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Original research article

Assessment of intravascular volume by correlation of IVC diameter and collapsibility index with central venous pressure in critically ill patients

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Abstract

Background and Objective: In earlier research, studies were done to evaluate how well CVP was predicted by IVC diameter and collapsibility Index but a direct comparison of the efficacy of both indices for predicting CVP was seldom performed. The purpose of this study is to further characterize the association between IVC diameters, collapsibility index, and central venous pressure (CVP) for determining volume status in critically ill patients, as well as to compare the efficacy of IVC MIN, IVC MAX, and IVCCI for predicting CVP.

Methods: A Cross-sectional comparative study was conducted at Department of Anaesthesia, Andhra Medical College, Visakhapatnam, Andhra Pradesh, India, between June 2022 to November 2022. After obtaining approval from the Hospital Ethics committee, and written informed patient content, we studied 50 patients who are critically ill with an intrathoracic central venous catheter that had been already inserted.

Results: In this study, the sonographic parameters, such as IVC max and IVC min, demonstrated a strong positive correlation with invasive CVP, indicating that as CVP rises, so too does the value of the aforementioned parameters. The IVC Collapsibility Index demonstrated a strong negative correlation with invasive CVP, indicating that the IVC Collapsibility Index's value decreases as CVP rises. IVC max, IVC min, and IVC-Collapsibility Index were found to have better results in identifying CVP>10. In detecting CVP 6, the IVC min also produced better outcomes. Therefore, all three parameters may have a significant impact for states with high CVP. IVC min can have a big impact in low CVP states. Due to the non-invasive nature of the technique, no complications were noted in the study.

Conclusion: From this study, we draw the conclusion that sonographic assessment of intravascular volume status in critically ill patients aids in the early detection of hemodynamic state and helps in directing early fluid resuscitation of the patient. IVC ultrasound can be used safely in a variety of clinical situations for better management of critical care patients and avoiding the risks connected with invasive procedures because it has a good approximation in predicting actual Central Venous Pressure, which estimates intravascular volume status.

Keywords: Sonographic assessment, collapsibility index, ultrasound, CVP states, IVC

Introduction

The management of fluids has an effect on body systemic perfusion, which affects the risk of organ dysfunction and mortality in critically ill patients, making intravascular volume status crucial [1]. But fluid overload can be dangerous and associated with increased mortality [2]. Intravascular volume assessment can be done by physical examination, biochemical markers, Central venous pressure (CVP) measurement, Sonographic IVC Diameter assessment, Pulmonary artery catheterization, etc. [3, 4]. However Central venous pressure (CVP) monitoring is still commonly used in guiding early resuscitative efforts especially in patients with severe sepsis or septic shock [5]. A central venous pressure of less than 8 mm Hg is regarded as indicating the need for aggressive intravenous fluid replacement in patients with severe sepsis/septic shock [6]. CVP stands for the right atrium or superior vena cava pressure, and it is used to advise emergency departments and critical care units about fluid management [7].

The most accurate method of determining CVP and RAP is central venous catheterization [6, 8]. It is an invasive procedure, so it may have side effects like arrhythmias, cardiac injury, vascular and nerve damage, pneumothorax, hemothorax, local bleeding manifestation, thrombosis, pulmonary embolism,

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and post-phlebitis syndrome. Additionally, there are negative effects like higher medical expenses, extended hospital stays and a lower quality of life [4, 5, 6, 7]. In order to determine central venous pressure non-invasively, bedside ultrasound, a non-invasive method for hemodynamic monitoring, can be used in conjunction with more common clinical parameters like urine output, pulse rate, blood pressure, etc. [5]. Measurement of IVC diameter and Inferior Vena cava Collapsibility Index (IVC-CI) are reliable parameters for assessing intravascular volume and clinical responsiveness to fluid administration [9]. The non-invasive approach of determining volume status is a valuable adjunct in patients with suspected hypovolemia, allowing the doctor to initiate rapid fluid resuscitation before using additional objective and invasive tests [10].

Aim and Objective

Aim: This study aims to estimate the intravascular volume status of the patient using sonographic parameters of IVC and its correlation with Central Venous Pressure.

Objective

1. To measure IVC Diameter and Collapsibility index by using ultrasound.
2. Study its correlation with conventionally measured Central Venous Pressure in critically ill patients.
3. Compare the efficacy of IVC MAX, IVC IMIN, and IVCCI in predicting the CVP thereby assessing the intravascular volume status.

Material and Methods

Methodology: After receiving approval from the institutional scientific committee and written informed consent from patients or patient relatives who participated in this study, the study was carried out at Department of Anaesthesia, Andhra Medical College, Visakhapatnam, Andhra Pradesh, India, between June 2022 to November 2022. Patients who are critically ill and between the ages of 18 and 60 with an intra-thoracically placed central venous catheter.

Study Design: Planned research will be cross-sectional and comparative. Based on their invasive CVP, fifty post-operative patients of either sex were divided into three groups: normal voluminous patients with normal CVP (N), hypervolemic patients with high CVP (H), and hypovolemic patients with low CVP (L). Their sonographically measured parameters, such as IVC-Collapsibility Index, IVC-Maximal Diameter, and IVC-Minimum Diameter, were contrasted with their invasive CVP values.

Group N: Normal CVP Group/Normovolemia.
Patients with invasive CVP values between 6-10 mm Hg.

Group H: High CVP Group/Hypervolemia.
Patients with invasive CVP values more than 10 mm Hg.

Group L: Low CVP Group/Hypovolemia.
Patients with invasive CVP values less than 6 mm Hg.

Inclusion criteria

- Patients 18-60 years of age both male and female.
- Critically ill patients with Intrathoracic Central venous line inserted.
- Non intubated patients are included.
- Those who gave valid informed consent.

Exclusion criteria

- Upper extremity deep vein thrombosis.
- Patients who are intubated or on mechanical ventilation.
- H/o neck surgery or radiotherapy.
- Clinically significant RV/PHT/SVC obstruction, dilated RA, MR/TR/TR, and TR.
- Patients unable to lie flat on their backs.
- Patient refusal.
- Bleeding disorders
- Pregnant ladies.

Results

In the groups with hypovolemia, hypervolemia, and normal volemia, the mean age and the proportion of men were 48.4 years and 56%, 40.0 years and 80%, and 38.25 years and 60%, respectively. As a clinically significant cutoff for high central venous pressure, 10 mm Hg was selected. It was set at 6 mm Hg for low CVP.

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The sensitivity of IVC max in our study was high (92%), for CVP 6 mm Hg. For all three parameters, specificity was 100 percent. The diagnostic tests for IVC max, IVC min and IVC-CI were excellent, and the PPV and NPV were both 100%. The sensitivity was 100% across the board for high CVP > 10mm Hg.
For IVC-CI, the specificity was high (98%). With 95% and 99% respectively, the PPV had high IVC min and IVC-CI. For all six parameters, the NPV was once more 100%. The results of the diagnostic tests AUC IJV max, IJV min, IJV area, IVC max, IVC min and IVC-CI were excellent.

Demographic data
Age distribution

Age distribution	Hypovolemia	%	Normovolemia	%	hypervolemia	%
18 to 30 years	2	8	5	25	2	40
31 to 40 years	5	20	6	30	0	00
41 to 50 years	8	32	5	25	2	40
>51 years	10	50	4	20	1	20
	25	100	20	100	5	100

Age distribution	Hypovolemia	Normovolemia	Hypervolemia
NO.	25	20	5
MEAN	48.4	38.25	40
SD	11.71	12.7	11.61
P-value Chi Square Test		0.111	

Patients in the hypovolemia group were mostly older than 51 years old (n=10, 50%), with a mean age of 48.4 years. The majority of the patients in the Normovolemia group (n=6, 30.0%), with an average age of 38.25 years, belonged to the age class interval of less than 31 to 40 years. Patients in the hypervolemia group tended to fall into the 18–30 and 41–50 age groups the most (n=2,8%, (n=2, 40.0%), respectively, with a mean age of 40 years. According to the Chi-square test, the relationship between the study groups and age distribution is deemed to be not statistically significant because $p > 0.05$.

Gender distribution

Gender status	Hypovolemia	%	Normal CVP	%	High CVP	%
Male	14	56	12	60	4	80
Female	11	44	8	40	1	20
Total	25	100	20	100	5	100
P-value Chi-Square Test	0.312					

The majority of the patients in the hypovolemia group (n=14, 56.0%) were men. The majority of the patients in the Normovolemia group (n=12, 60.00%) were male. The majority of patients in the hypervolemia group (n = 4, 80.00%) were men. Since $p > 0.05$ according to the Chi-square test, the association between the study groups and gender status is regarded as not statistically significant.

BMI Distribution

BMI Distribution	Hypovolemia	%	Normovolemia	%	Hypervolemia	%
Under Weight (≤ 18.49)	0	0.00	0	0.00	0	0.00
Normal (18.50 to 24.99)	18	72.0	17	85.0	5	100
Overweight (25 to 29.99)	7	28.0	3	15.0	0	0.00
Obese	0	0.00	0	0.00	0	0.00
Total	25	100	20	100	5	100

BMI Distribution	Hypovolemia	Normovolemia	Hypervolemia
N	25	20	5
Mean	24.23	23.70	22.68
SD	2.71	2.56	1.82
P-value Chi-Square Test		0.694	

With a mean BMI of 24.23 and n=18, 72.0% of the patients in the hypovolemia group, the majority of

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them belonged to the normal BMI class interval. With a mean BMI of 23.70, most of the patients in the Normovolemia group (n=17, 85.00%) belonged to the normal BMI class interval. With a mean BMI of 22.68, the patients in the high CVP group were mostly in the normal BMI class interval (n=5, 100%). The Chi-square test indicates that there is no statistically significant correlation between the study groups and BMI distribution because $p > 0.05$.

CVP Defining Intravascular Volume Status

As invasive CVP is taken as the gold standard test, according to the previous studies cutoff values for Hypovolemia - < 6 mm Hg, Normovolemia 6 to10 mm hg, Hypervolemia - >10 mm hg.

	Hypovolemia	Normovolemia	Hypervolemia
N	25	20	5
Mean	3.48	7.50	12.20
SD	1.29	1.19	1.30
P-value One way ANOVA test		<0.001	

The mean CVP among the hypovolemia, Normovolemia, and Hypervolemia groups is 3.48, 7.50, and 12.20 respectively. Mean CVP of normovolemia is 4.02mm Hg more than hypovolemia group. Mean CVP of Hypervolemia is 4.7mm Hg more than Normovolemia group. Whereas. Mean CVP of Hypervolemia is 8.72 mm Hg more than Hypovolemia group. Having a P-value < 0.001 the CVP values are highly significant in assessing intravascular volume status.

CVP vs. IVC Max

CVP vs. IVC MAX	Hypovolmia/Low CVP	Normovolemia/Normal CVP	Hypervolemia/High CVP
N	25	20	5
Mean	1.172	2.04	2.76
SD	0.303	0.211	0.151
Pearson's "r" Correlation			0.968705
P value	One Way Anova	Test	<0.001
Significance			Significant

In low CVP, normal CVP and high CVP, the mean IVC max measurements are, respectively, 1.17, 2.04, and 2.76 cm. IVC max measurements are 1.59 cm longer in the high CVP group compared to the low CVP group (57%), 0.72 cm longer in the high CVP group compared to the normal CVP group (42%), and 0.86 cm longer in the normal CVP group (42%). The IVC max and an increase in CVP have a very strong positive correlation. The Pearson's R Correlation value of 0.968705 indicates that this is the case. Accordingly, the CVP rises as IVC max rises. The analysis of variance test results indicate that this direct positive and high correlation is significant with a p-value of 0.0001. The scatter plot explains the percentage as well. The variability of the response data around its mean is completely explained by this linear model. 96% of the time, the variation in IVC max and CVP levels correlate.

CVP vs. IVC Min

CVP vs. IVC Min	Hypovolmia/Low CVP	Normovolemia/Normal CVP	Hypervolemia/High CVP
N	25	20	5
Mean	0.26	1.075	2.46
SD	0.104	0.304	0.151
Pearson's "r" Correlation			0.94524
P-value	ONE WAY ANOVA		<0.005
Significance			significant

Low CVP, normal CVP and high CVP have respective mean IVC min measurements of 0.26 cm, 1.07 cm and 2.46 cm. In comparison to the low CVP group (75%), the IVC min measurement is 0.815 cm longer in the normal CVP group, 1.38 cm longer in the high CVP group (56%), and 2.2 cm longer in the high CVP group compared to the low CVP group (89%). The IVC minimum and rise in CVP are strongly positively correlated. The Pearson's R Correlation value of 0.94524 indicates that this is the case. In other words, the CVP grows as the IVC area grows. Accordingly, 94% of the time, a high CVP causes an increase in IVC min. The analysis of variance test results indicate that this direct positive and high correlation is significant with a p-value of 0.0001. The scatter plot explains the percentage as well. The variability of the response data around its mean is completely explained by this linear model. There is a 94% correlation between this variation in IVC min and CVP levels.

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CVP vs. IVCCI

CVP vs. IVCCI	Hypovolmia/Low CVP	Normovolemia/Normal CVP	Hypervolemia/High CVP
N	25	20	5
Mean	77.687	47.625	10.864
SD	8.09	11.694	2.572
Pearson's "r" Correlation			-0.89639
P-value	One Way Anova		<0.001
Significance			Significant

In low CVP, normal CVP, and high CVP, the mean IVC CI measurements are 77.68, 47.62, and 10.86, respectively. IVC CI measurements differ by 30.06% in the normal CVP group compared to the low CVP group (39% decrease), 36.76% in the high CVP group compared to the normal CVP group (78% decrease), and 66.86% in the high CVP group compared to the low CVP group (86% decrease). The IVC CI and an increase in CVP have a significant negative correlation. The Pearson's R Correlation value of -0.89639 shows that this is the case. In other words, the CVP rises as IVC CI falls. This indicates that IVC CI declines as a result of high CVP 89% of the time. The analysis of variance test results indicates that this inverse, negative, and high correlation is significant with a p-value of 0.0001. The scatter plot explains the percentage as well. The variability of the response data around its mean is completely explained by this linear model. 89% of the time, this variation in IVC CI and CVP levels correlate.

Accuracy Analysis: Hypervolemia (CVP > 10)

Accuracy analysis hypervolemia	Sensitivity	Specificity	PPV	NPV	AUC	Accuracy	Cutoff	P value
IVC max	100	66.67	87.50	100.00	0.977	85.00%	>1.9	<0.001
IVC min	100	88.89	95.45	100.00	0.988	90.00%	<1.28	<0.001
IVCCI	100	97.78	99.06	100.00	0.998	98.00%	≤ 30	<0.001
CVP	100	63.50	78.80	100.00	1.000	85.00%	>7	<0.001

IVC max, IVC min and IVC CI have a high sensitivity, which means that 100% of people with CVP > 10 will test positively for them. 97% of people with CVP 10 will test negative with IVC min and IVC CI because of the high specificity of these two tests. IVC min and IVC CI have high positive predictive values, which means that CVP > 10 is present in 95% and 99% of the subjects with positive IVC min and positive IVC CI tests, respectively. IVC max, IVC min, and IVC CI have a high negative predictive value, which means that CVP 10 is present in all individuals with negative IVC max, IVC min, and IVC CI tests.

IVC minimum and IVC have a very high diagnostic efficacy or accuracy. In terms of diagnostic tests, the IVC CI, IVC min, and IVC max areas under the curves are all excellent. As a combined screening and confirmatory case finding test, IVC min and IVC CI's overall effectiveness in detecting CVP > 10 is good.

Accuracy Analysis: Hypovolemia (CVP <6)

Accuracy analysis hypovolemia	sensitivity	specificity	PPV	NPV	AUC	Accuracy	cutoff	P-value
IVC max	80.65	100.00	100.00	68.39	1.000	88.00%	<1.9	<0.001
IVC min	92.6	100.00	100.00	85.26	1.000	96%	<0.7	<0.001
IVCCI	58.14	100.00	100.00	50.59	1.000	64%	>30	<0.001
CVP	100	100.00	100.00	100.0	1.000	100.0%	<6	<0.001

IVC min has a high level of sensitivity, which means that 92% of people with CVP 6 will experience a positive test result. Since IVC max, IVC min, and IVC CI have a high level of specificity, all individuals with CVP greater than 6 will test negative for all three. IVC max, IVC min, and IVC CI have high positive predictive values, which means that CVP 6 is present in all individuals who have positive results for these tests.

Since 85% of people with negative IVC max tests also have CVPs of less than 6, the negative predictive value for IVC min is high. With IVC min and IVC max, the diagnostic effectiveness or diagnostic accuracy is average. The diagnostic tests for the IVC max, IVC min, and IVC CI have excellent areas under the curve. As a screening and confirmatory case finding test combined, it means that the overall value of IVC min in detecting CVP 6 is good. As a confirmatory case finding test, IVC max and IVC CI have a good overall value in identifying CVP 6.

Discussion

Numerous studies compared invasive CVP to non-invasive intravascular volume measuring techniques such as IVC ultrasonography. However, a few studies demonstrated that non-invasive ultrasound assessment is not a reliable indicator of intravascular volume measurement [11] and that additional

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research and data were required to fully comprehend the theory. Thus, the primary goal of our study was to compare non-invasive intravascular volume measurement via the inferior vena cava with invasive CVP in critically ill patients.
Sonographically determined measures such as IVC diameters and IVC - CI had a strong correlation with the conventional invasive CVP in this investigation. There were no difficulties due to the non-invasive nature of the procedure.

Demographic profile age
All of the patients in our study were older than 18 years old. In the low, high, and normal CVP groups, the study population's mean age was 48.4, 38.25, and 40 years old, respectively. The majority of low CVP group patients belonged to greater than 50 years age group. In the high CVP group, the majority age group is shared among 18 to 30 and 41 to 50 years and a majority of normal CVP patients belonged to 31 to 40 years of age. There was no significant relationship between CVP levels with age with p-0.111 (>0.05).

Gender
Patients from both the male and female genders participated in the study. There were 20 female and 30 male patients. In the hypovolemia group, there were 11 female patients and 14 male patients. There were 4 female and 1 male patient in the Hypervolemia group. There were 12 males and 8 females in the Normovolemia group. The majority of Hypo, Hyper, and normovolemic patients were males (56%, 80%, and 60% respectively). There was no significant relationship between CVP levels and gender with P: 0.312(>0.05).

BMI
In our study, only Normal and overweight categories (with BMI 18.5-24.9 and 25-29.99 respectively) were included. We did not include obese patients because of the technical difficulties involved in the assessment of IVC diameter. In the Normal BMI group, 18 patients are hypovolemic, 5 patients with Hypervolemia, and 17 patients with Normovolemia. BMI also did not have any significant Relationship with CVP as per our study.
Shivanand Patil *et al*. 2016 [12] analyzed 4126 participants in prospective observational research to see if there was a link between age, BMI, height, weight, and IVC diameter. They discovered a strong link between IVC diameters and BMI, height, and weight in their research. Expiratory and Inspiratory IVC diameters revealed a substantial connection with BMI (r= 0.686, 0.7), respectively. IVC diameter exhibited no significant link with age (p= 0.172) and had a negative correlation (r= -0.032). Age, gender, BMI and CVP had no significant association in our research.

CVP
The mean CVP among the hypovolemia, Normovolemia and Hypervolemia groups is 3.48, 7.50, and 12.20 respectively. In 2015, Mucahit *et al*. [13] used bimodal analysis to compare non-invasive ultrasound-guided CVP with invasive CVP (the cutoff value for low CVP was 6 mm Hg and high CVP >10 mm Hg). The same cutoff values-6 mm Hg for hypovolemia and >10 mm Hg for hypervolemia-were used in a similar analysis that we also conducted.

IVC max
The mean IVC max diameter was 1.17 cm in the hypovolemia group, 2.04 cm in the normal group, and 2.76 cm in the hypervolemia group. IVC max and invasive CVP have a significant positive correlation, according to our research. This indicates that as CVP rises, IVC diameter rises as well.

IVC min
In the hypovolemia, normovolemia and hypervolemia groups, the mean IVC min diameter is 0.26, 1.07, and 2.46, respectively. IVC min diameter and invasive CVP have a strong positive correlation, which means that as CVP rises, IVC min diameter also rises.

IVC-CI
The mean IVC-CI in Hypo, Normo, Hypervolemia groups were 77.68%, 47.62%, and 10.86% respectively. Strong, inverse, negative correlation exists between IVC-CI and CVP. The IVC-CI decreases as CVP rises.

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Hypervolemia States (CVP >10 mm Hg)
IVC max, IVC min and IVC-CI have 100% sensitivity, which is high. IVC-CI has a high specificity of 95% for IVC min. With 97%, IVC-CI and IVC-min have high PPV. Three parameters have a 100% NPV. With IVC min and IVC-CI from the study, the diagnostic accuracy is very high.

Hypovolemia States (<6 mm Hg)
IVC max sensitivity is high. Each of the three ultrasound parameters has a 100% specificity. Also 100% for all of them is PPV. IVC max has a high NPV of 93%. With IVC max, the diagnostic accuracy is very high.

Use of IVC for Intra Vascular Volume Assessment
In 1979 [14], Hiroshi Natori and others Ultrasonography was used to examine the impact of ventilation on the configuration of the inferior vena caval in 14 participants, including 5 with COPD, 3 with cardiac tamponade caused by carcinomatous pericardial effusion, 1 with tuberculous constrictive pericarditis, and 5 normal subjects. The lumen of the IVC contracted during maximum inspiration, decreased during the early inspiratory phase, reached a minimum at the end of inspiration, expanded once more during expiration, and briefly closed 2 to 3 cm below the diaphragm. These ventilatory alterations in the inferior vena cava were reversed with an increase in intrathoracic pressure during the Valsalva maneuver and positive pressure ventilation. The inferior vena cava dilates throughout inspiration and expiration when the CVP is high, similar to cardiac tamponade. When the central venous pressure was less than 10 cm H_2O, the collapsibility of the inferior vena cava was inversely related to the pressure, but not when the pressure was greater than 10 cm H_2O. They discovered that examining the inferior vena cava configuration using ultrasonography is a helpful noninvasive clinical tool for determining central venous pressure. In our study, the collapsibility index has a strong negative correlation with the CVP, suggesting that regardless of how it is measured, the collapsibility index is inversely proportional to the CVP.
John T. Walsh *et al*. in 2000 [15] stated that central venous cannulation can be also be achieved via the femoral vein by positioning the catheter in the right atrium. He concluded that CVP measured via the femoral vein is less trustworthy, and that mean venous pressure within the abdomen IVC is nearly identical to mean right atrial pressure. The IVC is a useful, safe alternative for the measurement of CVP. In our study, we included patients who are having a central venous catheter placed IJV or subclavian vein.
Joerg C. Schefold, 2007 [16] used the single-pass thermal trans-pulmonary dilution approach to see if IVC diameters correspond with invasively evaluated hemodynamic measures such as volume-based hemodynamic parameters. The mechanical ventilation of thirty patients was used. They found a correlation between IVC MAX and MIN diameters and invasive CVP (p = 0.004 and 0.001, respectively), extravascular lung water index (p = 0.001 and 0.002, respectively), intrathoracic blood volume index (p = 0.026 and 0.05, respectively), intrathoracic thermal volume (p = 0.001) and PaO_2/FiO_2 oxygenation index (p = 0.007 and p = 0.008, respectively). According to our study, there is a significant correlation between CVP and IVC MAX and MIN, with p values of 0.001 and 0.005, respectively.

Correlation of IVC Ultrasound with CVP
Arun D. Nagdev, MD *et al*. [5] calculated the CAVAL INDEX in 2009 as the relative decrease in inferior vena cava diameter over the course of one respiratory cycle. Calculated was the correlation between the CVP and the caval index. They conducted an investigation. IVCCI and central venous pressure had a negative correlation of -0.74 (95% confidence interval [CI]: -0.82 to -0.63). The sensitivity, specificity, positive predictive value, and negative predictive value of the caval index for predicting a central venous pressure less than 8 mm Hg were 91 percent (95 percent CI 71 percent to 99 percent), 94 percent (95 percent CI 84 percent to 99 percent), 87 percent (95 percent CI 66 percent to 97 percent), and 96 percent (95 percent CI 86 percent to 99 percent) respectively. In our study, we used a low CVP threshold of 6 mm Hg. In our study, we used an IVCCI cutoff value of >30% to predict CVP 6 mm Hg, and as a result, we obtained a sensitivity of 58%, specificity of 100%, PPV of 100%, and NPV of 50% for detecting Low CVP. IVC diameter and CVP have a good correlation, it can be said.
In order to determine the correlation between IVC ultrasound parameters and IVCCI, Ilyas *et al*. 2017 [1] conducted a cross-sectional study on 100 ICU patients. In this study, the inferior vena cava's collapsibility index was 30.68 10.93 and the average CVP was 10.38 4.14 cmH2O. The correlation between CVP and the IVC collapsibility index (percent) was statistically significant negative (r = -0.827, n = 100, p 0.005). Maximum IVC diameter and minimum IVC diameter significantly positively correlate with CVP (r = 0.371, n = 100, p 0.005 and r = 0.572, n = 100, p 0.005, respectively). The average CVP in our study was 5.92 +/- 0.44, and the average IVCCI was 59.12 +/- 23.45. There was a strong negative correlation between CVP and IVCCI, with r = -0.8969 and P = 0.001, as well as a significant positive correlation between CVP and both IVC max and min diameter.
Made Wiryana *et al*. 2017 [17] measured for CVP and ultrasound parameters of IVC and found a strong negative correlation between CVP and IVCCI with r = -0.854, p<0.001. In our study, we too found the

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same relationship.
In a retrospective analysis of an audit, J. Govender *et al*. (2018) evaluated the inferior vena cava collapsibility index (IVC-CI) within 5 minutes of CVP measurement. While the average IVC -CI was 39.4 17.8%, the average CVP was 13.7 7.7 cm H2O. A Pearson correlation test revealed that there was a weak negative association between CVP and IVC-CI for all individuals, but it was not statistically significant (r = 0.05, n = 24, p = 0.81, 95 percent CI 0.5 to 0.4). However, there was a weak negative correlation between CVP and IVC-CI in females (r = 0.16, n = 17, p = 0.53, 95 percent CI 0.3 to0.6), which was not statistically significant (r = 0.34, n = 7, p = 0.34, 95 percent CI 0.9 to0.5), whereas there was a weak positive correlation in males (r = 0.16, n = 17, p = 0.53, 95 percent CI 0.3 to). CVP and IVCCI have a very strong negative correlation in our study (r = - 89639) in a study by Sinan Karacabey et al. from 2016 (18), which examined the status of intravascular fluid without invasive procedures, CVP measurements showed a statistically significant correlation (p0.05, r: 0.1). IVC collapsibility measurements and CVP measurements did not correlate well. (p<0.01, r:- 0.68). The findings of our study, which are similar to those of this study, show that IVC measurements are very helpful in evaluating the intravascular volume status non-invasively.

Effects of position on IVC diameters
In 1987 [19], Shoichiro Nakao *et al*. conducted research on the relationship between right atrial pressure and the size and shape of the inferior vena cava (IVC) in supine and lateral positions. IVC area and diameter mean values significantly decreased from the right lateral position (22 +/- 3 mm and 3.9 +/- 0.6 cm2, respectively) to the supine position (15 +/- 5 mm; 1.8 +/- 0.9 cm2) to the left lateral position (7 +/- 3 mm; 0.8 +/- 0.4 cm2) (p0.01). IVC diameters and RAP were positively correlated in every position, with the left lateral position showing the strongest correlation (r=0.89) and the supine position the weakest (r=0.85). Considering the convenience of the patient studies were done in the supine position in our study.
In 2013 [20], Bahman Naghipour and Gholamreza Faridaalaee conducted a small number of studies using transesophageal echocardiography analyses to identify the ideal anatomic site to obtain an exact correlation between CVP and IVC diameter. They found that at the point of IVC entry into the right atrium, the IVC sonographic diameter and IVC/aorta ratio had an acceptable correlation with CVP. As advised by the American Society of Echocardiography, we took measurements in this study between 0.5 and 3.0 cm from the right atrium (just outside the area where the hepatic vein enters the internal jugular vein).

Effect of ventilation
According to Amir Khalil *et al*. (2014) [21], their CVP had a range of -4 to 26 cm H_2O and a mean of 8 cm H_2O (SD=6.24). Mean IVC diameters increased along with the rise in CVP. A moderate and significant correlation (r=0.53, p0.001) was found between CVP and maximum IVC diameter. Additionally moderate and significant (r=0.58, p0.001) was the correlation between CVP and the minimum IVC diameter. They excluded patients who required intubation. We did not include intubated patients in our study either.
A study was conducted on 45 patients by Serenat Citilcioglu *et al*. in 2014 [22] that included both mechanically ventilated and spontaneously breathing patients. In contrast to mechanically ventilated patients, they came to the conclusion that there is no statistically significant relationship between CVP and IVC diameters in spontaneously breathing patients. We excluded non-intubated patients from our study.
A significant correlation between the CVP and IVC diameters was discovered by SA Aydin *et al*. in 2015 [23]. When the relationship between IVC diameter and CVP was examined, it was discovered that IAP (Inspiratory Antero-Posterior) and EAP (Expiratory Antero-Posterior) values significantly correlated with CVP values. (p 0.001). The results of ROC analyses indicated a significant correlation between EAP diameter and levels of hemoglobin, hematocrit and scvO2.
According to Nik Azlan Nik Muhamad *et al*. [24] IJV height and IVC diameters had a good correlation with invasive CVP.
There is a stronger association between measurements of IVC diameter and collapsibility and CVP or RAP, according to a systemic review by William Ciozda *et al*. (2016) [25] that included 21 clinical studies comparing IVC diameter with RAP and CVP. However, there is a higher degree of diagnostic accuracy when using pre-determined cut points. Except in the absence of positive End Expiratory Pressure, findings among mechanically ventilated patients were mixed.
In order to compare the correlation between sonographic IVC parameters and CVP in patients who were mechanically ventilated as well as those who were breathing on their own, Dodhy AA. 2021 [26] conducted a study. There is a significant correlation between them (p 0.001), but the regression coefficients in mechanically ventilated patients were lower (r=0.779 for IVC maximum diameter and -0.725 for collapsibility index) than in spontaneously breathing patients (r=0.850 for IVC maximum diameter and -0.899 for collapsibility index), suggesting that it is more helpful in spontaneously

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breathing patients than in mechanically ventilated patients. Our study only included patients who breathed on their own, and the regression coefficients for IVC MAX and IVCCI were 0.968 and 0.896, respectively.

Comparison between IVC max, min diameter and IVCCI in detecting intravascular volume

We employed a similar analysis with the same cut-off values as Mucahit *et al*. in 2015 [27] when they used bimodal analysis to compare non-invasive ultrasound-guided CVP with invasive CVP. In their study, the IJV max, IJV min, IJV area, CVP USG, IVC max, IVC min, and IVC-CI parameters were compared. A moderate correlation was found between invasive CVP and the CVP USG, IJV max, and IJV min. IVC max, IVC min, and IVC -CI values had poor correlations (R =0.66, 0.53 and 0.54, respectively). (R2 equals 0, 29, 32, and 0, 27 respectively). The CVP USG threshold value of 7 indicated invasive CVP > 10 mm Hg with 90% sensitivity and 67.3 % specificity and predicted CVP inv 6 mm Hg with 77% sensitivity and 68 % specificity. IJV max, IJV min, IJV area, and IVC max each had high sensitivity for detecting low CVP values (90.32 percent, 83.87 percent, 90.32 percent, and 93.10 percent, respectively).

IVC-CI has a 95.2 percent sensitivity and a 42.9 percent specificity for high CVP readings. The CVP USG threshold value of 7 predicted CVP inv 6 mm Hg with a sensitivity of 77% and specificity of 68%, and indicated invasive CVP > 10 mm Hg with a sensitivity of 90%. IJV max, IJV min, IJV area, and IVC max all showed high sensitivity in detecting low CVP values (90.32 percent, 83.87 percent, 90.32 percent, and 93.10 percent, respectively). IVC-CI has a high sensitivity of 95.2% but a low specificity of 42.9% for CVP readings above the threshold. They discovered from their research that IVC-CI and CVP USG had better diagnostic performance for predicting high CVP. IJV area, IJV maximum, and IVC maximum all displayed excellent sensitivity and NPV for low CVP values. The specifications or levels of difficulty of the procedure were not objectively evaluated or statistically interpreted. Additionally, we lacked any statistical explanations. In order to do this, they adopted a bi-modal analysis with two cutoff values, which is similar to a 2012 study by Siva *et al*. Our cutoff thresholds were similar to those used in this study in contrast. The highest test results for hypervolemia conditions were found in the CVP USG and IVCCI during their investigation. IVC max, IJV area and IJV max provided the best test results for hypovolemia conditions. IJV max, IJV min, IJV area, and CVP USG were not examined in our study.

When compared to their study diagnostic accuracy of hypovolemic states is high for IVC max and Hypervolemia states are high with IVC max and IVCCI. CVP and IVC ultrasound have a good correlation with one another. The length of the procedure and the levels of difficulty involved were not evaluated objectively or statistically. We also lacked such a statistical interpretation.

Hans Vaish *et al*. 2017 [3] did a prospective observational study in a pediatric intensive care unit (PICU) of 50 children who were with a mean age of 11 years. In our study we did a comparative cross-sectional observational study, we did not follow up with patients but in our study, we found a significant correlation between CVP and IVC ultrasonography with $p<0.001$.

Sharareh Babaie, Azita Behzad, *et al*. 2018 [28] did a study aimed to determine the correlation between CVP and IVC sonographic indices in pediatric patients. From bedside ultrasonography measurements of the IVC, the collapsibility index (CI) and IVC/aorta (AO) ratio were determined. Out of 70 individuals, 22 (31.4%) had a CVP of less than 8 mm/Hg and 48 (68.6%) had a CVP of more than 8 mm/Hg. The IVC CI was 0.5 or more in 56 patients (80%), while the IVC/AO was 0.8 or less in 17 patients (24.3%). The IVC CI index predicts CVP 8 with a sensitivity of 45.5 percent and specificity of 91.7 percent, with a positive predictive value of 71.4 and a negative predictive value of 78.6. When compared to our study 50% had CVP < 6 mm Hg, 50% had CVP >6 mm Hg and 90% of patients had IVCCI > 30%. IVCCI index had a sensitivity of 58.14, specificity of 100%, PPV 100%, and NPV OF 50.59% for predicting CVP of < 6 mm Hg. The sensitivity decreased as we took a cutoff of >30% for predicting low CVP.

Mostafa Ibrahim Mostafa Shalaby *et al*. 2018 [29], conducted a study on the assessment of the correlation of CVP with IVCCI in the assessment of fluid status. A significant correlation between CVP and the two studied ultrasound parameters, IVC CI and IVC max found. The receiver operating characteristic curve was examined. The inferior vena cava collapsibility index (IVC CI) performed the best of the two ultrasonography measures in predicting CVP 10 cm H_2O, according to ROC. They discovered that ROC analysis revealed that the IVC collapsibility index and IVC diameter had superior diagnostic accuracy for predicting fluid responsiveness than the IVC collapsibility index and IVC diameter. In our study as we took a lower cutoff value of IVCCI for predicting a low CVP, there is low sensitivity, low NPV, high specificity and high NPV. Diagnostic accuracy is low with IVCCI at 64%. There is moderate diagnostic accuracy with IVC MIN and IVC MAX.

Conclusion

This study has led us to the conclusion that sonographic assessment of intravascular volume status in critically ill patients aids in the early detection of hemodynamic state and helps in directing early fluid resuscitation of the patient. IVC ultrasound can be used safely in a variety of clinical situations to improve the management of critical care patients while minimizing the risks involved with invasive

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procedures. IVC ultrasound has a good approximation in predicting actual Central Venous Pressure, thereby estimating intravascular volume status.

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