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VARIABILITY IN CENTRAL VENOUS PRESSURE MEASUREMENTS AND THE POTENTIAL IMPACT ON FLUID MANAGEMENT

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ABSTRACT—In the intensive care unit (ICU) of our tertiary care university medical center, central venous pressure (CVP) measurements derived from bedside monitors differ considerably from measurements by trained intensivists using paper tracings. To quantify these differences, printed CVP tracings and concurrent respiratory waveforms were collected from 100 consecutive critically ill patients along with the corresponding monitor-displayed CVP. Four blinded intensivists interpreted the tracings. The mean difference between the intensivists and the monitor was −0.26 mmHg (95% confidence interval, +7.19 to −7.71 mmHg). Seventy-six percent of the paired measurements were within 2 mmHg, whereas 7% differed by more than 5 mmHg. To determine the potential clinical impact of these differences, we used the original Surviving Sepsis Campaign Guidelines for fluid administration based upon the measurement of CVP. For individual physicians, protocol-driven fluid management strategy would have differed in 19.2% to 25.3% of cases, dependent upon which measured value was chosen. Although protocol-driven strategies to direct fluid infusion therapy may improve outcomes, these interventions in a specific patient are dependent upon the method by which the CVP is measured.

KEYWORDS—Central venous pressure, errors in measurement, fluids, hemodynamic monitoring, hemodynamics, Surviving Sepsis Campaign, volume resuscitation

INTRODUCTION

Central venous pressure (CVP) is the intravascular pressure in the great thoracic veins measured relative to atmospheric pressure. Central venous pressure monitoring has been used extensively to assess the intravascular volume status of critically ill patients. Central venous pressure may be significantly affected by changes in intrathoracic pressure, as induced by respiratory effort or ventilatory support, which can add complexity to obtaining an accurate measurement. Although several studies have questioned the use of pulmonary artery occlusion pressure or CVP as accurate representations of preload or volume responsiveness either in critically ill patients or in normal volunteers their use in the evaluation of volume status in critically ill patients remains common (1–5).

The "Surviving Sepsis Campaign Guidelines" (SSCG) (6) for severe sepsis and septic shock emphasize volume resuscitation in the initial phase of management and using CVP measurements as one of the endpoints of this resuscitation. These recommendations are based on data (7) that demonstrate reduced mortality when therapy is initiated rapidly and guided by CVP and central venous oxygen saturation. Additionally, the Fluid and Catheter Treatment trial (8) demonstrated that outcomes are similar when CVP is used to guide fluid therapy compared with pulmonary arterial catheter data in patients with acute respiratory distress syndrome. Incorporation of the results of these highly publicized clinical trials into daily standard care has resulted in increased use of CVP monitoring and titration of volume therapy to prespecified CVP goals.

Despite the widespread use of CVP monitoring, there remain questions as to the application of the measurements of CVP in the clinical environment. Anecdotal experience in our intensive care unit (ICU) has demonstrated that the monitor-derived CVP (CVP-M) values documented in the patient record by nurses frequently do not correspond to measurements of CVP by intensivist physicians (CVP-P) analyzing CVP waveforms—discrepancies that might have a significant impact on therapy. We hypothesize that the CVP value displayed on the bedside monitor will differ from the value derived by experienced intensivists from inspection of CVP waveforms and simultaneous respiratory waveforms. We further hypothesize that these differences would have a significant impact on clinically used fluid management strategies designed to achieve prespecified CVP goals such as the SSCG.

MATERIALS AND METHODS

Patient selection

The study population consisted of 100 consecutive patients (between June 2006 and August 2006) in our medical and surgical ICUs who had CVP catheters in place and in whom CVP values were being recorded. The purpose of this study was to compare CVP values between the monitor-derived measurements and those measured by physicians using printed tracings; therefore, every patient with CVP values being documented on the ICU patient record was included for evaluation, regardless of the patient's diagnosis, frequency of CVP recording, presence or absence of mechanical ventilation, or how the CVP values were being used to guide therapy. Only patients with CVP catheters inserted via the subclavian or internal jugular veins were studied. All patients were at least 18 years old. Patients were excluded if CVP was measured through a port in a pulmonary arterial catheter. The study design was approved by the institutional review board at Wake Forest University School of Medicine. Signed informed consent was not required for this observational study.

Patient data

Demographic data are displayed in Table 1 and were limited to age, sex, the admitting service for the patient (surgical or medical), whether or not the

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Table 1. **Demographic information from 100 patients' CVP measurements**

Patient age, mean (range)	58.7 (23–82) years
Sex	50% male
Service	
Medical, %	49
Surgical, %	51
Mechanical ventilation (yes), %	69
Goals for CVP identified (yes), %	18

patient was on mechanical ventilation at the time of measurements, and whether or not the patient's orders contained instructions to alter therapy (including contacting a member of the treating team) based upon the value of the CVP being measured. No information was obtained as to why CVP was being monitored.

CVP measurements

Our ICU uses bedside hemodynamic monitors from Philips (IntelliVue Patient Monitor MP 70) that use a proprietary software algorithm using modified exponential filter equations to allow different weights for each beat. The monitor displays a respiratory waveform reflecting changes in thoracic impedance measured between two electrocardiographic electrodes on the patient's chest. Using the thoracic impedance, these monitors can define the respiratory cycle and respiratory rate. The software algorithm uses a "constant weight exponential filter" to better identify pressure measurements that occur at the end of the respiratory cycle (i.e., end-exhalation). The waveform is sampled every 8 ms by a 10-bit A/D converter, followed by two-pole 12-Hz low-pass filter.

At the time a patient was identified, the patient's nurse was asked to record the CVP using whatever method the nurse customarily used for the CVP measurements. An initial objective was to ascertain the method by which bedside nurses measured CVP: whether printed or screen-captured waveforms were used or if the number displayed at the time of measurement on the monitor was recorded. In every instance, however, nurses used the value displayed on the monitor as their "measurement." Immediately after this, a recording of the CVP waveform and simultaneous respiratory waveform were printed from the monitor. The duration of the recordings was determined by respiratory rate because a minimum of three respiratory cycles was obtained and printed for submission to the physicians. Because this study was a comparison of the monitor-derived CVP and the measurement using waveforms recorded at the same time, we did not collect information regarding peak airway pressures or other clinical parameters.

After collecting data from 100 patients, the entire collection of printed tracings was given to four board-certified intensivists, each blinded to the monitor readings and the other physicians' measurements. Data included with the recordings contained only the patient age and the presence or absence of mechanical ventilation. No other clinical data were given to the intensivists. The intensivists' previous residency training was based on internal medicine and/or anesthesiology and included fellowships in pulmonary medicine, cardiac anesthesiology, cardiology, and critical care. The average duration of faculty status (post-training) was 17.2 years (range, 3–26 years). The intensivists were not given any specific training or reeducation concerning CVP measurements; however, each was asked to describe the methods they used to determine the CVP-P.

The CVP-P and CVP-M values were divided into three strata based on the clinical perspective of volume resuscitation (less than 8, 8 to 12, and greater than 12 mmHg). These values were chosen because of their clinical use in the SSCG, with the goal level for volume resuscitation being a CVP of 8 to 12 mmHg.

Statistical methods

All analyses were conducted using SPSS 13.0 (SPSS, Inc., Chicago, Ill). Three distinct analysis goals were established *a priori* for this study. First was to compare measurement agreement by determining how frequently two different physicians measured the CVP within ±2 mmHg of each other and also to determine how frequently each CVP-P was within ±2 mmHg of the CVP-M. The ±2-mmHg value has been used previously as a definition of "accuracy" for CVP measurements (9, 10). This measurement agreement was assessed using Cohen κ and total percentage agreement. Kappa is a commonly used method to assess inter-rater agreement that adjusts for chance agreement (i.e., that the two raters agreed by chance alone). Bland-Altman plots were used to graphically examine patterns of discrepancy in raw scores between measuring systems (11).

The second phase of the analysis was designed to determine the stratification agreement or how often each CVP-P placed the value in the same stratum of volume status as the CVP-M: less than 8, 8 to 12, and greater than 12 mmHg. This was determined for each individual physician measurement and for the median value of the physicians' measurements. Finally, analysis was done to determine how frequently the choice of subsequent clinical care would be altered by the method of measuring CVP based on SSCG for CVP (increase, maintain, or limit fluid administration). This analysis included the frequency each individual physician would alter the fluid administration strategy defined by the monitor-derived reading (i.e., considering the physician as the criterion standard) and the frequency that the monitor would change physician-directed therapy (considering the monitor as the criterion standard). Descriptive statistics are presented as frequencies (n) of occurrence, and inference testing was two-tailed, with significance interpreted at $P < 0.05$.

RESULTS

The patients enrolled in the study were an equal mix of medical and surgical ICU patients, with most being mechanically ventilated, and most having no specific goals for CVP measurements directed in the physician's orders (Table 1). Only 3 of the 100 patients had orders to adjust fluid administration based on the CVP, and only 3 others had orders to contact physicians for values outside a specified range. Of the 100 CVP tracings obtained, 1 was deemed "uninterpretable" by each of the four intensivists and was discarded from all subsequent analyses. Thus, the statistics shown are for the remaining 99 CVP measurements.

Physician method of CVP measurements

The printed recordings given to the physicians consisted of the respiratory and the CVP waveforms over at least three full respiratory cycles. The mean duration of the recordings was 8.15 s (range, 4.4–15 s). To better replicate current clinical practice and to minimize the introduction of bias into the assessment of interphysician variability in CVP measurements, no pretest instructions were provided on how to interpret the CVP waveforms. After completion of the readings by all four physicians, they were asked to describe the method they used. Independently, each of the four physicians described similar methods to measure the CVP-P. To measure the CVP, the physicians chose a representative waveform of the CVP tracing that occurred at the end of exhalation, or at the completion of the respiratory cycle, thus reducing the impact different modes of mechanical ventilation might have on CVP. Using that waveform, the physicians determined the A, C, and V waves, and measured the CVP value as the pressure that was present

Table 2. **Measurement agreement between physicians and the monitor-derived CVP**

Rater	Physician 1	Physician 2	Physician 3	Physician 4	Physician median
Physician 1	—	—	—	—	—
Physician 2	78.6	—	—	—	—
Physician 3	62.2	68.7	—	—	—
Physician 4	70.4	84.9	70.7	—	—
Physician median	78.8	91.9	76.8	88.9	—
Bedside monitor	62.6	77.8	67.7	67.7	76.0

Values represent the percentage of times the paired measurements were within ±2 mmHg.

immediately after the A wave, which theoretically represents the filling pressure for the ventricle. Once this waveform was identified, the value the physicians chose as the CVP was the pressure at the point in the curve between the A wave (atrial contraction) and the C wave (valve closure).

Measurement agreement

Average agreement (±2 mmHg) for all paired comparisons between physicians was 76.1% (SD, 11.1%; Table 2). Bland-Altman plots were used to compare the different determination methods for CVP values. Figure 1A displays the difference between the CVP-M and CVP-P versus the average of the physician and monitor readings aggregated for all physicians. Average measurement agreement between each physician and the CVP-M was 69.0% (SD, 6.4%; range, 62.6%–77.8%), as demonstrated in Table 2. The mean bias (mean difference) across all four physicians was −0.26 mmHg (SD, 1.1 mmHg), and the precision (1.96 × SD) is +7.19 to −7.71 mmHg. Figure 1B compares the difference between the CVP-M with the median of CVP-P. Using this median value for CVP-P resulted in a bias of −0.41 mmHg, and the precision (1.96 × SD) is +4.39 to −5.21 mmHg.

Stratification agreement

Table 3 demonstrates the level of agreement between the CVP-P and CVP-M relative to the stratifications of CVP (<8, 8–12, and >12 mmHg). Using the Cohen analysis, the median CVP-P placed patients into the same stratum of resuscitation as the CVP-M reading 83% of the time ($\kappa = 0.74$; $P < 0.001$), although each individual intensivist agreed with the monitor classification less frequently (range, 74.7%–80.8%). The percentages of stratification agreement between physician and monitor were highest in the patients who were stratified into the less-than 8-mmHg group (93% agreement) and the greater-than 12-mmHg group (88% agreement). The lowest percentage of agreement between physicians and monitor was in patients stratified into the 8- to 12-mmHg group, where agreement was 65.5%.

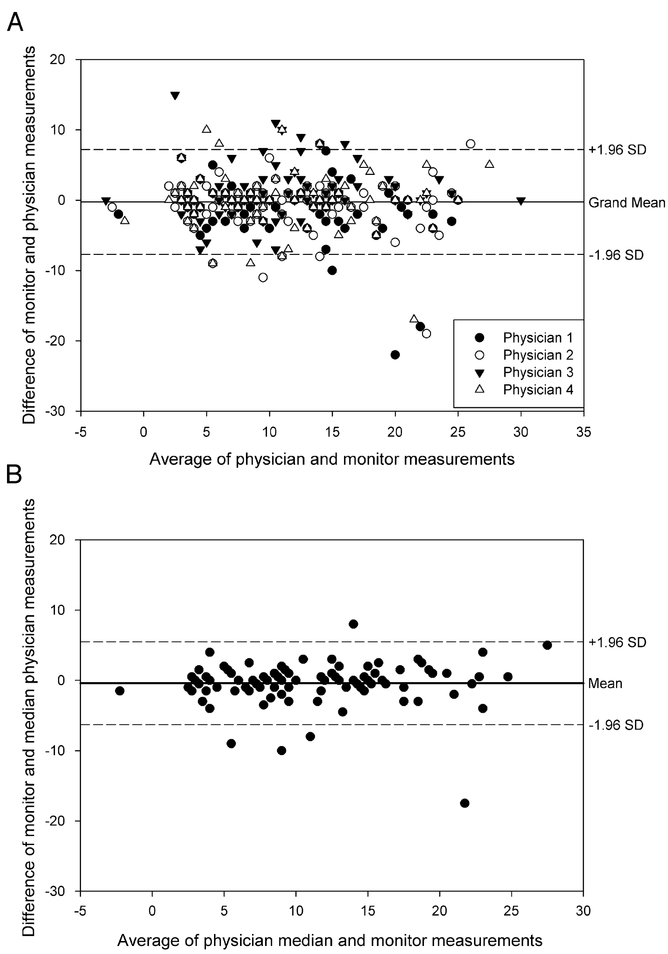

FIG. 1. Comparison of CVP-M and CVP-P.

TABLE 3. **Percentage agreement for classification of volume resuscitation (CVP) between physician and bedside monitor**

	Agreement by CVP stratification, %			Overall agreement	
Rater	<8 mmHg	8–12 mmHg	>12 mmHg	%	κ
Physician 1	92.0	57.1	82.6	77.8	0.66
Physician 2	89.3	63.3	87.8	80.8	0.71
Physician 3	80.0	55.6	92.9	74.7	0.63
Physician 4	84.8	60.7	86.8	78.8	0.68
Physician median	93.0	65.5	88.0	83.0	0.74

Clinical implications

Many protocols for fluid resuscitation are based on CVP measurements. Table 4 shows the frequency that therapy would be altered depending on whether the CVP-M or the CVP-P was used to direct therapy. Even when the median intensivists' CVP-P is used, therapy would have changed in 17 of the patients. However, in clinical practice, obtaining a median value of several physician measurements could rarely be used, and individual physicians would have altered the monitor-directed fluid strategy between 19 and 25 times in our 99 patients. The specific changes (increase, maintain, or

TABLE 4. **Clinical implications of CVP measurements**

	Monitor would change physician action (monitor as criterion standard)			Physician would change monitor action (physician as criterion standard)		
Rater	Increase fluids, n	Maintain fluids, n	Limit fluids, n	Increase fluids, n	Maintain fluids, n	Limit fluids, n
Physician 1	2	12	8	11	8	3
Physician 2	3	11	5	9	5	5
Physician 3	7	16	2	6	4	15
Physician 4	5	11	5	6	7	8
Physician median	2	10	5	6	5	6

Data demonstrate the number of times the fluid management strategy would be altered depending upon which method of measurement is used as the criterion standard.
Columns 2 to 4 show the number of times that using the monitor as the criterion standard would alter the fluid resuscitation goals that were based upon the physician's measurement of CVP. Columns 5 to 7 show the number of times that using physicians' measurement of CVP would alter the fluid resuscitation strategy that was based upon the monitor measurement of CVP.

limit fluids) depended upon whether the physician(s) or the monitor value is considered the criterion standard.

DISCUSSION

We have demonstrated considerable imprecision in the estimation of CVP values between physician measurement using tracings of the CVP and respiratory waveforms, and those obtained using the bedside hemodynamic monitor. Although the bias of individual physicians and the physician median was less than 1 mmHg, the precision of agreement was more than ±7 mmHg for individual physicians and nearly ±5 mmHg when median values are compared with the monitor-derived values. The interphysician agreement was 76.1% in our study. This is similar to that reported by Rizvi et al. (10), who found an interobserver agreement of 86% within ±2 mmHg. Overall, there was an 83% concordance between CVP-P and CVP-M in placing patients into the same category of CVP groups (<8, 8–12, >12 mmHg). When physicians were compared individually, the disagreement ranged from 19% to 26%. Thus, the categorization of patients into one of the three early goal-directed therapy groups would have been altered in more than 20% of patients depending upon the method of CVP measurement (Table 3).

Despite criticisms of the use of CVP measurements (3, 5, 12), it is among the simplest procedures available to guide fluid management at the bedside and has been incorporated into therapeutic guidelines (6). Rivers et al. (7) demonstrated that protocolized therapy for emergency department patients with severe sepsis or septic shock who were rapidly volume resuscitated to a CVP between 8 and 12 mmHg significantly reduced in-hospital and 28-day mortality. Although this was a single-center trial that may have reduced the variability in interpretation of CVP values, our medical center and many others have adopted early goal-directed therapy as a mainstay of care for septic patients.

The biggest limitation of our study is that there is no criterion standard for the measurement of CVP. Although this random sampling of consecutive patients in our ICU did not select only septic patients being treated to a goal CVP, our study clearly shows that goal-directed fluid resuscitation could vary depending on what is considered as the criterion standard. The differences become larger when individual physician readings, as opposed to group mean values, are considered—the common bedside situation. All four physicians who read the tracings for the current study, however, were trained at the same institution, which may lead to similar biases in the method of interpretation and may have minimized interphysician variability. In addition, the monitor-derived readings were obtained and documented in the flow sheet by the nursing staff, and we did not examine either their training or their protocol for documentation. The aim was to replicate clinical decision making at the bedside.

Central venous pressure–guided, goal-directed therapy has been most widely advocated in the treatment of septic shock; however, very few of our patients were septic at the time of their CVP measurements. It seems unlikely, though, that differences between the monitor and the physicians' CVP values would decrease in a subgroup of septic patients. Another limitation of the current study is that all of our patients who were receiving mechanical ventilation had CVP measured on positive end-expiratory pressure (PEEP). In all but two of these cases, the PEEP was set at 5 cmH_2O and was set at 7 and 8 cmH_2O in the other two cases, respectively. Because PEEP was less than 10 cm H_2O in all patients, it was felt that changing the PEEP for the purpose of our measurements would not influence CVP (13, 14).

CONCLUSIONS

Our results demonstrate that different methods of determination and different physicians obtaining the measurements can lead to discrepant assessment of CVP. These results confirmed our hypothesis that the method of measuring CVP may result in alteration of fluid management strategies. These results do not contradict studies demonstrating that goal-directed fluid resuscitation results in increased survival in sepsis and septic shock. Rather, they suggest that interpretive variability should be a consideration in future studies that examine clinical outcomes of resuscitation strategies using specific monitored hemodynamic goals. Pending the outcome of such studies, it would seem prudent for physicians who use CVP measurements to either print or record respiratory and CVP pressure waveforms and measure the CVP at end-exhalation before using this measurement as the diagnostic discriminate point for fluid management.

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