Internal Jugular Vein Height and Inferior Vena Cava Diameter Measurement using Ultrasound to Determine Central Venous Pressure: A Correlation Study

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SUMMARY

Objective: To determine the correlation between central venous pressure (CVP) measured by conventional central venous access and ultrasonographic measurement of internal jugular vein (IJV) height and inferior vena cava (IVC) diameter. Methods: A prospective, cross-sectional, convenience sampling observational study. Results: 25 patients from the Emergency Department (ED) Universiti Kebangsaan Malaysia Medical Centre (UKMMC) were studied between 1st March and 30th April 2013. The median age was 63 years (95% CI 54-67). There was a significant correlation between IJV height and CVP using central venous access (r=0.64 p<0.001). Correlation between IVC diameter in end expiration and CVP was 0.74 (p<0.001). An IJV height measurement >8cm predicted a CVP >8cm H2O (sensitivity 71.4%, specificity of 83.3%). Conclusion: Measurement of IJV height and IVC diameter by ultrasonography correlates well with invasive CVP and is useful for the assessment of volume status in critically ill patients in the ED.

KEY WORDS:
Central venous pressure, internal jugular vein height, inferior vena cava diameter, ultrasonography

INTRODUCTION

Estimation of intravascular volume status is an important parameter in assessing ED patients. It is necessary both for initial assessment and response to treatment. The central venous pressure (CVP) is a key physiologic estimate of preload, which in turn helps define the intravascular volume status.[1] In 1930, Sir Thomas Lewis described the non-invasive estimation of CVP by measuring the height of the column of blood in the internal jugular veins (IJV).[2] However, the technique is often difficult especially in obese or elderly patients and is of little value in shocked or hypotensive patients. Invasive measurement via a central venous catheter (CVC) has been the standard technique to measure CVP.[3] CVC insertion is time consuming and has potential complications and risks.[4] These difficulties are increased in hypovolaemic patients.[5]

Other techniques for assessing volume status include clinical examination, biochemical markers and sonographic assessment. Some of these techniques have limitations when used in clinically especially in patients with multiple comorbidities.[1,5]

Ultrasound is a non-invasive technique which is portable, readily accessible and increasingly used in the ED for a variety of presentations.[6] An ability to non-invasively measure the CVP would be extremely useful. Bedside ultrasound has been suggested as a useful tool in the assessment of intravascular volume status by examining the IJV height and IVC diameter.[7]

MATERIALS AND METHODS

The study was a prospective, cross-sectional, convenience sampling observational study. A single point in time assessment of IJV height and IVC diameter was performed using ultrasound and correlated with invasive CVP measured via standard central venous access. It was conducted in the Emergency Department, Universiti Kebangsaan Malaysia Medical Centre (UKMMC), Cheras, Kuala Lumpur between 1st March and 30th April 2013.

A portable ultrasound machine (GE Logic) was used. For IJV height measurement a high frequency transducer 7.5, and for IVC diameter a 3 MHz probe were used.Ultrasound measurement was performed at end expiration and end inspiration. Both operators had previously undergone training and certification in the technique (Winfocus Ultrasound in Central Venous Access (USCVA) Certification in Hospital Sungai Buloh, Selangor).

Inclusion criteria:
1. Adult patients > 18 years.
2. Non-ventilated and non-intubated patients.
3. Patients with a CVC already inserted for various indications i.e. the CVC was not inserted specifically for the purpose of the study.

Exclusion criteria:
1. Patients in whom the ultrasound examination would not be tolerated e.g. severe orthopnea or elevation of

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intracranial pressure.
2. Patients with known severe tricuspid regurgitation.
3. Patients with raised intra-abdominal pressure e.g. second and third trimester pregnancy, intra-abdominal compartment syndrome.
4. Trauma involving or and abdomino-pelvic region.

Patients' demographic data collected included age, sex, race, co-morbid features and mode of arrival to the hospital. Informed consent was obtained from patients or relatives before the study was commenced.

Ultrasound estimation of the height of the IJV was performed by identifying the top of the venous pulsation with the patient lying at 45°. Minimal pressure was applied with the probe to ensure that venous occlusion did not occur. Both longitudinal and transverse views were obtained (Figure 1 and Figure 2).The height of the IJV was measured as the vertical distance between the top of the venous pulsation and the sternal angle. The CVP was estimated by adding 5cm to the measured IJV height. All measurement was done via ultrasonographic method and none was done manually. The tip of venous pulsation is viewed via the longitudinal view and tapering of the IJV at its tip. The reason for adding 5 cm to the measured IJV height is due to the sternal angle lies approximately 5 cm above the right atrium.

Following this, the patient was put in a supine position to measure the IVC diameter. The anterior-posterior internal diameter of the IVC was measured 2 cm from the atrio-caval junction or just caudal to the confluence of the hepatic veins and the IVC. Imaging was performed in the longitudinal plane, measured on the M mode during end inspiration and end expiration. All diameters were determined using frozen images and measured in centimeters. No attempt was made to coach the patient in breathing.

Simultaneous CVP measurement using a pressure manometer or transducer, zeroed and levelled parallel to the patient's heart was performed simultaneously with IJV height and IVC diameter measurement. Data was recorded in the trial sheet. Still images were recorded and kept for future reference. The researchers were blinded to the CVP (via the central venous line) readings during the study. These readings were performed solely by the clinician managing the patient.

Sample size
Sample size calculation was performed using StatTools.net with probability of Type 1 error (alpha) - 0.05, Power (1-beta) - 0.95, Correlation coefficient based on previous study (rho) - 0.6. The calculated sample size was 25.

Data analysis
Data collection from each patient included: blood pressure, mean arterial pressure, heart rate and respiratory rate. The measurement of IJV height was recorded in (cm) and later converted by adding 5cm to the reading. The IVC diameter during end inspiration and end expiration was measured in cm and the collapsibility index were calculated as a percentage. The CVP measurement was recorded as cmH_20.

All data were recorded using a standard data collection format and were coded into SPSS software version 21.0 (SPSS IBM Corp. US). The continuous data distribution was tested for mean and median for descriptive data. The correlation data were analysed with Kendall's tau-b. Bland Altman plot and linear regression were used to assess agreement between CVP measurement by central venous access (the reference standard) and IJV measurement using same clinical measurement. In addition, performance characteristics (sensitivity, specificity and likelihood ratio) of the ability of IJV measurements to predict CVP measurements were calculated.

RESULTS

A total of 25 patients were recruited during the study period. 16 patients were male. The mean and median ages were 60 and 63 years respectively (Table I). 88% of patients had self presented to hospital and the remaining 12% arrived by ambulance. Co-morbidities included diabetes mellitus (80%), hypertension (68%), ischaemic heart disease (24%), chronic kidney disease (20%). Sepsis was the primary diagnosis in nearly 80% of the patients. 60% cases had had central venous access to guide fluid therapy; in 40% it was for infusion of a vasoactive agent. Five patients (20%) were obese. Peripheral long line access was the most commonly used method for CVC insertion (72%), followed by right internal jugular vein access in 24% and right subclavian vein with 4%. We were able to image the IJV and IVC in all subjects.

The correlation coefficients comparing CVP to IJV measurement was 0.32 using Kendall's tau-b, (Figure 1). Kendall's tau-b method was used as is more reliable for a small population. Kendall tau coefficient is a non-parametric hypothesis test for statistical dependence.[8] The Bland-Altman graphical comparison of methods technique was used to compare the new measurement technique (IJV) with a "gold standard" (CVP) reading through central venous access (Figure 2). There was no fixed bias since the mean value of the difference did not deviate from 0 on the basis of a 1-sample t-test. The relationship between IJV and CVP in an unadjusted linear regression model was Beta -0.119 (95% CI 0.58-0.181), adjusted R^2 0.38 ($p < 0.001$).

Our results indicate that IJV measurement can be used to predict the CVP in volume overloaded patients with a sensitivity and specificity of 71.4% and 83.3% respectively. IJV measurement can also be used to predict CVP in volume-deplete patients with high specificity but low sensitivity. This means that if the IJV measurement was < $5cmH_20$, a low CVP cannot be accurately predicted.

The correlation coefficients comparing CVP to IVC expiration measurement was 0.22 using Kendall's tau-b, For these parameters, there was bias since the mean value of the difference deviated from 0 (-5.5) on the basis of a 1-sample t-test. Accordingly, IVC expiration measurement alone could not estimate the CVP reading. However, the relationship between IVCexp and CVP in an unadjusted linear regression model was Beta 0.57 (95% CI 0.35-0.79), adjusted $R^2$0.54. ($p<0.001$).

DISCUSSION

There has been much interest in using IVC diameter to predict the CVP and the relationship between the imaged diameter of IVC and CVP has been described.9, 10 The most common method for non-invasive CVP measurement is to measure the collapsibility index of IVC in end inspiration and end inspiration. The collapsibility index of IVC in non-positive pressure ventilated patients is:

$$\text{Collapsibility Index (CI) (\%)} = \frac{\text{IVCexp (cm) - IVCinsp (cm)}}{\text{IVCexp (cm)}} \text{ x100}$$

In 2008 the American College of Emergency Physicians (ACEP) published a policy statement on emergency ultrasound guidelines. This includes the evaluation of intravascular volume status and estimation of CVP based on sonographic examination of the inferior vena cava in end expiration.[11] Table II is used to predict CVP by using IVC size and calculation the collapsibility index.

In adult patients the inferior vena cava is a high capacitance vessel. In volume depletion, it is easily collapsible with a smaller diameter. With fluid replacement, the collapsibility reduces and its diameter increases. In fluid overload, the vein's elasticity reaches a threshold of maximal distension and cannot collapse, and thus maintains a constant diameter. The IVC is also affected by its phase of respiration. It collapses with decreased intrathoracic pressure during inspiration and expands with increased intrathoracic pressure during expiration. The degree of collapsibility during the respiratory cycle predicts the fluid status and response of the individual patients.[12]

Other ultrasound techniques can make similar assessments of fluid volume status but typically these require bedside transthoracic echocardiography and necessitate an increased level of expertise by the operator and a sedated or anaesthetised patient. In this study we describe a simple extension of a routinely taught component of clinical assesment using a tool that is easy to use and increasingly available in Emergency Departments.

Table I: Characteristic of patients

Characteristics	Mean (95%Confidence Interval) (N=25)
Age, years	
Median (IRQ)	63 (54-67) years
Mean	60 years
Gender	
Male, n(%)	16 (67%)
Female, n(%)	9 (36%)
Vital signs	
Pulse rate, beats/min	110 (104-113)
Systolic blood pressure, mmHg	89 (85-98)
Diastolic blood pressure, mmHg	53 (48-59)
Mean arterial pressure, mmHg	64 (60-71)
Respiratory rate, breaths/min	20 (18-20)
Measurement	
IVC expiratory diameter, cm	1.34 (1.22-1.68)
IVC inspiratory diameter, cm	0.63 (0.62-1.07)
IVC collapsibility index, %	44.2 (36.1-50.0)
CVP measurement, cm H20	5.0 (4.0-10.0)

* IVC-Inferior Vena Cava, CVP-central venous pressure

Table II: Correlations between IVC size and CVP

Inferior Vena Cava size in expiration(cm)	Collapsibility Index (related to respiratory change)	Central VenousPressure (cm H_20)
<1.5	Total collapse (kissing)	0-5
1.5-2.5	>50% collapse	6-10
1.5-2.5	<50% collapse	11-15
>2.5	<50% collapse	16-20
>2.5	No change	>20

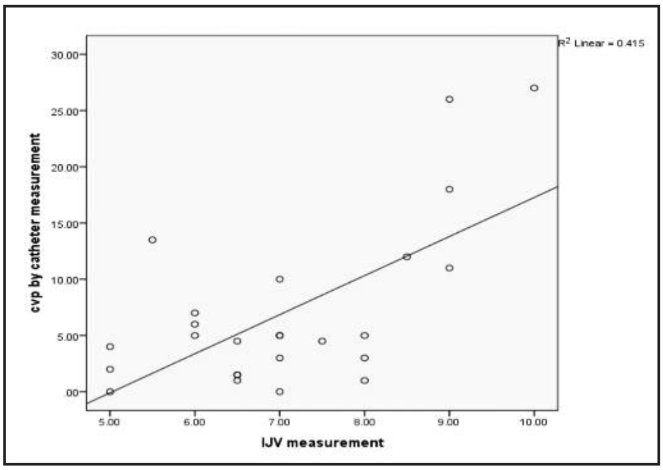

Fig. 1: The correlation between central venous pressure (CVP) and internal jugular vein (IJV) measurement.

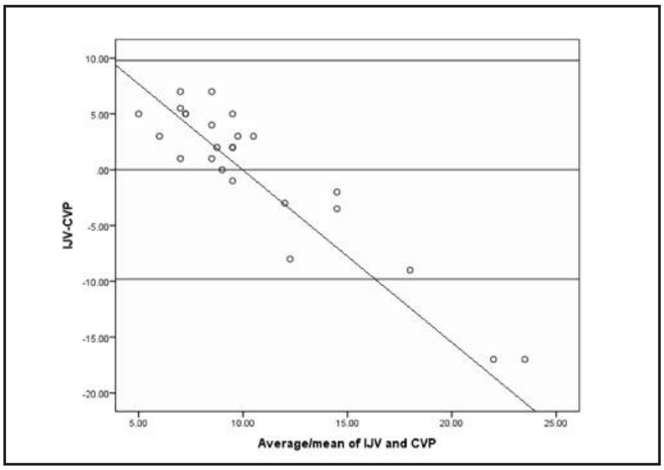

Fig. 2: The Bland-Altman plot of the comparison between internal jugular vein (IJV) and central venous pressure (CVP) measurement.

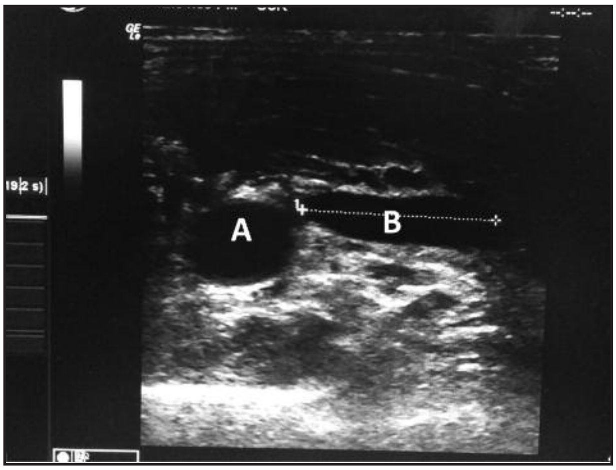

Image 1: The transverse view of the carotid artery and internal jugular vein (IJV) A: Carotid artery. B: Jugular vein measurement.

Image 2: The longitudinal view of the internal jugular vein. X marks the tip of pulsation, which the height of the IJV can marked.

Measurements were made in real time and did not require elaborate or time consuming procedures such as multiple views or complicated techniques e.g. review of sine images, trans-esophageal probes, or formal echocardiography study requiring sophisticated interpretation. The high degree of correlation between IJV sonographic measurement and CVP via central venous access confirms that IJV ultrasound measurement can estimate the CVP in non-ventilated adult patients and can be used when examination of IVC by ultrasound is difficult e.g. in obese patients.

We have demonstrated that ultrasound examination of the IJV provides a simple, non-invasive estimation of the CVP and has clear advantages in patients who are obese or cannot lie flat. The value of reduced CVP alone as an absolute marker of intravascular volume has been questioned. While a low CVP may be a proxy marker for volume depletion, a high CVP can be caused from upstream cardiac dysfunction, and aggressive fluid resuscitation may not increase myocardial fibre recruitment to further increase cardiac output.

CONCLUSION

We have shown that bedside ultrasound measurement of IJV height and IVC in end expiration correlates well with CVP measurement using central venous access. Bedside ultrasonography is a non-invasive, easily applied technique which has considerable prospects in the evaluation of volume status in ED patients. The knowledge and technique is simple to acquire and can be performed in elderly and obese patients without difficulty.

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