Measurement of Femoral Vein Diameter by Ultrasound to Estimate Central Venous Pressure

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Abstract

Rationale: Central venous pressure (CVP) can be estimated by ultrasound of the inferior vena cava (IVC), but imaging the IVC is sometimes challenging. The femoral vein is easily imaged by ultrasound and might therefore provide an alternate target for estimating CVP.

Objectives: To assess femoral vein diameter (FVD) measured by ultrasound imaging for estimating CVP.

Methods: We prospectively measured CVP and FVD in 97 patients. Receiver operating characteristic curves were used to assess the ability of FVD to predict specific CVP values: less than 10 mm Hg, less than 8 mm Hg (low CVP), and greater than 12 mm Hg (high CVP). Interobserver variability of FVD measurement was assessed in 20 patients.

Measurements and Main Results: There was moderate correlation between FVD and CVP ($r = 0.66$, $P < 0.001$). FVD less than or equal to 0.8 cm was the best predictor of CVP $<$ 10 mm Hg, with an area under the curve (AUC) of 0.894 and a 95% confidence interval (CI) of 0.82 to 0.97. FVD less than or equal to 0.7 cm performed best for predicting low CVP (AUC = 0.97; 95% CI, 0.94–0.99) and FVD greater than or equal to 1.0 cm for high CVP (AUC = 0.80; 95% CI, 0.72–0.89). However, FVD greater than or equal to 1.2 cm had the greatest specificity (94%) for high CVP. Interobserver variability in FVD measurements was 8.3 $\pm$ 7.2%.

Conclusions: The results of this exploratory study suggest that the accuracy of FVD measured by ultrasound imaging for estimating CVP is comparable to that which has been reported for ultrasound measurement of IVC diameter. FVD may provide an alternative approach when the IVC is difficult to image. Additional studies on other cohorts of patients are warranted to validate our proposed FVD cutoff values for predicting low and high CVP.

Keywords: critical care; ultrasound; central venous pressure

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Ultrasound of the inferior vena cava (IVC) has been used to provide a noninvasive estimation of central venous pressure (CVP) (1–6). The IVC is sometimes difficult to image due to poor acoustic windows or obstructing medical devices, and it takes longer to learn how to correctly image the IVC than more superficial vessels. An alternative noninvasive method for estimating CVP that is simple, rapid, readily available, and easily mastered would be desirable.

The femoral vein is relatively superficial and anatomically predictable. Previous studies have shown a high degree of correlation between pressure within the common iliac vein and superior vena cava (7–9). The purpose of this study was to assess use of femoral vein diameter (FVD) for estimating CVP.

Methods

This was a prospective, single-center, cross-sectional study conducted between November 2012 and February 2013 in the medical intensive care unit of Hennepin County Medical Center, Minneapolis, Minnesota. Written informed consent was obtained from the patient or surrogate decision maker. The hospital's human subjects in research committee approved the study protocol.

To be eligible for study, patients had to be 18 years of age or older and have a central venous catheter in place for transducing CVP. All patients were mechanically ventilated at the time of study and without clinical evidence of active expiration or increased intraabdominal pressure. In sequential

order, the right FVD and CVP were measured with patients supine and completely flat. Ultrasounds were obtained with a SonoSite M-Turbo (SonoSite Inc., Bothell, WA) and a vascular transducer (5–10 MHz, 38-mm linear array).

The right common femoral vein was initially identified at the inguinal ligament crease using established technique (10). Scanning caudally, the great saphenous vein takeoff was identified at the anterior-medial aspect of the common femoral vein (Figure 1B). The FVD was measured as the maximal anterior-posterior dimension of the common femoral vein using the leading edge technique, just caudal to the point where the great saphenous vein was no longer visible (Figures 1C and 1D). Compression was used to confirm that the vessel was venous and to exclude the presence of a deep vein thrombus (11). Because there was no detectable cardiac or respiratory variation in FVD diameter, measurement could be made without regard to the respiratory cycle.

After zeroing the system, the CVP was obtained from a two-channel (ECG lead II and CVP) paper strip recording with the transducer at the midaxillary position. The recorded CVP value was measured at end-expiration and end-diastole.

In a subset of 20 patients, two investigators (R.J.C. and D.R.W.) measured FVD to assess interobserver variability. Each investigator was blinded to the result of the other, and the two measurements were obtained a few minutes apart.

Descriptive statistics were used to summarize patient characteristics and study measurements. Linear regression was used to assess the correlation between FVD and CVP. To assess the accuracy of FVD for predicting specific CVP values (*see below*), we constructed receiver operating characteristics (ROC) curves and calculated test characteristics including sensitivity, specificity, and positive and negative predictive values. Area under the curve (AUC) and corresponding 95% confidence interval (CI) were calculated and compared using Wilcoxon statistic as described by Hanley and McNeil (12). Parameters for standard error of area assumed a nonparametric distribution.

We examined the ability of FVD to predict three different CVP values: less than 10 mm Hg, less than 8 mm Hg, and greater than 12 mm Hg. We selected CVP less than 10 mm Hg because this cut-point value was used in an earlier study that examined several noninvasive methods for predicting CVP (6). The cut-point values of less than 8 mm Hg and greater than 12 mm Hg were used to define "low CVP" and "high CVP," respectively (13).

Results are expressed as mean ± SD. A P value of less than 0.05 was considered to indicate statistical significance. All reported P values are two-sided. All calculations were computed with the aid of SPSS v21.0 and Microsoft Excel 2013.

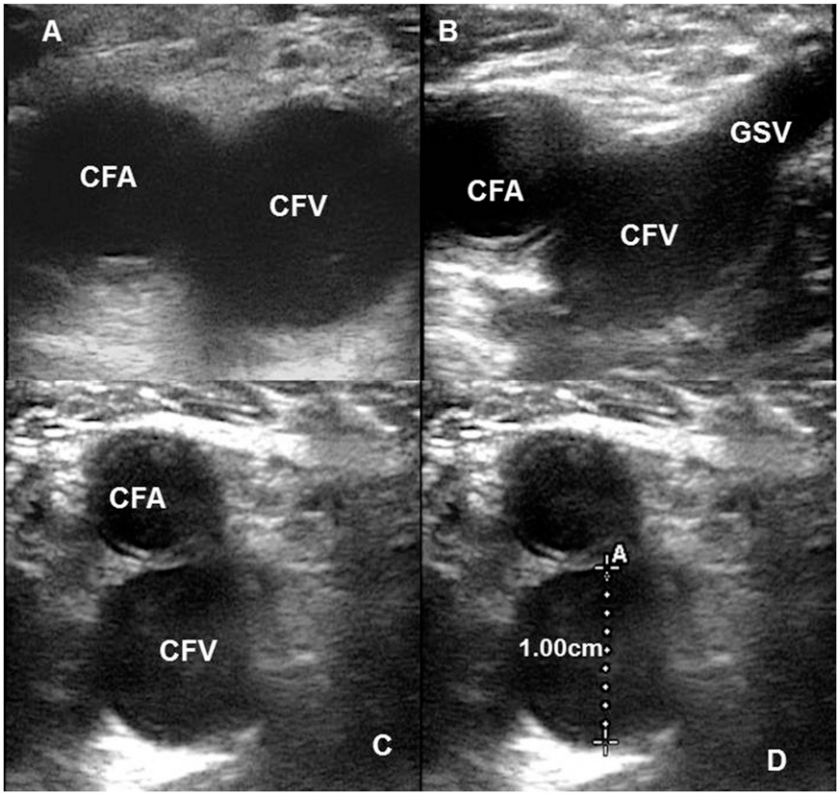

Figure 1. Ultrasound images of the right femoral vein scanning caudally from the inguinal ligament. (*A*) Transverse image of the common femoral artery (CFA) and vein (CFV) at the inguinal ligament. (*B*) Junction of the great saphenous vein (GSV) with the CFV. (*C*) CFV just distal to the point where the GSV disappeared. This is the point at which femoral vein diameter (FVD) was measured. (*D*) FVD was measured as the maximum anterior (A)-posterior dimension using the leading edge technique.

Results

We enrolled 97 patients (mean age, 59 ± 15 years; 54 men). Table 1 illustrates demographic and clinical features of the study population. With the exception of a single patient who had a peripherally inserted central catheter, CVP was measured from catheters inserted in the internal jugular vein. The FVD was obtained in all patients. The mean CVP and FVD of the 97 study patients were 10.8 ± 3.3 mm Hg and 0.94 ± 0.25 cm, respectively.

Figure 2 shows the bivariate correlation curve of FVD to CVP. Linear regression demonstrated a moderate correlation between FVD and CVP ($r = 0.66$, $P < 0.001$).

Figure 3 shows the area under the curve (AUC) for prediction of various CVP values by FVD. For prediction of CVP less than 10 mm Hg by FVD, the AUC was 0.894 (95% CI, 0.82–0.97). Best FVD cutoff values were obtained based on the generated ROC curve. FVD less than or equal to 0.8 cm had the best testing characteristic in predicting a CVP less than 10 mm Hg (sensitivity, 77%; specificity, 95%; positive predictive value, 89%; and negative predictive value, 90%).

Table 1. Demographic and clinical features

Variables	N = 97
Male sex	54 (55)
Age, yr	59 ± 15
Body mass index	29 ± 9
ICU characteristics	
MAP, mm Hg	71 ± 13
Tidal volume, ml/IBW	7.8 ± 1
F_{IO_2}	45 ± 12
PEEP, cm H_2O	5.6 ± 2
Primary diagnosis	
Septic shock	56 (60)
Congestive heart failure	12 (13)
Cardiac arrest	8 (8)
Toxic overdose	7 (7)
Gastrointestinal bleeding	4 (4)
Seizure	3 (3)
Stroke	2 (2)
COPD exacerbation	1 (1)
Diabetic ketoacidosis	2 (2)

Definition of abbreviations: COPD = chronic obstructive pulmonary disease; IBW = ideal body weight; ICU = intensive care unit; MAP = mean arterial pressure; PEEP = positive end-expiratory pressure.
Data presented as n (%) or mean ± SD.

For predicting a low CVP (<8 mm Hg), a FVD cutoff less than or equal to 0.7 cm had the highest sensitivity (95%) and specificity (89%), with AUC of 0.97 (95% CI, 0.94–0.99). For predicting a high CVP (>12 mm Hg), an FVD cutoff of greater than or equal to 1.0 cm had the best overall testing characteristics, with sensitivity and specificity of 70% and AUC of 0.80 (95% CI, 0.72–0.89). However, a FVD cutoff of greater than or equal to 1.2 cm had the highest specificity (94%) for predicting a high CVP.

Interobserver variability in measuring the FVD was examined in 20 cases. The mean FVD for the 40 measurements (20 for each investigator) was 1.11 ± 0.23 cm. The absolute mean difference in FVD measurements was 0.08 ± 0.07 cm, with an interobserver variability of 8.3 ± 7.2%.

Discussion

Several studies have reported on use of ultrasound of the IVC or internal jugular vein for estimating CVP (1–6, 14–17). A recent study from our institution found the IVC maximal diameter to be a better predictor of CVP than either IVC collapsibility index or internal jugular vein aspect ratio in spontaneously breathing patients (6). Unfortunately, performing high-quality ultrasound of the IVC is sometimes challenging because of occlusive dressings or poor acoustic windows. In addition, respirophasic movement of the IVC can occur during ultrasound imaging, potentially introducing errors in the measurements of vessel diameter and collapsibility (18). The latter pitfall may become more important in patients with prominent respiratory efforts and when imaging is done by less experienced operators.

In the current study we examined an alternative noninvasive method for estimating CVP: measurement of FVD. Previous studies that established a high degree of correlation between right atrial and common iliac venous pressures provided a rationale for this approach (7-9). We found that there was a statistically significant relationship between FVD and CVP, with a moderate degree of correlation between the two parameters.

In both our current and previous study (6), we evaluated the performance of various ultrasound techniques at predicting a CVP less than 10 mm Hg through use of ROC curves. It appears that FVD may be comparable to IVC diameter for predicting a CVP less than 10 mm Hg in that the AUC for FVD (0.89; 95% CI, 0.82–0.97) was only slightly lower than that previously reported for IVC diameter (0.91; 95% CI, 0.84–0.98) (12). In the current study, an ROC analysis showed that a FVD less than or equal to 0.7 cm was best able to predict a low CVP (<8 mm Hg). Although an FVD greater than or equal to 1.0 cm provided the best overall testing characteristics for predicting a high CVP (>12 mm Hg), a FVD greater than or equal to 1.2 cm had the highest specificity (94%).

We found a high degree of concordance between observers in measurements of the FVD. In comparison, a recent investigation reported a much higher degree of interobserver variability for measurement of IVC diameter (19).

There are a number of limitations to our study. First, our study was primarily designed to evaluate the correlation of FVD to CVP and to generate cutoff values for FVD to provide the best testing characteristics for specific CVP values; therefore, it was not prospectively corroborated. Second, our study population was biased to a high-CVP group, because patients had been resuscitated at the time of study. This could potentially introduce error in the testing characteristics of our low-CVP group, because a lower prevalence of this subset of patients could increase the number of false positives and negatives in the study population. Third, our study population

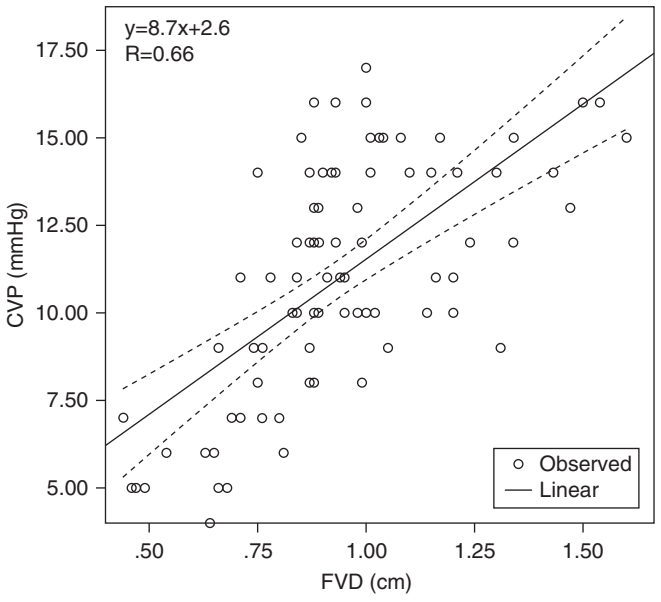

Figure 2. Correlation between femoral vein diameter (FVD) and central venous pressure (CVP).

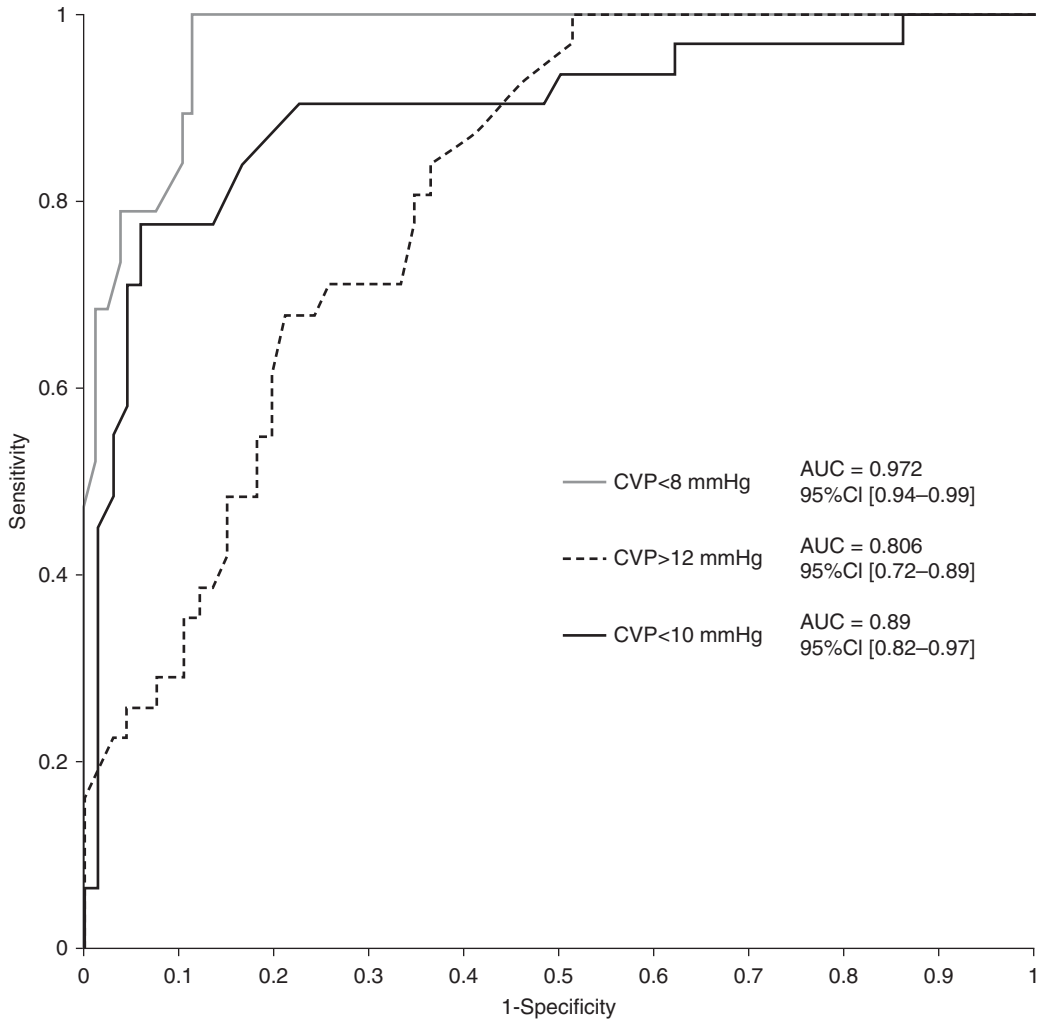

Figure 3. Receiver operating characteristic curves for prediction of various central venous pressure (CVP) values by femoral vein diameter. AUC = area under the receiver operating characteristic curve.

varied considerably with respect to age, sex, BMI, and height. These population-based characteristics may influence FVD (20) and could potentially influence the relationship between CVP and FVD. For example, the FVD threshold for low and high CVP might be different for petite women than large men. Fourth, because the FVD is greatest proximally and tapers toward the superficial femoral vein, there is potential for interobserver variability in measurement (21). The minimal interobserver variability of FVD measurements in our study is likely due to uniform use of the great saphenous vein take-off as the target for measurement, and measurements at other locations may be less reliable. Finally, we studied patients who were supine, on low levels of positive end-expiratory pressure, and without evidence for increased intraabdominal pressure. Change in body position, high-level positive end-expiratory pressure, and intraabdominal hypertension could potentially alter the relationship between FVD and CVP.

In conclusion, the results of this exploratory study suggest that the accuracy of FVD for estimating CVP is comparable to that reported for ultrasound of the IVC and could provide an alternative approach when the IVC is difficult to image. A low CVP (<8 mm Hg) is very likely when FVD is less than or equal to 0.7 cm, and a FVD greater than or equal to 1.2 cm is highly predictive of a high CVP (>12 mm Hg). FVD values between 0.7 and 1.2 cm appear to be less reliable for predicting either a low or high CVP. Additional studies on other cohorts of patients are needed to validate FVD cutoff values for low and high CVP. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

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