP levels. Rising BNP levels have been associated with an increase in pleural effusion and pulmonary edema, which are identified as clinical indicators of fluid overload and cardiac dysfunction. Therefore, a strong correlation between BNP and PES and PE underscores the critical importance of fluid management in individuals with heart failure. In this context, the current study elucidated the strong relationships between BNP and IVC measurements, PES, and PE. The findings indicated the strongest correlation of BNP with IVCL.CSA, and PE with IVCU.APD.

This research evaluated the diagnostic value of measurements related to the diameter of the IVC for diagnosing PE through a comprehensive ROC analysis. Examined metrics included the IVCU.CSA and IVCU.APD, as well as the IVCL.CSA and IVCL.APD. Results showed that the IVCU.APD measurement possess the highest diagnostic performance with an AUC value of 0.889 (Fig. 3), indicating that this measurement can guide clinicians as a strong diagnostic indicator in diagnosing pleural effusion. While IVC measurements already hold significant importance in the noninvasive evaluation of cardiovascular pathologies, this study also emphasizes their potential effectiveness in diagnosing PE. Our results indicated that IVC measurement parameters can play a crucial role in the early diagnosis of acute cardiac events, and can provide significant contributions to timely clinician decision-making processes in patients suspected of pleural effusion.

Based on the ROC analysis, the optimal cutoff value for IVCU.APD in the diagnosis of pleural effusion was determined to be 616 mm. At this cutoff value, the sensitivity was 79.4%, and specificity was 83.3%, representing the best-balanced state.

Another ROC analysis was also conducted based on BNP values that included four different IVC measurements. The capacity of each of these measurements to identify a high-risk condition (defined as BNP >400 pg/mL) was assessed with their respective ROC curves and AUC values. The AUC values obtained for IVCU.CSA was 0.807, for IVCU.APD was 0.752, for IVCL.CSA was 0.776, and for IVCL.APD was 0.770. These results indicated good performance of these measurements in distinguishing high-risk conditions, with the IVCU.CSA measurement slightly superior to the others. This demonstrates the potential utility of these measurements in clinical practice for identifying patients at high risk with high BNP levels. The ROC curves for BNP and PE are presented in Fig. 3.

Given the strong association between IVCU.APD and pleural effusion, as well as the relationships between IVCU.APD and other clinical and biochemical parameters, further analyses were conducted to explore its relationships using correlation analysis, *t*-test, Mann-Whitney U test, Chi-square test, and univariate regression analysis. ARDS showed a significant negative correlation with smaller IVCU.APD (Odds Ratio (OR): 0.63, $p < 0.001$). Conversely, pleural effusion (PE; OR: 19, $p < 0.001$) and Pleural Effusion Score (PES; OR: 1.74, $p = 0.004$) exhibited significantly positive relationships with larger IVCU.APD. As expected, BNP levels also showed a strong positive correlation with IVCU.APD (OR: 44, $p < 0.001$). These results underline the critical importance of the IVCU.APD measurement in evaluating cardiac and pulmonary disorders.

No significant associations were observed between IVCU.APD and demographic or comorbidity variables, including age, gender, hypertension, diabetes mellitus, coronary artery disease (CAD), and previously diagnosed heart failure (OR for age: 1.025, $p = 0.85$; OR for gender: 1.15, $p = 0.49$; OR for hypertension: 1.07, $p = 0.63$; OR for diabetes: 0.95, $p = 0.98$). These findings indicate that these

TABLE 1. Demographic data at the time of diagnosis.

	N = 105	%	Median	Mean	Sd	Minimum	Maximum
Age (yr)			72	70	16	27	105
Gender							
Male	47	45					
Female	58	55					
Hypertension (n, %)	71	67					
Diabetes mellitus (n, %)	36	34					
CAD (n, %)	22	21					
History of heart failure (n, %)	11	10					
ARDS (n, %)	16	15					
PE (n, %)	67	63					
PES			3.0	3.5	0.2	1.0	10.0
APACHE score			23.0	23.0	8.5	5.0	48.0
Hemoglobin (g/dL)			9.4	9.8	2.1	6.0	17.0
Platelet count (10^9/L)			202.0	229.0	134.0	2.0	776.0
Lymphocyte count (10^9/L)			0.8	1.1	0.9	0.1	6.7
Leukocyte count (10^9/L)			10.0	12.0	6.2	1.0	40.0
Albumin (g/dL)			2.6	2.6	0.6	1.4	4.2
BUN (mg/dL)			38.0	48.0	27.0	19.0	117.0
Na (mEq/L)			138.0	138.0	7.8	112.0	164.0
ALT (U/dL)			21.0	92.0	29.0	20.0	2500.0
BNP (pg/dL)			819.0	417	112.0	7.0	5072.0
ECHO EF performed in the last 6 months			56.0	60.0	8.9	20.0	60.0
IVCU.CSA (mm^2)			593.0	600.0	409.0	137.0	3878.0
IVCU.APD (mm^2)*			728.0	688.0	254.0	154.0	1440.0
IVCL.CSA (mm^2)			433.0	401.0	170.0	10.0	716.0
IVCL.APD (mm^2)*			520.0	494.0	294.0	31.0	1038.0

*ALT: Alanine Aminotransferase; APACHE: Acute Physiological and Chronic Health Assessment; ARDS: Acute Respiratory Distress Syndrome; BUN: Blood Urea Nitrogen; BNP: Brain natriuretic peptide; CAD: Coronary artery diasease; EF: Ejection Fraction; ECHO: echocardiography; IVCU.CSA: Inferior Vena Cava Upper Cross-Sectional Area; IVCU.APD: Inferior Vena Cava Upper Anteroposterior Diameter; IVCL.CSA: Inferior Vena Cava Lower Cross-Sectional Area; IVCL.APD: Inferior Vena Cava Lower Anteroposterior Diameter; Na: sodium; PES: Pleural Effusion Score; PE: Pleural Effusion; Sd: Standard Deviation. *IVCU.APD and IVCL.APD were calculated as anterior posterior diameters × transverse diameter (APD × TSD).*

variables do not have an independent effect on the dimensions of IVCU.APD.

Among the variables examined in patients with BNP levels below 100 pg/mL, ARDS and high albumin levels were associated with low risk (OR: 0.25, $p = 0.004$). Conversely, pleural effusion and PES were associated with significantly higher risks (OR: 4.20, $p = 0.003$ and OR: 2.18, $p = 0.001$, respectively). These findings suggest that even in patients with low BNP levels, cardiovascular and pulmonary conditions remain critical indicators for evaluation. A deeper understanding of the effects on the hemodynamic and respiratory system could further emphasize the importance of these criteria in clinical decision-making processes. These findings are detailed in Table 2.

Logistic regression modelling was performed to predict pleural effusion positivity incorporating IVCU.CSA, IVCU.APD, IVCL.CSA, IVCL.APD, and BNP values. The results showed a *p*-value for IVCU.APD to be 0.020 and OR of 1.006, while for BNP, the *p*-value was 0.045 and OR was 1.004. These results suggest that IVCU.APD and BNP are independent predictors for diagnosing pleural effusion and may serve as better alternatives. The details of the logistic regression analysis are presented in Table 3.

4. Discussion

Fluid management in critically ill patients, particularly those on mechanical ventilation, requires a nuanced understanding of hemodynamic responses. Recent evidence highlights the importance of tailoring fluid strategies to ventilation settings and lung protective goals. A study by De Carvalho *et al.* [5] emphasized that the interaction between mechanical ventila-

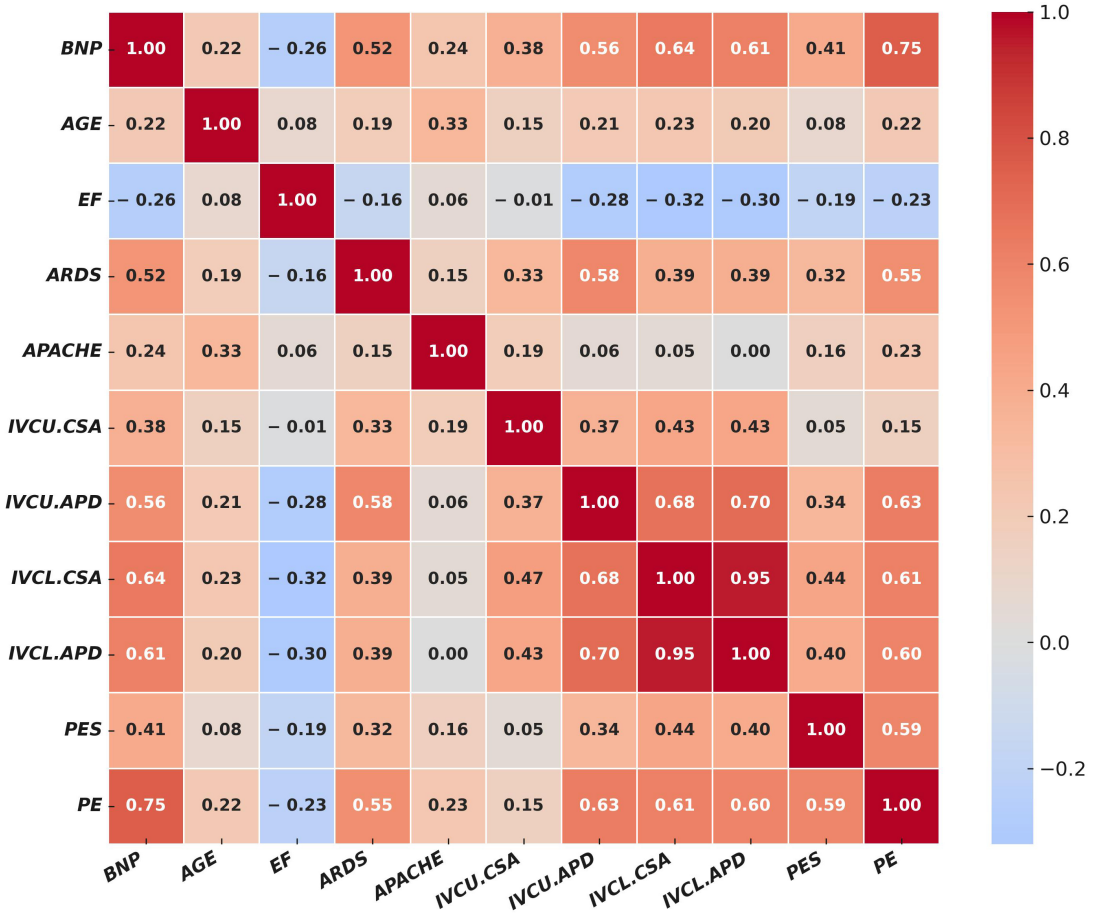

FIGURE 2. Correlation heat map. APACHE: Acute Physiology and Chronic Health Evaluation; ARDS: Acute Respiratory Distress Syndrome; BNP: Brain natriuretic peptide; EF: Ejection fraction; IVCL.APD: Inferior Vena Cava Lower Anteroposterior Diameter; IVCL.CSA: Inferior Vena Cava Lower Cross-Sectional Area; IVCU.APD: Inferior Vena Cava Upper Anteroposterior Diameter; IVCU.CSA: Inferior Vena Cava Upper Cross-Sectional Area; PE: Pleural Effusion; PES: Pleural Effusion Score.

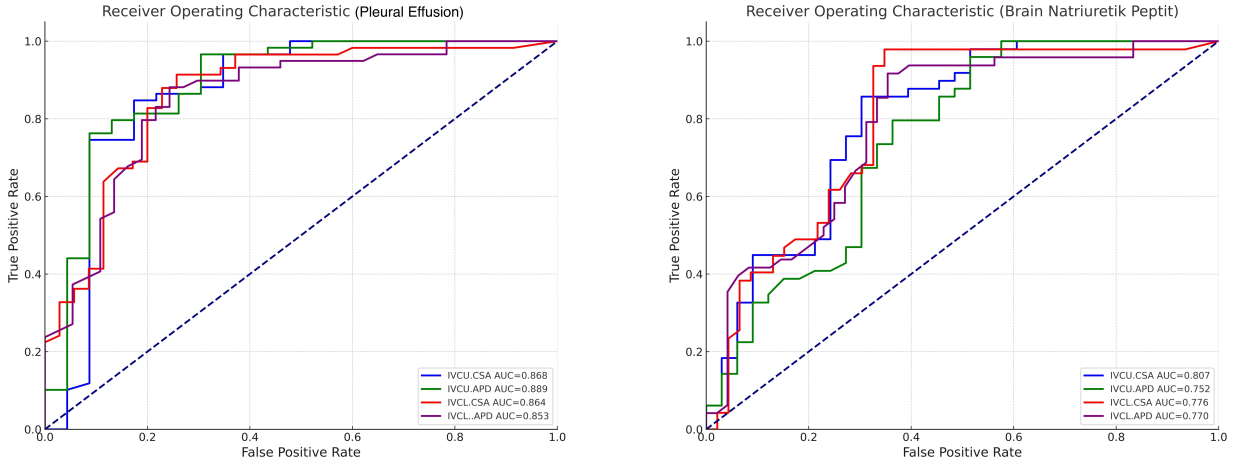

FIGURE 3. ROC analysis of the lower and upper sections of the inferior vena cava. (a) ROC Curve for Pleural Effusion (PE), Using Measurements from the Lower Section of the IVC. (b) ROC Curve for Brain Natriuretic Peptide (BNP) Testing Using Measurements from the Upper Section of the IVC. These figures compare the diagnostic accuracy of two different medical tests conducted using measurements taken from the lower and upper sections of the Inferior Vena Cava (IVC) through ROC curves. Inferior Vena Cava Lower Anteroposterior Diameter (IVCL.APD) and Inferior Vena Cava Lower Cross-Sectional Area (IVCL.CSA) represent measurements from the lower section of the IVC, while Inferior Vena Cava Upper Anteroposterior Diameter (IVCU.APD) and Inferior Vena Cava Upper Cross-Sectional Area (IVCU.CSA) represent measurements from the upper section. The AUC (Area Under the Curve) is presented for both tests as an indicator of the model's predictive ability.

TABLE 2. BNP and inferior vena cava upper cross-sectional area univariate logistic regression analysis.

	IVCU.APD >616 (mm^2)		BNP <100	
	OR (95% CI)	*p*	OR (95% CI)	*p*
Age (yr)	1.02	0.850	1.04	0.070
Gender male	1.15	0.490	1.14	0.790
Hypertension	1.07	0.630	0.81	0.880
Diabetes mellitus	0.95	0.980	0.90	0.930
CAD	0.95	0.910	1.00	0.920
History of heart failure	0.50	0.710	2.70	0.180
ARDS	0.63	**<0.001**	0.25	**<0.001**
PE	19.00	**<0.001**	4.20	**0.003**
PES	1.74	**0.004**	2.18	**0.001**
APACHE score	1.02	**0.330**	1.10	**0.009**
Hemoglobin (g/dL)	0.95	0.620	0.78	0.370
Platelet count (10^9/L)	0.99	0.750	1.00	0.850
Lymphocyte count (10^9/L)	1.01	0.600	0.76	**0.001**
Leukocyte count (10^9/L)	1.02	0.510	1.01	0.140
Albumin (g/dL)	0.99	0.980	0.25	**0.004**
BUN (mg/mL)	1.01	0.370	1.01	0.090
Na (mEq/L)	0.97	0.420	0.91	0.430
ALT (U/dL)	1.01	0.770	1.01	0.140
BNP (pg/mL)	44.00	**<0.001**	Reference variable	
ECHO EF performed in the last 6 months	0.95	0.160	0.88	0.210
IVCU.CSA (mm^2)	1.01	**0.001**	1.01	**<0.001**
IVCU.APD (mm^2)*	Reference variable		1.07	**0.001**
IVCL.CSA (mm^2)	1.03	**<0.001**	1.01	**<0.001**
IVCL.APD (mm^2)*	1.01	**<0.001**	1.01	**<0.001**

*ALT: Alanine Aminotransferase; APACHE: Acute Physiological and Chronic Health Assessment; ARDS: Acute Respiratory Distress Syndrome; BUN: Blood Urea Nitrogen; BNP: Brain natriuretic peptide; CAD: Coronary artery diasease; CI: Confidence; EF: Ejection Fraction; ECHO: echocardiography; IVCU.CSA: Interval Vena Cava Upper Cross-Sectional Area; IVCU.APD: Inferior Vena Cava Upper Anteroposterior Diameter; IVCL.CSA: Inferior Vena Cava Lower Cross-Sectional Area; IVCL.APD: Inferior Vena Cava Lower Anteroposterior Diameter; Na: sodium; PES: Pleural Effusion Score; PE: Pleural Effusion; OR: Odds Ratio. *IVCU.APD and IVCL.APD were calculated as anterior posterior diameters × transverse diameter (APD × TSD). Bold p-values indicate statistical significance ($p < 0.05$).*

TABLE 3. Logistic regression analysis of factors associated with pleural effusion.

Variables in the Equation	B	S.E.	Wald	*df*	Sig.	Exp(B)
IVCU.CSA	−0.001	0.002	0.772	1	0.370	0.999
IVCU.APD*	0.006	0.003	5.453	1	**0.020**	1.006
IVCL.CSA	0.003	0.005	0.371	1	0.540	0.997
IVCL.APD*	0.004	0.006	0.522	1	0.470	1.004
BNP	0.004	0.002	4.018	1	**0.045**	1.004

*B: Beta coefficient; df: Degrees of freedom; Exp(B): Multiplier effect of the independent variable; Wald: Wald chi square statistic; BNP: Brain natriuretic peptide; IVCU.CSA: Inferior Vena Cava Upper Cross-Sectional Area; IVCU.APD: Inferior Vena Cava Upper Anteroposterior Diameter; IVCL.CSA: Inferior Vena Cava Lower Cross-Sectional Area; IVCL.APD: Inferior Vena Cava Lower Anteroposterior Diameter; S.E.: Standard deviation of the estimate; Sig.: Statistical significance. *IVCU.APD and IVCL.APD were calculated as anterior posterior diameters × transverse diameter (APD × TSD). Bold p-values indicate statistical significance ($p < 0.05$).*

tion and intravascular volume status can significantly influence outcomes. Liberal fluid approaches may exacerbate pleural effusion in patients with compromised lung function, while restrictive strategies may lead to hypoperfusion if not carefully monitored. Therefore, dynamic monitoring tools and context-specific assessment techniques are essential in guiding individualized volume resuscitation in the ICU setting.

Central venous pressure (CVP) remains one of the widely used methods in ICUs for assessing patients' hemodynamic status obtained via a central venous catheter placed within the superior vena cava close to the right atrium. However, existing literature have indicated decreased sensitivity of this method due to errors in volume assessment encountered with CVP measurements. This may be due to factors such as increased thoracic pressure caused by positive pressure ventilation in intubated patients [6].

Recent studies have validated the use of point of care ultrasound (POCUS) in estimating right atrial pressure (RAP), supporting its utility as a non-invasive alternative to invasive hemodynamic monitoring. Istrail L *et al*. [7]. demonstrated a strong correlation between IVC diameter and collapsibility with invasively measured RAP, particularly when assessments were performed by trained clinicians. Their findings support the clinical applicability of POCUS in evaluating central venous pressure and volume status, especially in emergency and intensive care settings where rapid assessment is critical [8]. While IVC ultrasound is widely used for non-invasive volume assessment, it has inherent limitations, such as suboptimal visualization and operator dependency [9]. The literature includes numerous studies evaluating volume status through ultrasonography (USG). However, a review of these studies concluded that although USG is widely available, its diagnostic performance remains limited and may not reliably aid clinical decision-making in uncertain or complex scenarios [10]. Another disadvantage of USG measurements is their operator dependence. In contrast, CT-based measurements of the IVC are less influenced by operator variability due to their cross-sectional nature, making it possible to establish reproducible cut off values. Unlike USG, which can lead to inconsistent measurements across different clinicians or clinical settings due to its operator dependency, CT provides objective measurements with greater reproducibility.

Although advanced dynamic monitoring methods, such as pulse contour cardiac output (PiCCO) or pulmonary artery catheterization, offer superior diagnostic precision, they were not available during the study period in our institution. Nevertheless, in the absence of dynamic tools, static parameters, especially IVC diameter, may still provide valuable insights in clinical decision-making. Monnet *et al*. [11] demonstrated, in a meta-analysis, that while dynamic tests (*e.g.*, passive leg raising) outperform static measurements in predicting fluid responsiveness, static indicators like IVC size can be pragmatically useful, particularly in emergency or resource-limited settings [12].

POCUS offers distinct advantages in the ICU, as it is non-invasive, free of ionizing radiation, and allows for bedside evaluation without requiring patient transport. Its repeatability and rapid applicability make it particularly useful in unstable or deteriorating patients. However, in certain patient populations, such as those with morbid obesity or high subcutaneous tissue echogenicity, adequate acoustic windows may not be achievable, thereby reducing the reliability of IVC visualization. In such cases, computed tomography (CT) imaging, although not traditionally used solely for volume evaluation, provides more objective and reproducible cross-sectional measurements of the IVC, as is less affected by operator variability.

Importantly, in many critically ill patients, CT imaging is already performed in the emergency department for other clinical indications (*e.g.*, suspected pneumonia, pulmonary embolism, or trauma). In these situations, IVC measurements can be assessed retrospectively from the available CT data without requiring an additional test. This incidental use of CT enables volume status evaluation in patients who are often intubated, hemodynamically unstable, or being considered for ICU admission. Nonetheless, due to radiation exposure, cost, and logistic considerations, routine CT imaging for the sole purpose of fluid assessment is neither practical nor recommended.

The results of this study demonstrate significant correlations between the lower cross-sectional area and anteroposterior diameter of the IVC with both pleural effusion and BNP levels, suggesting their potential application in fluid management in critically ill patients. Elevated BNP levels reflect increased ventricular wall stress, which may be transmitted to the right atrium and subsequently to the IVC, leading to dilation. This observed correlation between BNP levels and IVC dilation finds its basis in the hemodynamic interplay of right-sided heart pressures. Elevated right atrial pressure, resulting from volume overload, is transmitted to the IVC, causing it to dilate. BNP, being secreted by ventricular myocardium in response to pressure and wall stretch, effectively reflects this heightened central venous and myocardial stress. A recent meta-analysis by Di Nicolò *et al*. [13] reinforces this mechanism, demonstrating a moderate correlation between ultrasound measured IVC diameter, collapsibility and right atrial pressure, underscoring the pathophysiological link between venous congestion and IVC morphology. Importantly, our study found no significant relationship between the IVCU.APD diameter and intubation status ($p = 0.70$) compared to errors in CVP measurements in intubated patients. This supports the reliability of CT-derived IVC measurements in mechanically ventilated individuals.

Although there is no precise CT classification for pleural effusion yet, our study developed a classification system including three primary findings of pleural effusion. The correlation matrix identified a strong correlation between BNP and pleural effusion, suggesting that our evaluation system could be useful for future studies with dynamic volume assessment tools. BNP is widely accepted in the scientific literature as a fundamental biomarker in both acute and chronic heart failure conditions [14]. Literature suggests a critical role of BNP in the diagnosis and management of heart failure as it has been documented to be elevated in individuals with heart failure due to ventricular distension and pressure loading [15]. Consistent with prior evidence, our results demonstrate that BNP levels are directly related to the severity of heart failure symptoms and are consistent with the impact on IVC sizes and pulmonary scores.

In our research, no statistically significant difference in BNP levels and IVC measurements were found between patients who had previously been diagnosed with Heart Failure (HF) and those who had not. Similarly, no difference was observed in BNP and IVC measurements based on Ejection Fraction values measured with Echocardiography (ECHO) in the last six months. These findings can be interpreted as signs of an acute process, such as sepsis-induced decompensation or septic hyperdynamic states, in hospitalized patients. Furthermore, these findings support the proposition that standard ECHO may not adequately detect diastolic heart failure. In recent years, our understanding of heart failure with preserved ejection fraction (HFpEF) has evolved significantly. Borlaug provides a comprehensive examination of HFpEF's pathophysiology, epidemiology, diagnostic complexity, and emerging treatment strategies, highlighting the diverse phenotypes and therapeutic challenges associated with this condition [16]. It is considered that the CT-derived IVC measurements may provide a valuable adjunct in screening for diastolic dysfunction, supporting their potential application beyond conventional fluid assessment.

The relationship between the IVC diameter and BNP serum levels has been evaluated as another significant parameter of diagnostic performance. The IVC diameter strongly correlates with the pleural effusion score and BNP, thus being recognised as a significant indicator in diagnosing pleural effusion. A second notable finding is that the IVCU.APD had a statistical significance similar to BNP in excluding ARDS, a factor known for non cardiac origin pleural effusion in critical illness conditions. This relationship, when expressed in odds ratios, was determined as 0.63 ($p < 0.001$) and 0.25 ($p < 0.001$), respectively. These findings suggest that IVCU.APD may serve as an effective biomarker for differentiating ARDS from cardiogenic fluid overload, similar to BNP.

The existing literature on CT-based evaluation of pleural effusion and fluid status remains limited. While the classical CT findings differentiating cardiogenic pulmonary edema from ARDS have been well described by Komiya *et al.* [17], their study was methodologically limited, with only 20 patients and no standardized measurement approach. More recently, Barbas *et al.* [18] emphasized the evolving role of imaging in distinguishing these two conditions, highlighting the values of high resolution CT features in combination with clinical context to improve early diagnosis and guide personalized ventilation strategies. This supports the need for updated imaging-based diagnostic approaches in critically ill patients with acute respiratory failure.

Our regression analysis further supports the diagnostic utility of IVC measurements. In the regression analysis model referencing the presence of pleural effusion, both BNP and IVCU.APD were identified as independent variables in determining pleural effusion. This analysis revealed that the IVCU.APD measurement is a statistically stronger indicator for detecting pleural effusion, compared with BNP, evidenced by $p = 0.02$ (Exp(B): 1.006) and $p = 0.045$ (Exp(B): 1.004) values, respectively. Taken together, our findings support the integration of IVC evaluation with CT into broader diagnostic strategies and highlight the need for larger, prospective studies incorporating dynamic monitoring tools to clarify its role in guiding fluid resuscitation.

5. Conclusions

This study evaluated the diameter and area of the IVC using CT and demonstrated their relationship with intravascular volume. While CT scans may not be ideal for volume status or diastolic heart failure evaluations due to high radiation exposure, opportunistic measurement of the IVC diameter, from any thoracic or upper abdominal CT image made for any indication, emerges as a practical and beneficial method. This research has demonstrated that IVC measurements can be a significant tool in managing critically ill patients to assess fluid balance and hemodynamic status. The diameter and area measurements of the IVC have shown significant relationships with pleural effusion and BNP levels, indicating that this method could occupy an important place in clinical practice, especially for intravascular volume assessment and optimisation of fluid therapy. The study has yielded reliable and consistent results in intubated and non-intubated patients, highlighting IVC measurements' operator independence and wide application potential. Among the measurement levels assessed, the optimal site was identified 1–2 cm above the diaphragm at the T7–T8 vertebral level, offering a reproducible reference point for clinical application. Overall, IVC assessment on CT holds promise as a supportive tool in intravascular volume evaluation and fluid therapy optimization.

6. Limitations of the study

This study has several limitations. First, its single center and retrospective design may introduce selection bias and restrict generalizability of the results. Second, the diagnosis of pleural effusion was primarily based on radiological findings, which may not fully capture the clinical complexity in all cases. Third, the absence of dynamic hemodynamic monitoring tools, such as PiCCO or pulmonary artery catheterization, limits the precision of intravascular volume assessment. Additionally, individual anatomical variations, particularly differences in patient height and age, may influence vascular measurements, thereby affecting the external validity of the findings. Finally, no formal interobserver variability assessment was conducted for the IVC measurements. Although all measurements were reviewed and confirmed by a senior radiologist blinded to the clinical data, the lack of a reproducibility analysis may affect the robustness of the findings. Future multicenter studies with larger cohorts and dynamic monitoring methods are warranted to validate and extend these findings.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

EM—conceptualized and designed the study; performed the research; collected, analyzed, and interpreted the data; wrote the original draft and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Written informed consent was obtained from all participants involved in the study. The study's protocol was reviewed and adheres to the principles of the Helsinki Declaration, as reflected by the approval granted by the Clinical Research Ethics Committee of İzmir Katip Celebi University (decision number: 0541, date: 26 October 2023).

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CONFLICT OF INTEREST

Dr. Eren Mingsar declares that there is no financial or personal conflict of interest related to this study. The research was conducted in accordance with the principles of scientific accuracy, transparency, and objectivity.

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