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Original Article

Comparision of ultrasound-based methods of jugular vein and inferior vena cava for estimating central venous pressure

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Abstract: Objective: The aim in this study was to compare the ultrasound estimation of the jugular vein diameter (IJVmax, IJVmin) and area (IJVarea), the height of the right internal jugular vein (CVPusg), the vena cava diameter (IVCmax, IVCmin), and the vena cava index (IVCindex) with direct estimation of central venous pressure (CVPinv). Methods: Ultrasonography was performed on 37 nonventilated and 36 ventilated patients while monitoring central venous pressure. The IJV and IVC were measured during the respiratory cycle and the IJVarea and IVCindex were calculated. Tapering portion of the right IJV defined and height from this point to the sternal angle was used to estimate CVPusg. Results: A CVP of 10 mmHg was chosen as a clinically significant cutoff for high CVP, and 6 mmHg was chosen for low CVP estimation. The CVPusg, IJVmax and IJVmin correlated moderately with CVPinv (R^2 = 0.66, 0.53, and 0.54, respectively) whereas the IVCmax, IVCmin and IVCindex showed poor correlation (R^2 = 0.29, 0.32 and 0.27, respectively). The CVPusg cutoff value of 7 predicted CVPinv > 10 mmHg with sensitivity of 90%, specificity of 67.3% and predicted CVPinv < 6 mmHg with sensitivity of 77%, specificity of 68%. IJVmax, IJVmin, IJVarea and IVCmax showed high sensitivity (90.32%, 83.87%, 90.32%, and 93.10%, respectively) for low CVP levels. The IVCindex has high sensitivity (95.2%) and poor specificity (42.9%) for high CVP levels. Conclusion: IVCindex and CVPusg has better diagnostic performance for estimating high CVP. IJVmax, IJV area, and IVCmax showed high sensitivity and NPV for low CVP levels.

Keywords: Jugular vein, vena cava inferior, ultrasound, central venous pressure

Introduction

Estimation of central venous pressure (CVP) is crucial in emergency and critical care medicine. Bedside ultrasound is being increasingly used for this purpose. Many methods have been described to estimate CVP using bedside ultrasound such as size and collapsibilty of inferior vena cava, and size and area of internal juguler vein. These methods are based on the measurement of elastic venous structures that connect to the right side of the heart. Although these methods show correlations with invasive CVP measurements, none have been accepted as a part of routine clinical practice [1].

There are four ultrasound-based methods that are commonly used for CVP estimation. These are 1) jugular vein diameter and jugular vein area measurements, 2) ultrasound estimation of the height of the jugular vein (CVPusg), which is done by identifying the top of the venous pulsation, 3) inferior vena cava (IVC) diameter, and 4) IVC collapsibility index (percent decrease in IVC diameter with inspiration).

Both jugular vein diameter and ultrasound estimation of the height of the jugular vein (CVPusg) are a topic of interest in CVP estimation. Numerous studies have shown that these methods correlate well with invasive CVP measurements, and their sensitivity and specificity are acceptable for this purpose [2-5].

Ultrasound estimation of the height of the jugular vein (CVPusg) is more diffucult and is influ-

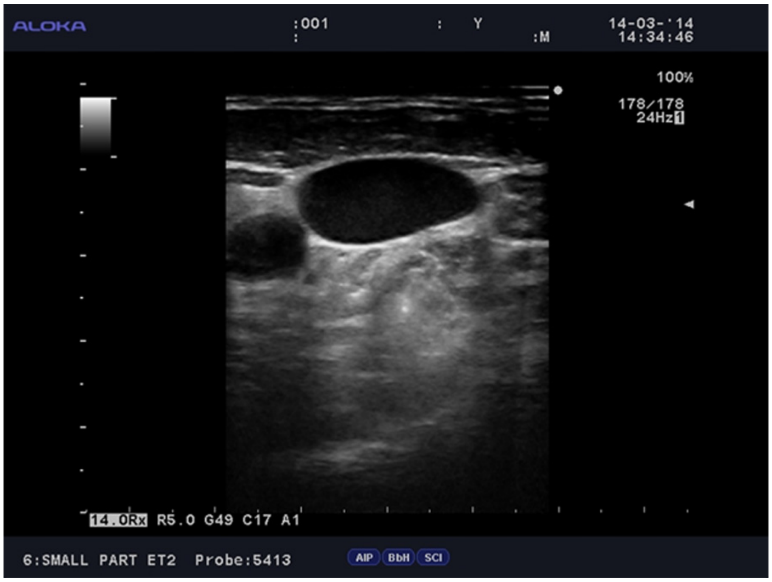

Figure 1. Transvers view of internal juguler vein maximal diameter (IJVmax).

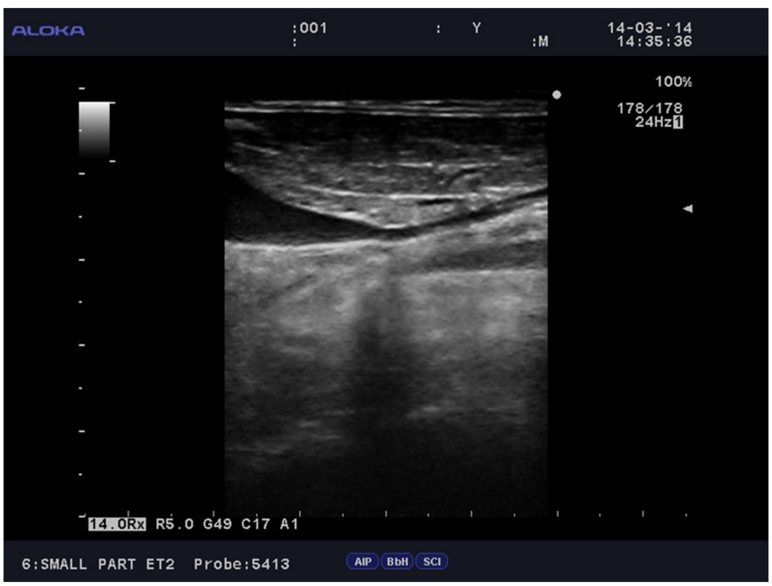

Figure 2. Sagittal view of the IJV showing the tapering portion of the vein.

enced by the elevation of the head of the bed and the timing of the end of the expiration. It is also difficult to measure the vertical distance from the top of the blood column and the sternal angle.

Both measurement of the IVC diameter and IVC index are accepted as conventional methods and has been used widely in daily practices of emergency medicine and critical care medicine [6-12].

To date, no single trial has directly compared these four non-invasive measures of CVP for accuracy as determined by invasive CVP measurements. In our study, we examine ultrasonographic measurements obtained using these four methods and compare them with patients' invasive CVP as the criterion standard.

Methods

Study setting and population

The study was conducted between October 2012 and December 2013 in the six-bed emergency critical care unit at a university hospital in Aydın, Turkey. Our critical care unit has approximately 900 discharges per year and a case mix of 80% medical, 10% trauma, and 10% toxicologic diagnoses.

The study population was a sample of patients older than 18 who required invasive hemodynamic monitoring. Patients were enrolled in the study sequentially. The exclusion criteria were as follows: 1) deep vein thrombosis in the upper extremities, 2) a history of radiotherapy or neck surgery, 3) clinically significant tricuspid or mitral regurgitation or a very distended right atrium and ventricle upon sonographic evaluation, 4) being unable to lie in a supine position for the necessary measurements, 5) patients requiring other mechanical ventilation mode than P-SIMV, and 6) patients whose Peak Inspiratory Pressure (PIP) value was > 25 mmHg and Positive End Expiratory Pressure (PEEP) value was > 5 mmHg in mechanically ventilated patients. The study protocol was approved by the local ethics committee. Written informend consent was obtained from the patients or close relatives.

Figure 3. Vertical distance between marked skin and sternal angle.

Study protocol

Internal jugular vein (IJV) and inferior vena cava (IVC) measurements were obtained using a bedside ultrasound device (ProSound Alpha 6; Hitachi Aloka Medical Ltd., Tokyo, Japan). We used a vascular transducer for IJV imaging (4 MHz-13 MHz linear array) and a cardiac transducer for IVC imaging (1 MHz-5 MHz phased array). Two residents in emergency medicine familiar with bedside ultrasound and critical care enrolled eligible patients and performed all ultrasound examinations. Before the study began, our two residents underwent two hours of focused training in the methods of sonographic measurement and practiced the techniques on five volunteer subjects under supervision. During the collection of ultrasound data, the ultrasonographers were blinded to CVP monitoring.

1) IJV diameter and area measurements were obtained with the patients in a supine position. The transducer was placed on the right side of the patient's neck in a transverse plane over the IJV, 2 cm above the level of the clavicle. It was ensured that at least 1 cm of subcutaneous tissue was preserved by observing on the display monitor. An image of the IJV was recorded for one respiratory cycle and saved on the ultrasound machine (**Figure 1**). The maximum and minimum values were recorded. The IJV area was automatically calculated by the ultrasound machine.

2) An ultrasound estimation of CVP using IJV was obtained with the patients in a semirecumbent position (with the head of the bed at 45°). The transducer was placed on the right side of the patient's neck in a longitudinal plane, and the tapering portion of the vein was marked with a skin marker (**Figures 2** and **3**). The vertical distance between this point and the sternal angle was measured using a ruler. The CVP was estimated by adding 5 cm to the vertical distance. Minimal pressure was applied with the ultrasound probe during measurement.

3) IVC measurements were obtained with the patients in a supine position. The IVC diameter was measured in the subxiphoid sagittal view (**Figure 4**). The junction of the IVC and the hepatic vein was observed. Measurements were made 1 cm distally from the junction. Images were recorded for one respiratory cycle and were saved on the ultrasound machine. The maximal and minimal anterior-posterior IVC diameters were recorded.

4) The IVC collapsibility index was calculated from the maximal and minimal anterior–posterior IVC diameters as follows: [(expiratory IVC j-inspiratory IVC)/expiratory IVC].

A three-lumen catheter was placed in the right jugular vein under ultrasound guidance. One channel of the three-lumen catheter was used for measurement, and it was connected to a monitor via a pressure transducer. The transducer was zeroed to the level of the heart, and the values were noted by the nursing staff after the completion of the ultrasonographic examination.

Statistical analyses

The data were analyzed using SPSS software (version 16.0; SPSS, Chicago, IL, USA). The Kolmogorov-Smirnov test was used to evaluate whether the distribution of continuous variables were normal. Independent Samples t-test was used to compare normally distributed inde-

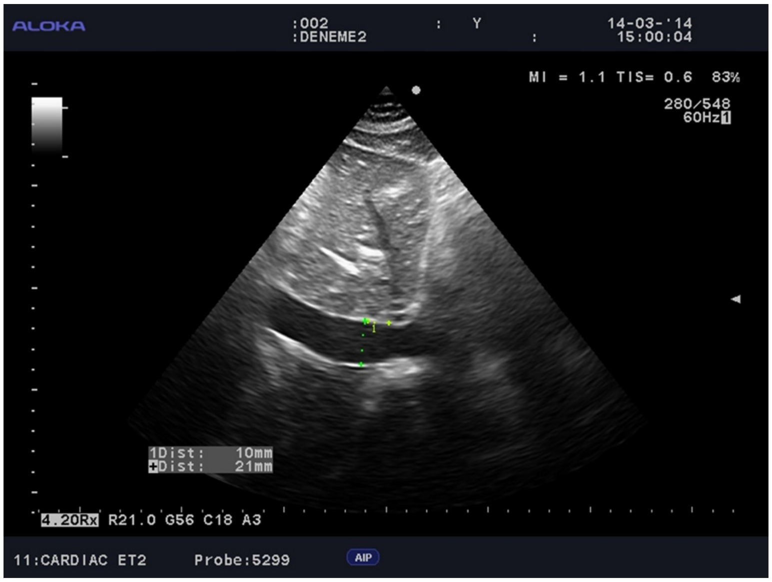

Figure 4. Ultrasonographic determination of inferior vena cava diameter.

pendent variables and descriptive statistics are presented as mean ± standard deviation. Mann-Whitney U test was used to compare the non-normally distributed independent variables and descriptive statistics are presented as median (25-75 percentiles). Spearman correlation analysis was used to find out a correlation between non-normally distributed independent variables. For categorical data, descriptive statistics are presented as frequency (%). Receiver operating characteristics (ROC) analysis was performed to find the cut-off value of each ultrasound techniques. We compared area under the ROC curves (AUC), accuracy, sensitivity, specificity, positive and negative predictive values of these ultrasound techniques. p values below 0.05 were considered statistically significant.

Results

Of the 75 patients evaluated, 73 were actually enrolled in the study. Two patients were excluded from the analysis because one had superior vena cava syndrome, and we could not insert a CVP catheter into the other. The IJV diameter and area measurements were successfully recorded. However, IVC imaging could not be obtained in two cases because of morbid obesity. These two patients were not excluded from the analysis but were recorded as missing value data.

The mean age of study participants was 64±14, and 62% were men. The median CVP was 6 mmHg (range 1 mmHg-20 mm Hg). Thirty participants were mechanically ventilated, and 37 were breathing spontaneously. Four of the patients included in the study were toxicology patients and the rest of the patients were medical patients but there were no traumatic patients.

A CVP of 10 mmHg (≥ 11 mmHg) was chosen as a clinically significant cutoff for high CVP, and 6 mmHg (≤ 5 mmHg) was chosen for low CVP level. Mean and median values of ultrasound methods are given in **Table 1**. Test characteristics of ultrasound methods in the predicting high and low volume status are given in **Tables 2** and **3**.

For volume load estimation, CVPusg with a cut-off value of > 7 had a sensitivity of 90%, specificity of 67.3%, a PPV of 51.4%, and an NPV of 94.6%. The area under the ROC curve was 0.872. The CVPusg correlated well with CVPinv (P = 0.000; r = 0.662). Correlations between ultrasound methods and CVPinv are given in **Table 4**.

In the prediction of low CVP, IJVmax and IVCmax, (cutoff value of ≤ 1.01, ≤ 1.9) had a sensitivity of 90.3%, and 93.1%, specificity of 52.3%, and 29.2%, PPVs of 58.3%, and 48.2%, NPVs of 88%, and 85.7% respectively.

IVC collapsibility index estimation for CVPinv with a cutoff value of ≤ 30 for detecting high CVP had a sensitivity of 95.2%, and an NPV of 95.5%. Test values of IVCindex were less strong in low CVP levels (sensitivity 72.4% , specificity 63.4%, area under the ROC curve 0.675). CVPindex correlated poorly with CVPinv (P = 0.022; r = 0.273).

The area under the ROC curve for CVPusg to determine a high CVP (> 10 mmHg) was 0.87, which was significantly higher than the IVC maximum diameter (area under the curve: 0.26; P = 0.001; 95% confidence interval (CI) of 0.101 to

Table 1. Characteristics of ultrasound methods

Parameters	Descriptive statistics		
	N	Mean ± sd or median (25-75 percentiles)	min-max
IJVmax	73	0.88 (0.66-1.23)	0.22-3.30
IJVmin	73	0.65 (0.46-0.97)	0.10-2.72
IJVarea	73	0.66 (0.39-1.24)	0.13-4.15
Ultrasound estimation of CVP using IJV (CVPusg)	72	7 (6-9)	1-15
IVCmax	70	1.52±0.50	0.18-2.70
IVCmin	70	1.1±0.51	0-2.60
IVC collapsibility index (IVCindex)	70	26.20 (19.83-34.77)	3.70-100

IJV: internal jugular vein, IVC: inferior vena cava, IJVmax: maximal IJV diameter with expiration, IJVmin: minimal IVC diameter with inspiration, IJVarea: area of IJV in transverse plane, CVPusg: height of IJV blood column, IVCmax: maximal IVC diameter with expiration IVCmin: minimal IVC diameter with inspiration, IVCindex: percent collapse of the IVC, during respiration, defined as [IVCmax-IVCdmin]/IVCmax × 100%.

Table 2. Test Characteristics of ultrasound methods in predicting central venous pressure > 10 mm Hg

	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC	Cutoff	P
IJVmax	71.4	82.7	62.5	87.8	79.5	0.802	> 1.04	< 0.001
IJVmin	66.7	84.6	63.6	86.3	79.5	0.772	> 0.84	< 0.001
IJVarea	66.7	84.6	63.6	86.3	79.5	0.760	> 0.91	0.001
CVPusg	90	67.3	51.4	94.6	73.6	0.872	> 7	< 0.001
IVCmax	42.9	89.8	64.3	78.6	75.7	0.620	> 1.9	0.112
IVCmin	57.1	71.4	46.2	79.5	67.1	0.661	> 1.28	0.029
IVCindex	95.2	42.9	41.7	95.5	58.6	0.654	≤ 30	0.025

IJV: internal jugular vein, IVC: inferior vena cava, IJVmax: maximal IJV diameter with expiration, IJVmin: minimal IVC diameter with inspiration, IJVarea: area of IJV in transverse plane, CVPusg: height of IJV blood column, IVCmax: maximal IVC diameter with expiration, IVCmin: minimal IVC diameter with inspiration, IVCindex: percent collapse of the IVC during respiration, defined as [IVCmax-IVCmin]/IVCmax × 100%.

Table 3. Test Characteristics of ultrasound methods in predicting central venous pressure < 6 mm Hg

	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC	Cutoff	P
IJVmax	90.32	52.38	58.3	88	68.5	0.717	≤ 1.01	< 0.001
IJVmin	83.87	59.52	60.5	83.3	69.9	0.736	≤ 0.71	< 0.001
IJVarea	90.32	45.24	54.9	86.4	64.4	0.723	≤ 0.91	< 0.001
CVPusg	77.40	68.30	64.9	80	72.2	0.796	≤ 7	< 0.001
IVCmax	93.10	29.27	48.2	85.7	55.7	0.633	≤ 1.9	0.045
IVCmin	37.93	87.80	68.8	66.7	67.1	0.658	≤ 0.7	0.015
IVCindex	72.41	63.4	58.3	76.5	67.1	0.675	≥ 26	0.008

IJV: internal jugular vein, IVC: inferior vena cava, IJVmax: maximal IJV diameter with expiration, IJVmin: minimal IVC diameter with inspiration, IJVarea: area of IJV in transverse plane, CVPusg: height of IJV blood column, IVCmax: maximal IVC diameter with expiration, IVCmin: minimal IVC diameter with inspiration, IVC index: percent collapse of the IVC during respiration, defined as [IVCmax-IVCdmin]/IVCmax × 100%.

0.416). The area under the ROC curve to determine a low CVP (< 6 mmHg) was 0.79 for CVPusg, was significantly higher than the IVCmax (area under the curve: 0.63; P = 0.03; 95% CI of 0.0156 to 0.322).

Discussion

There are several methods for obtaining a non-invasive surrogate marker of central venous pressure in critically ill patients; however, a direct comparison of the efficacy of these methods has been barely performed. The goal of this study was to compare 4 methods of non-invasive CVP estimation in both high- and low-CVP states among critically ill patients.

While performing this comparison, CVP > 10 mmHg was selected as the cut-off value for high CVP, and CVP < 6 mmHg was selected as the cut-off value for low CVP. In the literature, most of the studies used a monomodal analysis, choosing a single cut-off point [1, 2, 6, 7, 9]. However, in this study, a bimodal analysis was used, similar to Siva et al. With this bimodal analysis, the effect of the

Table 4. Correlations between ultrasound methods and CVP invasive

	r	P
IJVmax	0.536	< 0.001
IJVmin	0.546	< 0.001
IJVarea	0.495	< 0.001
CVPusg	0.662	< 0.001
IVCmin	0.325	0.006
IVCmax	0.292	0.014
IVCindex	0.273	0.022

IJV: internal jugular vein, IVC: inferior vena cava, IJVmax: maximal IJV diameter with expiration, IJVmin: minimal IVC diameter with inspiration, IJVarea: area of IJV in transverse plane, CVPusg: height of IJV blood column, IVCmax: maximal IVC diameter with expiration, IVCmin: minimal IVC diameter with inspiration, IVCindex: percent collapse of the IVC during respiration, defined as [IVCmax-IVCdmin]/IVCmax × 100%.

range between 6-10 mmHg to the analysis was reduced. By defining the groups in this way, the low- and high-CVP patient groups became much more specific than in prior studies.

In this study, the CVPusg method had the highest test values for estimating high CVP situations. No objective evaluation and statistical inference were made in terms of the time required for the process and the difficulty levels of the methods in our study. Also, in our opinion, the CVPusg method is difficult, time consuming, and open to faults when compared to the other methods. For this measurement, head of the bed must be elevated to 45 degrees, the tapering portion of the blood column in the jugular vein must be marked correctly, the horizontal line from this point should be parallel to the surface, and the vertical measurement should be performed accurately (**Figure 3**). The correct application of this technique is not simple. In a study investigating this method, CVPusg had a sensitivity of 64.4%, specificity of 81.3%, and PPV of 85.7% for high CVP levels and had sensitivity of 88.9%, specificity of 77.1%, and NPV of 96.4% for low CVP levels [3]. Our cut-off values were similar, and our study found satisfactory test values for high CVP levels, similar to the study by Siva et al [3].

The results of the IJVmax, IJVmin, and IJVarea measurements were similar. Thus, any of these may be preferred in evaluations using the jugular vein. A study by Donahue et al measured the diameters and areas of jugular veins [2]. As a result of their study, they suggested that ultrasound could easily be learned for CVP measurements. Furthermore, it has a perfect reliability that is independent of the body habitus of the patient. In our study, we demonstrated that the jugular vein has various diagnostic abilities for cases with excess or low CVP levels. Jugular vein measurements exhibited medium sensitivity and specificity for the determination of high CVP. The IJVmax and IJVarea had high sensitivity and specificity values for low CVP levels. Additionally, when compared to IVC, the measurement process was easier, and it was not affected by problems such as obesity, surgical dressings, and bowel gas. The test values were also as good as the IVC diameter measurements.

In our study, we have determined that IVCmax ≤ 1.9 cm is a strong indicator to demonstrate low CVP. However, it is ineffective in showing high CVP. Our results are highly compatible with the results of a similar study conducted by Prekker et al [1]. Additionally, IVCmax measurements showed a significant and high correlation with CVPinv. In contrast with IVC diameter, IVCindex has been weak to show low CVP, whereas it has a sensitivity of 95.2% and a NPV of 95.5% within the cut-off value of ≤ 30 to show high CVP. These results are also compatible with the study of Prekker et al [1]. In contrast, Nagdev et al. reported significantly high IVC collapsibility test values to estimate low CVP [6]. Difference between Nagdev et al and our study may arise from the fact that the CVP cut-off values are different. Literature related to IVC diameter and IVC collapsibility index are summarised in **Table 5**.

When previous studies are examined, it is seen that there are no distinct emphasis that the diameter measurements of venous structures could reflect low CVP better; also, they are a weak indicator for high CVP. A few recently conducted studies confirmed this regarding IVC and IJV diameter measurements; however, they did not make clear interpretations as to why [1, 3]. The reason behind the fact that this is more apparent in our study may be that we marginalised our cut-off values more. It is seen that, when invasive CVP values remain within normal ranges, both diameter measurements and IVCindex measurements give good results; however, when more extreme values are exam-

Table 5. Summary of the studies in literature about diameter of inferior vena cava and inferior vena cava collapsibility

	N	Main results	Comments
Prekker et al	65	For CVP < 10 mmHg, IVCmax < 2 cm predicted sensitivity 85%, specificity 81%, PPV 87%, NPV 78%. For CVP < 10 mmHg, IVC index > 50% predicted sensitivity 47%, specificity 77%	They wrote that IVCmax was more efficient in determining low CVP and IVC index was less reliable in low volume conditions.
Nagdev et al	73	For CVP < 8 mmHg, IVC index > 50% predicted sensitivity 90.9%, specificity 94.1%, PPV 87%, NPV 96%	Study focused on low volume status.
Brennan et al	91	IVCmax < 2 cm predicted CVP < 10 mmHg had sensitivity 73%, specificity 85%, IVC index (sniff) > 40% predicted sensitivity 73% and specificity 84%	IVC index cut off was %40, IVC index and IVCmax had high NPV
Schefold et al	30	IVC diameters were found to correlate with CVP, extravascular lung water index, intrathoracic blood volume index, intrathoracic thermal volume, and the PaO_2/FiO_2 index	Mechanically ventilated patients were included in this study. PEEP was 12±3 cmH_2O
Stawicki et al	101	There was significant although poor correlation between IVC index and CVP (R = -0.315; P = 0.007). Patients grouped into high (> 60), intermediate (20 to 60) and low (< 20) IVC index ranges	IVC index correlate best with CVP in the setting of low and high collapsibility ranges
Current study	73	For CVP < 6 mmHg, IVCmax < 1.9 cm predicted sensitivity 93.1%, specificity 29.2%, for CVP > 10 mmHg, IVC index < 29 predicted sensitivity 95.2%, NPV 95.5.7%	Study is comparing ultrasound based CVP estimation methods. The diagnostic capabilities of these methods differ for hypervolemic and hypovolemic situations

CVPusg: height of IJV blood column, IVCmax: maximal IVC diameter with expiration, IVC index: percent collapse of the IVC during respiration, defined as [IVCmax-IVCdmin]/IVCmax × 100%, CVP: central venous pressure.

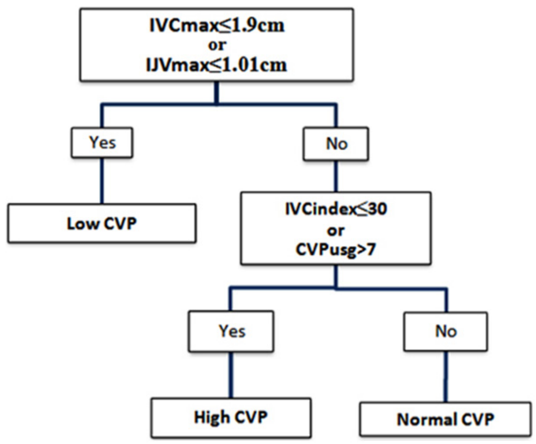

Figure 5. Basic algorithm of CVP estimation via ultrasound based methods.

ined, diameter measurements are more effective to measure low CVP (< 6 mmHg), while CVPusg and IVCindex values are more effective to measure high CVP (> 10 mmHg). In the light of these findings, it would be a significant improvement to use these measuring methods together in non-invasive estimation of CVP in critically ill patients. Our recommendations related to the use of these methods together are present as an algorithm in **Figure 5**.

The low ability of jugular vein and inferior vena cava diameter measurements to reflect high CVP, but perform well in low CVP situations, can be explained by the physiology of the venous structures. Such structures can expand to a certain point when the CVP increases and then, the expansion ratios do not significantly change, even though the CVP may increase. Besides, the CVPusg does not measure the vein diameter, but rather the height of the blood column in the jugular vein. When the CVP increases, the expansion of the vein diameter stops, but the column may continue to rise upward. Again, the capability of the IVCindex in reflecting high CVP levels conforms to the vein physiology. While the CVP increases, vein diameter enlargement stops, and it does not collapse during the expiration after the CVP exceeds a specific limit.

Our study has several important limitations. First, our study included a relatively small sample size, which hampered us in that we had to use both mechanically and spontaneously ventilated patients. This could influence the calculation of the IVC collapsibility index and other ultrasound parameters. However, we excluded patients who needed high PEEP and PIP values in order to minimise this limitation. Second, we did not compare the inter-rater or intra-rater reliability of the ultrasound techniques. Third, we did not stratify for the use of vasopressors or the use of sedatives that could affect measurements

When the data in our study are interpreted, using the CVPusg and IVCindex values will provide more precise results for high CVP levels. For the determination of low CVP, we suggest that it is more efficient to use the IJVmax, IJVarea, and IVCmax values.

Conclusion

The diagnostic capabilities of ultrasound based CVP estimation methods differ for high and low CVP levels. It is rational to have the clinicians know the weaknesses of these methods, select the suitable method that is specific to the condition, and use more than one method. While IJVmax and IVCmax performed better in the determination of low CVP levels, CVPusg and IVCindex showed high sensitivity and high NPV for high CVP. It seems a good way to start with IVCmax (or IJVmax) measurement for low CVP estimation. If low CVP is excluded then investigating for high CVP via IVCindex (or CVPusg) method would be the most reasonable approach for estimating CVP in general.

Disclosure of conflict of interest

None.

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