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Original Research

CRITICAL CARE

Ultrasound Accurately Reflects the Jugular Venous Examination but Underestimates Central Venous Pressure

Gur Raj Deol, MD; Nicole Collett, MD; Andrew Ashby, MD; and Gregory A. Schmidt, MD, FCCP

Background: **Bedside ultrasound examination could be used to assess jugular venous pressure (JVP), and thus central venous pressure (CVP), more reliably than clinical examination.**
Methods: **The study was a prospective, blinded evaluation comparing physical examination of external jugular venous pressure (JVPEXT), internal jugular venous pressure (JVPINT), and ultrasound collapse pressure (UCP) with CVP measured using an indwelling catheter. We compared the examination of the external and internal JVP with each other and with the UCP and CVP. JVPEXT, JVPINT, UCP, and CVP were compared graphically using Bland-Altman plots, and correlation coefficients were calculated.**
Results: **The correlation coefficients comparing CVP to UCP, JVPEXT, and JVPINT were 0.62, 0.57, and 0.50, respectively. When UCP was compared with JVPEXT and JVPINT, correlation coefficients were 0.91 and 0.81, respectively. Last, the correlation coefficient comparing JVPEXT and JVPINT was 0.98. The Bland-Altman graphical comparison of methods technique revealed that CVP was often underestimated by UCP, and clinical examination of JVPEXT and JVPINT. In contrast, there was no systematic bias between UCP and either JVPEXT or JVPINT, nor between JVPEXT and JVPINT.**
Conclusions: **Ultrasound examination is capable of measuring accurately the JVP as judged from the internal or external jugular vein. However, like the JVP, ultrasound typically underestimates CVP. A systematic bias between UCP and CVP suggests the presence of a variable degree of venous tone, possibly signaling contraction of jugular venous smooth muscle.**
Trial registry: **ClinicalTrials.gov; No.: NCT01099241; URL: clinicaltrials.gov**

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Abbreviations: CVP = central venous pressure; JVP = jugular venous pressure; JVPEXT = external jugular venous pressure; JVPINT = internal jugular venous pressure; UCP = ultrasound collapse pressure

The central venous pressure (CVP) is a measure of the filling pressure of the whole heart and a major determinant of the cardiac output.[1] This has led to its longstanding role as a guiding parameter in the management of patients with septic shock,[2,3] acute lung injury,[4] trauma, and following high-risk surgery. The CVP can be estimated by physical examination of the jugular venous pressure (JVP), facilitating differential diagnosis and empirical resuscitation even before central venous catheters can be inserted. Yet, the JVP has been criticized as difficult to measure reliably, because of a perceived loss of clinical examination skills[5-9] and the increasing prevalence of obesity in critically ill patients.[10,11]

JVP is recognized as the level at the top of the blood column in the (usually internal) jugular vein, seen as the height at which the vein collapses. Accurate determination of the JVP is often challenged by patient positioning and anatomy as well as by ambient lighting and the presence of devices and dressings. Ultrasound examination yields clear images of the jugular vein,

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including the collapse point, even in obese subjects.[12] We hypothesized that bedside ultrasound examination could be used to assess the JVP more reliably than clinical examination. Furthermore, we reasoned that ultrasound could estimate the value of the JVP, potentially speeding diagnosis and therapy in critically ill patients before CVP could be measured invasively.

Materials and Methods

The study was performed prospectively in the medical ICU of the University of Iowa Hospitals and Clinics and included mechanically ventilated and spontaneously breathing subjects, all of whom had central venous catheters placed as part of their clinical management. Patients were eligible for the study, regardless of diagnosis or neck size, as long as the central venous catheter terminated in the superior vena cava. Age, sex, BMI, ICU admission diagnosis, severity of illness as measured by the Acute Physiology and Chronic Health Evaluation II score, and degree of sedation (Richmond Agitation Sedation Scale) were recorded for all patients. Consecutive patients admitted to the ICU were screened daily. All eligible subjects were approached, and informed consent was obtained as soon as possible after ICU admission. Informed consent was obtained directly from the patient or from a surrogate decision maker when the subject was unable to make informed decisions. The study was approved by the University of Iowa institutional review board (ID number 200706777) and is listed on clinicaltrials.gov (NCT01099241).

Measurements

The observer estimated JVP by visual examination of the external jugular vein (JVPEXT) on the side opposite the central venous catheter using a previously published method.[13] The bed angle was adjusted to yield the best view of the collapsing vein, and this angle was recorded. Tangential lighting was used when needed and the observer could compress the base of the neck or strip the veins to facilitate recognition of the anatomy. The apex of venous pulsations was located and respiratory variation noted. The site of the venous meniscus was found at end-expiration, and the vertical distance between this level and the sternal angle was measured with a ruler, using a yardstick and level to accurately reference the vein to the sternal angle. The JVPEXT was recorded in centimeters of water. In a similar fashion, the internal jugular vein was examined (also on the side opposite the catheter), taking care to distinguish jugular from carotid pulsations, and the internal JVP (JVPINT) was recorded. The investigator was blinded to the bedside monitor display of CVP before and during these clinical examinations as well as for the ultrasound studies below.

Maintaining a constant bed angle, ultrasound gel was applied over the jugular vein (opposite the central venous catheter). A Sonosite Titan 180 or M-Turbo (SonoSite Inc; Bothell, Washington) portable ultrasound machine with a 13.6-MHz broadband linear array transducer was used to visualize the internal jugular vein. The probe was moved superiorly on the neck rotating between longitudinal and transverse views to locate the area of vein collapse. Using the longitudinal view, the apex of the zone of collapse at end-expiration was marked on the neck (Fig 1). Using the two-ruler method described above, the height above the sternal angle was measured and the value recorded as the ultrasound collapse pressure (UCP).

Without changing the bed angle, the central venous catheter was zeroed at the level of the sternal angle. The venous waveform was recorded along with a simultaneous plethysmographic tracing, and the value at the base of the "a" wave at end-expiration was taken.

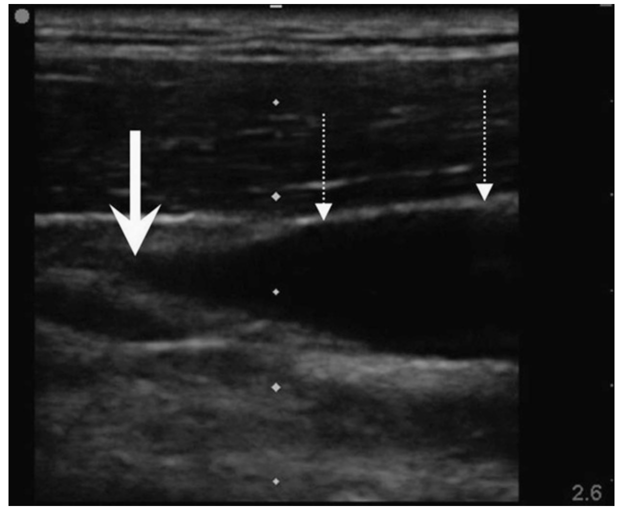

Figure 1. Internal jugular vein area of collapse. The internal jugular vein is shown in longitudinal view (left is cephalad). The skin surface is at the top of the figure and the total depth is 2.6 cm. Thin dotted arrows mark the anterior border of the vein, which appears echo-free (dark). The solid arrow shows the point of vein collapse.

The CVP was read in millimeters of mercury and converted to centimeters of water (1 mm Hg = 1.36 cm H_2O).

Finally, we marked the phlebostatic axis (intersection of the midaxillary line and a perpendicular extended to the fourth intercostal space at the sternum) and determined the vertical distance between the sternal angle and the phlebostatic axis in order to convert JVPEXT, JVPINT, UCP, and CVP to values typically used clinically. We preferred this approach to referencing each measurement directly to the phlebostatic axis in order to minimize error in judging pressure. Furthermore, the distance between the sternal angle and the phlebostatic axis is known to be quite variable between subjects and typically is not 5 cm H_2O.[14]

Analysis

Our primary hypothesis was that the internal jugular vein collapse point as judged by portable ultrasound (UCP) would equal the CVP as measured by the central venous catheter. Secondary analyses included comparing clinical examination of the JVPEXT and JVPINT with each other and with the UCP and CVP. JVPEXT, JVPINT, UCP, and CVP were compared graphically using Bland-Altman plots, and correlation coefficients were calculated.

Results

Of 38 patients who provided informed consent, 11 were orally intubated and mechanically ventilated, and 27 were not ventilated. Patient characteristics are given in Table 1. The median time between admission to the ICU and study procedures was 1 day. Thirty-three examinations were performed in patients with internal jugular catheters, with the remaining patients having subclavian catheters (two patients) and percutaneously inserted central catheter lines (three patients). Subjects having percutaneously inserted central catheter lines were accepted only when the pressure tracing showed clear respiratory variation. JVPEXT was

Table 1—*Characteristics of 38 Subjects*

Demographic	Value
Age, y	58.3 ± 14.7
Male (female) ratio	19 (19)
Acute Physiology and Chronic Evaluation II Score	16.4 ± 6.0
BMI, kg/m²	30.5 ± 9.2
ICU diagnosis, No.	
Sepsis/septic shock/bacteremia	13
ALI/ARDS	4
GI bleed	4
Acute liver failure	4
Miscellaneous	13
Catheter CVP reading, mean ± SD, cm H_2O	13.9 ± 5.9
Right internal jugular catheterization, No.	33
Mechanical ventilation, No.	11
Days to study from admission	2.07 ± 2.87

Data are given as mean ± SD unless otherwise mentioned. ALI = acute lung injury; CVP = central venous pressure.

estimated successfully by clinical examination in 37 of 38 subjects, whereas JVPINT could be confidently measured in only 26 of 38. No anatomic abnormalities that could have compressed the veins, such as cervical lymphadenopathy, were seen.

The values (mean ± SD) for CVP, UCP, JVPEXT, and JVPINT were 13.9 ± 5.9, 9.2 ± 3.3, 8.8 ± 3.2, and 7.8 ± 3.2, respectively (Fig 2, Table 2). Correlation coefficients comparing CVP to UCP, JVPEXT, and JVPINT were 0.62, 0.57, and 0.50, respectively. When UCP was compared with JVPEXT and JVPINT, correlation coefficients were 0.91 and 0.81, respectively. Last, the correlation coefficient comparing JVPEXT and JVPINT was 0.98. (Fig 2, Table 3).

The Bland-Altman graphical comparison of methods technique[15] revealed that CVP was often underestimated by UCP as well as by clinical examination of JVPEXT and JVPINT. In comparing CVP and UCP, the mean bias was 5 cm H_2O (CVP higher than UCP). This difference increased as the absolute value of the CVP increased. In contrast, there was no systematic bias between UCP and either JVPEXT or JVPINT, nor between JVPEXT and JVPINT (Fig 3).

Discussion

Our findings showed that ultrasound was able to image the internal jugular vein in all subjects, whereas clinical examination was not always successful, suggesting that ultrasound may be useful in estimating JVP in patients who do not yet have central venous catheters or have femoral catheters and who are difficult to examine clinically. The high degree of correlation between UCP and JVPEXT and JVPINT, along with the lack of systematic bias, shows that ultrasound can estimate accurately the JVP as measured by the

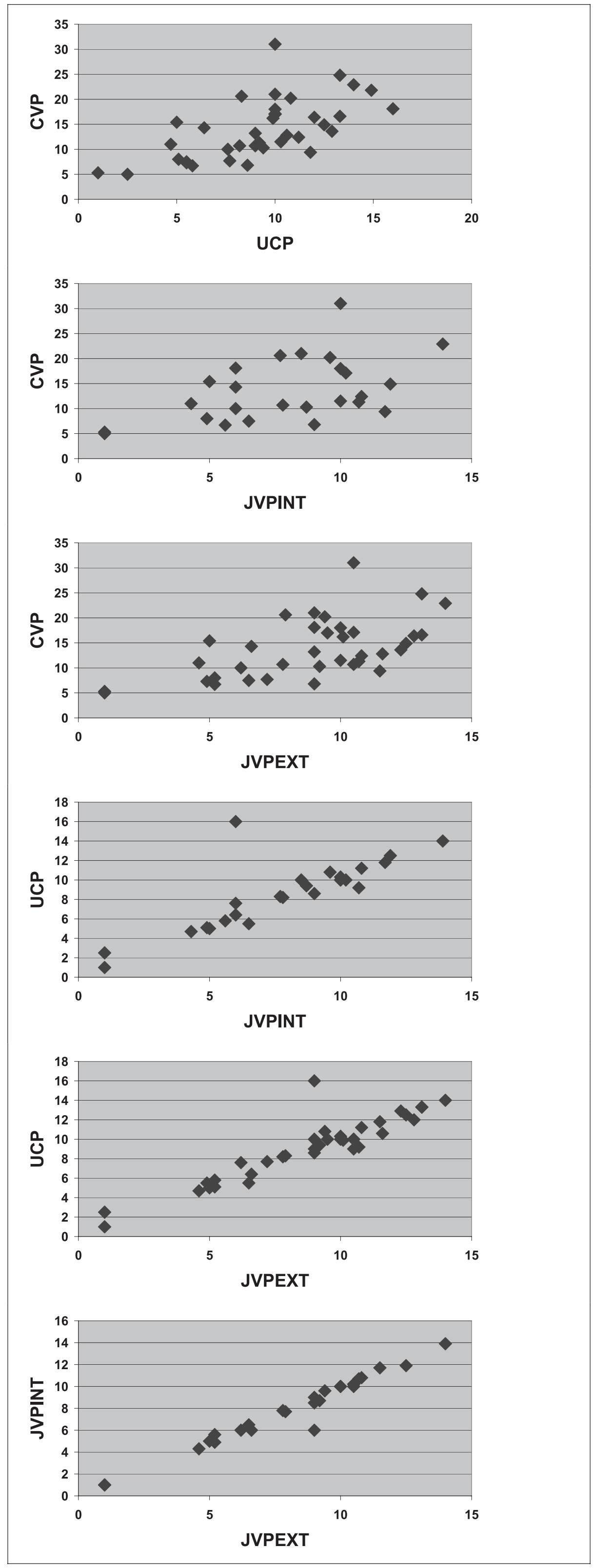

FIGURE 2. The correlation between CVP and UCP, CVP and JVPINT, CVP and JVPEXT, UCP and JVPINT, UCP and JVPEXT, and JVPINT and JVPEXT. CVP = central venous pressure; JVPEXT = external jugular venous pressure; JVPINT = internal jugular venous pressure; UCP = ultrasound collapse pressure.

Table 2—*Values for CVP, Ultrasound Collapse Pressure, Internal Jugular Venous Pressure, and External Jugular Venous Pressure*

Method of CVP Measurement	Value
Central venous catheter (CVP)	13.9 ± 5.9
Ultrasound collapse of IJV (UCP)	9.2 ± 3.3
IJV examination (JVPINT)	7.8 ± 3.2
EJV examination (JVPEXT)	8.8 ± 3.2

Values are given as mean ± SD. EJV = external jugular vein; IJV = internal jugular vein; JVPEXT = external jugular venous pressure; JVPINT = internal jugular venous pressure; UCP = ultrasound collapse pressure. See Table 1 for expansion of other abbreviation.

clinical examination. Therefore, ultrasound could replace or supplement the clinical findings when the examination is difficult or equivocal. Our findings are strengthened by a rigorous methodology to maximize the accuracy of the clinical examination.

On the other hand, all of the methods relying on detection of the collapse point of the jugular veins (UCP, JVPEXT, JVPINT) underestimated significantly the actual CVP measured invasively. We considered numerous explanations for this discrepancy between UCP (or JVP) and CVP. For example, failure to reference these independent measures to a common zero point could produce the systematic bias that we observed. However, our use of an easily identified reference (the sternal angle), combined with a strict protocol to correlate that reference point to the CVP transducer and site of ultrasound examination in the neck should reduce the likelihood of error. Alternatively, hemodynamic changes between imaging of the jugular vein and measurement of the CVP could explain different values. In this regard, we did not change body position or bed angle between measurements and allowed < 5-min interval between measurements. Yet another potential explanation relates to pressure of the ultrasound transducer on the jugular vein. If the weight of the probe were allowed to compress the vein, one would expect the collapse point to occur below the measured CVP, resembling our findings. First, however, we took care to apply only the minimum pressure required to establish ultrasonic coupling of skin and probe (and this was often applied laterally, rather than from above). Second,

Table 3—*The Correlation Coefficients of the Comparison of Different Methods of CVP Measurement*

Method of CVP Measurement	Correlation Coefficient *r*
CVP and UCP	0.62
CVP and JVPINT	0.50
CVP and JVPEXT	0.57
UCP and JVPINT	0.81
UCP and JVPEXT	0.91
JVPINT and JVPEXT	0.98

See Tables 1 and 2 for expansion of abbreviations.

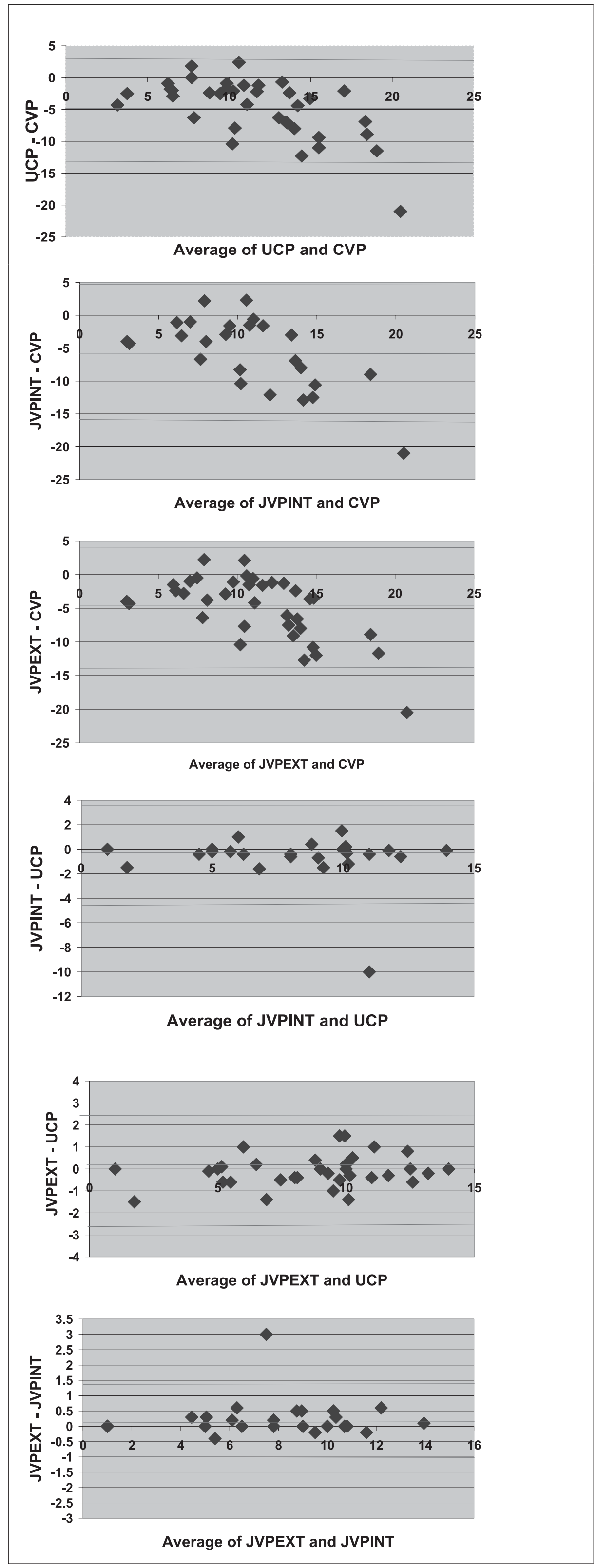

FIGURE 3. The Bland-Altman plots of the comparison between CVP and UCP, CVP and JVPINT, CVP and JVPEXT, UCP and JVPINT, UCP and JVPEXT, and JVPINT and JVPEXT. See Figure 2 legend for expansion of abbreviations.

and perhaps more convincingly, error related to probe pressure should have created a bias between UCP and JVPEXT or JVPINT as well as between UCP and CVP. As seen in Figures 2 and 3, UCP and JVP were nearly identical. In a similar fashion, if neck tissues above the internal jugular vein tended to compress the vein, JVPINT would tend to underestimate the true CVP. However, the vertical depth of the internal jugular vein averages about 1 cm and this would be insufficient to bias the JVPINT by 5 cm H_2O, because the specific gravity of neck tissues is roughly 1.0.[16,17] The precise anatomic location of the tip of the catheter should not create a bias as long as the transducer is appropriately zeroed.[18] Finally, we considered the impact of mechanical ventilation or abdominal pressure, but these should have similar impacts on both UCP and JVP. Our measuring of values at end-expiration lessens any error related to changes in juxtacardiac pressure.

If jugular veins act as passive, floppy tubes, they should collapse precisely at the level at which the atmospheric pressure just, and only just, exceeds the luminal pressure (assuming no weight of the tissues superior to the jugular vein). At this point, the transmural venous pressure just exceeds zero, producing collapse. The bias we found between UCP and CVP led us to question this fundamental assumption that jugular veins are passive. An alternative hypothesis is that the jugular venous walls are capable of exerting tone, presumably through contraction of smooth muscle in their walls. If this were true the vein would collapse at a lower extrajugular pressure than if the vein were simply passive (that is, the CVP will exceed the height of the collapse point by an amount equal to the transmural pressure produced by muscle contraction). The pressure in the lumen should exceed the extrajugular pressure by an amount related to the degree of active tension produced by the venous wall, and this could account for largely varying discrepancies in different subjects.

The discrepancy we found between JVP and CVP has been reported previously,[19-23] although this is not widely appreciated. For example, in a study comparing clinical examination of the neck veins to the invasively measured CVP, observers at all levels of training underestimated the true CVP.[20] In another study of clinical skills, examiners were asked to estimate the range of CVP (low, normal, or high) based on the neck veins. Whichever group the clinicians judged the CVP to lie in, the actual measurements tended to be higher.[21] In one large study, the external jugular venous collapse point at end-expiration was correlated with the CVP. As in our study, clinical examination tended to underestimate the invasive CVP, often by large amounts, and the discrepancy was greater at higher CVP.[19] Similar findings have been reported by others.[22,23]

Active venoconstriction has been long recognized to contribute to circulatory adaptation to exercise, postural change, hemorrhage, reduced carotid sinus pressure, hypoxia, and acceleration.[24-27] Because 85% of the blood volume resides in the veins, control of venous, rather than arterial, tone has a greater ability to control the cardiac output. This response is mediated by the autonomic nervous system and is believed to reside largely in the splanchnic veins, particularly those within the liver.[28] Nevertheless, venoconstriction has been documented in peripheral veins[29-30] and in the superior vena cava[31] in animal models. Thus we believe that veins have the potential to produce active wall tension in a way that could explain our findings. The degree to which the jugular vein or other large central veins can constrict in humans is unknown.

In summary, we found that ultrasound examination is capable of measuring accurately the JVP as judged from the internal or external jugular vein, even when the physical examination is difficult. However, like the JVP, ultrasound typically underestimates the CVP. Discrepancies are sometimes quite large, especially at high CVP, suggesting that measuring the ultrasound collapse point (or the JVP) should not be assumed to reflect the true CVP. The excellent correlation and small bias at low CVP suggests that the UCP may be clinically useful in this setting.

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Author contributions: Dr Schmidt had full access to the data and takes responsibility for the integrity of the data analysis.

Dr Deol: contributed to data collection and contribution to manuscript writing, analysis and interpretation of data, and revision of the manuscript.

Dr Collett: contributed to study design and participated in data collection.

Dr Ashby: contributed to data collection.

Dr Schmidt: contributed to study conception and design, supervision of research, analysis and interpretation of data, drafting and critical revision of the manuscript for intellectual content, and statistical analysis.

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