BJA

British Journal of Anaesthesia, 118 (2): 223–31 (2017)

doi: 10.1093/bja/aew386
Neurosciences and Neuroanesthesia

Comparison of different techniques of central venous pressure measurement in mechanically ventilated critically ill patients

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Abstract

Background. Several techniques exist for measuring central venous pressure (CVP) but little information is available about the accuracy of each method. The aim of this study was to compare different methods of CVP measurements in mechanically ventilated patients.

Methods. CVP was measured in mechanically ventilated patients without spontaneous breathing using four different techniques: 1) end expiratory CVP measurement at the base of the" c" wave ($CVP_{MEASURED}$), chosen as the reference method; 2) CVP measurement from the monitor averaging CVP over the cardiac and respiratory cycles ($CVP_{MONITOR}$); 3) CVP measurement after a transient withdrawing of mechanical ventilation (CVP_{NADIR}); 4) CVP measurement corrected for the transmitted respiratory pressure induced by intrinsic PEEP (calculated CVP: $CVP_{CALCULATED}$). Bias, precision, limits of agreement, and proportions of outliers (difference > 2 mm Hg) were determined.

Results. Among 61 included patients, 103 CVP assessments were performed. $CVP_{MONITOR}$ bias [−0.87 (1.06) mm Hg] was significantly different from those of $CVP_{CALCULATED}$ [1.42 (1.07), $P < 0.001$ and CVP_{NADIR} (1.04 (1.29), $P < 0.001$]. The limits of agreement of $CVP_{MONITOR}$ [−2.96 to 1.21 mm Hg] were not significantly different to those of CVP_{NADIR} (−1.49 to 3.57 mm Hg, $P = 0.39$) and $CVP_{CALCULATED}$ (−0.68 to 3.53 mm Hg, $P = 0.31$). The proportion of outliers was not significantly different between $CVP_{MONITOR}$ (n = 5, 5%) and CVP_{NADIR} (n = 9, 9%, $P = 0.27$) but was greater with $CVP_{CALCULATED}$ (n = 16, 15%, $P = 0.01$).

Conclusions. In mechanically ventilated patients, $CVP_{MONITOR}$ is a reliable method for assessing $CVP_{MEASURED}$. Taking into account transmitted respiratory pressures, $CVP_{CALCULATED}$ had a higher proportion of outliers and precision than CVP_{NADIR}.

Key words: central venous pressure; measurement

Editorial decision September 27, 2016; **accepted:** October 22, 2016

Editor's key points

- This study compared four ways of measuring central venous pressure in 61 mechanically ventilated ICU patients.
- CVP averaged over several cardiac and respiratory cycles and displayed automatically was closest to direct end-expiratory measurements.
- This suggests that monitor-displayed CVP measurements are sufficient for use in clinical practice.

Central venous pressure (CVP) measurement remains widely used in the intensive care unit (ICU), especially for guiding fluid management in patients with haemodynamic instability.[1–3] As it represents the pressure in the right atrium and ventricle at the end of diastole, it is assumed that CVP reflects right ventricular preload and the backpressure to venous return. Because CVP depends on ventricular compliance and cardiopulmonary interactions, measurement technique is important:[4,5] 1) CVP must be measured in comparison to an arbitrary reference level usually defined as the midpoint of the right atrium and commonly assessed at the mid thoracic position at the level of the fifth rib (Fig. 1); 2) for an optimal assessment of the right atrial pressure at the end of the diastole, CVP should be measured at the base of the "c" wave, which corresponds to the impact of isometric ventricular contraction on right atrial pressure and to the Q wave of the ECG (Fig. 1);[5] 3) to reflect cardiac preload, CVP should be measured at end expiratory time (i.e. when the influence of intra-thoracic pressures surrounding cardiac cavity is minimal). However, even in these conditions, it might be argued that the CVP measured ($CVP_{MEASURED}$) at the end of the diastole, does not reflect the trans-mural pressure related to PEEP. This is of particular importance when high PEEP levels are applied or when intrinsic PEEP levels are created in patients with severe chronic obstructive pulmonary disease with pulmonary hyperinflation. Under these conditions, as reported by Teboul and colleagues[6] CVP could be measured after a transient airway disconnection, called CVP nadir (CVP_{NADIR}) in order to estimate transmural CVP. The measurement of CVP integrating the influence of the respiratory driving pressure (difference between plateau pressure and the intrinsic positive expiratory pressure ($P_{Plat} - PEEP_i$)) called CVP calculated, ($CVP_{CALCULATED}$) is another method to measure transmural CVP. Lastly, the mean reported by modern monitors, (called $CVP_{MONITOR}$), averaging CVP over several cardiac and respiratory cycles, could be considered as a reliable estimate of backpressure to venous return.

In daily practice, all these CVP measurements are associated with potential pitfalls,[5,7] and no previous study has compared their respective accuracy. Therefore, assessing the systematic error associated with these different methods could be of particular interest.[8,9] A high systematic bias with a narrow limit of agreement could be more useful for clinical decision-making than a small bias with a large limit of agreement.[9] Therefore, the aim of the present study was to compare the bias, limit of agreement, and proportion of outliers of several CVP measurements ($CVP_{MONITOR}$, $CVP_{CALCULATED}$, and CVP_{NADIR}) to the reference technique $CVP_{MEASURED}$, in mechanically ventilated patients.[5]

Methods

This prospective study was conducted from November 2013 to April 2014 in a 16-bed ICU of an academic hospital. Because this study was observational and did not change the daily practice, the Institutional Review Board of Nimes University Hospital approved the study and allowed a waiver of informed consent (IRB # 14/05.03). However, the patient next-of-kin was verbally informed and could refuse patient participation. Moreover, the patient, if awake, could opt-out of the study at any time during the study period.

Participants

We included mechanically ventilated patients without spontaneous breaths (recommended tidal volume = 6–8 ml kg^{-1} ideal body weight, monitoring of plateau pressure < 30 cm H_2O, respiratory rate in order to avoid respiratory acidosis with pH < 7.20, inspiratory/expiratory ratio = 1/2) without cardiac arrhythmias and without known or suspected tricuspid regurgitation and in whom a central venous catheter was inserted via subclavian or jugular internal vein approaches as part of their usual care.[10,11] The tip of the central venous catheter was checked to be in superior vena cava or right atria (standard of care), at the level of carina on a chest radiography.[12] In such patients, CVP monitoring is routinely prescribed every 6 h by the medical staff. After checking the absence of spontaneous breathing of the patient on the screen of the ventilator, CVP was carefully measured by the physician or by a trained nurse under the control of medical staff when necessary. Patients were not included when the CVP tracing showed tricuspid regurgitation (regurgitation on CVP tracing impeding the "x" wave). Finally, patients in whom a transient disconnection of mechanical ventilation could lead to a de-recruitment and deleterious gas exchange impairment (baseline P_aO_2/F_iO_2 ratio < 200 and FiO2 > 50%) were not included. Measurements in patients in whom a cardiac arrhythmia occurred were not performed or excluded.

Measurement

CVP measurement was performed according to the usual practices of our ICU. The pressure measurement system was placed on the right or left arm at the level of the mid thoracic position at the level of the fifth rib (Fig. 1).[5] The zero reference was carefully checked and calibrated as required. The pressure line was connected to the monitoring system (Intellivue™, Philips, Eindhoven, The Netherlands) and was alternatively used for the measurements of arterial bp and CVP. Therefore, during CVP measurements, continuous invasive arterial bpmonitoring was transiently interrupted (< 5 min). For the present study, several CVP measurements were assessed (Figs 1 and 2):

$CVP_{MEASURED}$

Considered as the reference technique, is the measurement of CVP at the base of "c" wave at the end expiratory phase (Fig. 2C).[5] For this measurement, the research staff (physician or research nurse) froze the screen allowing the measurement of pressure at end expiratory time at the base of the "c" wave.

$CVP_{MONITOR}$

Mean CVP value displayed on the monitor after three respiratory cycles without mechanical ventilation interruption and without spontaneous breaths. The pressure measurement system is connected to the distal lumen of the central venous catheter, allowing the measurement of CVP recording the mean CVP value displayed on the screen after three respiratory cycles (Fig. 2C). For each measurement, the operator checked that any