Comparison between noninvasive measurement of central venous pressure using near infrared spectroscopy with an invasive central venous pressure monitoring in cardiac surgical Intensive Care Unit

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ABSTRACT

Introduction: Central venous pressure (CVP) measurement is essential in the management of certain clinical situations, including cardiac failure, volume overload and sepsis. CVP measurement requires catheterization of the central vein which is invasive and may lead to complications. The aim of this study was to evaluate the accuracy of measurement of CVP using a new noninvasive method based on near infrared spectroscopy (NIRS) in a group of cardiac surgical Intensive Care Unit (ICU) patients. **Methodology:** Thirty patients in cardiac surgical ICU were enrolled in the study who had an *in situ* central venous catheter (CVC). Sixty measurements were recorded in 1 h for each patient. A total of 1800 values were compared between noninvasive CVP (CVPn) obtained from Mespere VENUS 2000 CVP system and invasive CVP (CVPi) obtained from CVC. **Results:** Strong positive correlation was found between CVPi and CVPn (R = 0.9272, P < 0.0001). Linear regression equation - CVPi = 0.5404 + 0.8875 × CVPn (r^2 = 0.86, P < 0.001), Bland–Altman bias plots showed mean difference ± standard deviation and limits of agreement: −0.31 ± 1.36 and − 2.99 to + 2.37 (CVPi–CVPn). **Conclusion:** Noninvasive assessment of the CVP based on NIRS yields readings consistently close to those measured invasively. CVPn may be a clinically useful substitute for CVPi measurements with an advantage of being simple and continuous. It is a promising tool for early management of acute state wherein knowledge of CVP is helpful.

INTRODUCTION

Central venous pressure (CVP) measurement is essential for the assessment of preload and volume status[1] in perioperative management of cardiac patients and Intensive Care Unit (ICU). CVP estimation guides in the management of critically ill patients with congestive cardiac failure, cardiogenic shock, sepsis and others.[2,3] Clinical estimation of CVP may not be reliable when compared with invasive monitoring of CVP using a catheter in superior vena cava (SVC) and right atrium (RA) junction through an internal jugular vein (IJV) or subclavian vein (SCV) approach.[4] Invasive

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placement of CVP catheter is time-consuming and complications associated with it are not uncommon.[5] Hence, a quick and reliable tool for measuring CVP without central venous access might be helpful.

Previous studies have reported the use of noninvasive and minimally invasive methods to assess CVP. However, noninvasive methods lack the accuracy and precision for routine use, and minimal invasive techniques which include cannulating peripheral limb veins, external jugular vein (EJV) have shown mixed results when compared with invasive CVP (CVPi).[6-15]

In the present era of ultrafast tracking in cardiac surgery, there is a need for a reliable noninvasive CVP (CVPn) monitor mostly in high dependency units where the patients are without *in situ* CVPi catheters. Hence, the purpose of this study was to evaluate the correlation, accuracy, and agreement for measuring CVP using a new noninvasive method-Mespere VENUS 2000 CVP system based on near-infrared spectroscopy (NIRS) in a group of cardiac surgical ICU patients.

METHODOLOGY

After obtaining Institutional Ethics Committee clearance thirty patients who were admitted to postoperative cardiac surgical ICU were enrolled in the study. Informed consent was obtained from these patients before the procedure in postoperative cardiac surgical ICU. Inclusion criteria were patients above 18 years of age who had an indwelling central venous catheter (CVC) placed either in IJV or SCV, during the perioperative period of cardiac surgery. Exclusion criteria were low cardiac output patients, allergic to medical grade adhesive tape and EJV thrombosis.

CVC was placed in each patient after induction of anesthesia into either IJV or SCV (CVPi), which was used for continuous monitoring during perioperative period. CVC was connected to a transducer that was calibrated at the level of the patient's RA. The tubing and transducer were inspected to ensure that there were no technical issues or air bubbles that could cause erroneous recordings.

Mespere VENUS 2000 CVP system (CVPn) consists of five components – CVP sensor, CVP sensor patch, reference patch, docking station and a display monitor [Figure 1a and b]. CVP sensor consists of light emitting diode/photodetector (LED/PD), sensor tube with a stopcock cap and connecting cables. It is to be placed
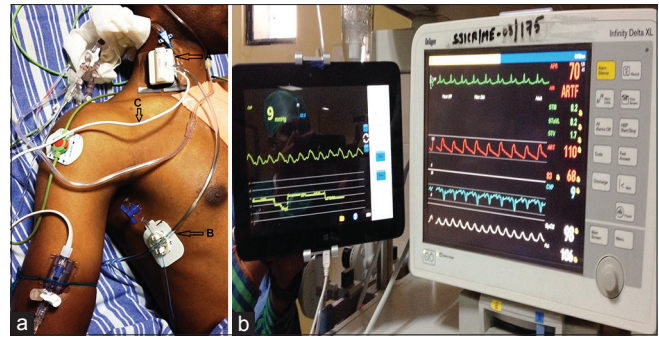

Figure 1: (a) A – Sensor, B – Reference patch and holder, sensor tube with a stopcock cap, C – Connecting cables from central venous pressure sensor to display monitor. (b) Noninvasive central venous pressure (Mespere VENUS 2000) display monitor and invasive central venous pressure display monitor

superficially on EJV with the help of sensor patch. Reference patch holder is used to connect reference patch to sensor tube of the MESPERE VENUS 2000 CVP sensor. Reference patch is placed on the reference point (zero reference), i.e., phlebostatic axis (PA) or sternal angle of Louis. PA is used to estimate the position of SVC-RA. It is commonly used as the zero reference point when using a CVP catheter which is at the intersection of the fourth intercostal space and the mid-axillary line. Docking station consists of two points required for the calibration of the CVP sensor. Display monitor shows CVP either in centimeters of H_2O or mmHg, pulse strength index (which should be >1), plethysmographic waveform and trend display area.

The MESPERE VENUS 2000 CVP sensor was placed on EJV after calibration, with the patient inclined between 15° and 30° and head slightly tilted to left. Meniscus of the liquid present in the sensor tube should be between the two clips of the reference patch holder. This reference patch holder was later stuck on to reference patch at the PA. Care to be taken to see that stopcock present at the end of sensor tube is kept open during measurement of CVP. Later, sensor was connected using cables to the display monitor. Display monitor was switched on, which displayed the CVP number and plethysmographic waveform.

Simultaneous CVP measurements were obtained from CVC placed invasively (CVPi) using Drager Infinity Delta XL monitor and from Mespere VENUS 2000 CVP system (CVPn) from thirty patients. A total of sixty values were recorded per patient over a period of 60 min. No clinical decision was made on the values obtained from CVPn.

Statistical analysis was done using MedCalc version 12.2.1.0. (Ostend, Belgium). CVPi and CVPn values

were analyzed by Pearson test of correlation (R) to determine the strength of relationship between the values. Correlation coefficient values range from negatively correlated (−1) to uncorrelated (0) to positively correlated (+1) (0.0 is no association, +0.2 is weakly positive, +0.5 is moderately positive, +0.8 is strongly positive, +1.0 is perfectly positive).

Linear regression analysis was used to calculate the regression equation between CVPi and CVPn. The coefficient of determination (r^2) is the proportion of variation in the dependent variable explained by a linear regression model using the independent variable. For all analysis, $P < 0.05$ was considered statistically significant.

Bland–Altman analysis[16] was used to find the agreement between CVPi and CVPn. The (CVPi–CVPn) difference versus the average value ([CVPi + CPVn]/2) was plotted. Means, standard deviations (SDs), and 95% prediction intervals (limits of agreement [LOA]) were evaluated. The LOA was calculated as a bias ±2 SD.

RESULTS

A total of thirty patients (22 males and 8 females) were included in the study. The average age being 43 ± 17 years (range from 18 to 73 years). Of thirty patients, three patients were postoperative closure of atrial septal defect, five aortic valve replacement, ten coronary artery bypass surgery, eight mitral valve replacement and four patients were preoperative moderate to severe tricuspid regurgitation patients with mitral valve involvement.

A total of 1800 values were analyzed (i.e., 60 values per subject). CVPi value ranged from 2 to 19 mmHg. A strong positive correlation was found between CVPi and CVPn with $R = 0.9272$ (confidence interval 0.92–0.93) and was statistically significant ($P < 0.0001$). Linear regression

equation was derived to estimate CVPi values from CVPn values, i.e. CVPi = 0.5404 + 0.8875 × CVPn ($r^2 = 0.86$, $P < 0.001$) [Figure 2a]. Bland–Altman bias plots showed mean difference ± SD and LOA: −0.31 ± 1.36 and −2.99 to + 2.37 (CVPi – CVPn). This implies that there is 95% chance of predicted CVPi value to lie within LOA of CVPn value [Figure 2b].

DISCUSSION

The principle of NIRS has been widely used in various monitoring devices during cardiac surgery such as Swan-Ganz monitoring catheter, SpO_2 plethysmograph and continuous noninvasive arterial pressure smart pod.[17] Mespere VENUS 2000 CVP system which is used in this study to monitor CVPn is also based on NIRS technology. It uses single wavelength LED and PDs to detect changes in the blood volume. It detects the jugular venous pulse (JVP) in the neck and the height of the JVP column relative to the SVC which requires that the patient lying at a proper inclination angle which aligns JVP pulse in the range of the sensor.

The CVPn could play a promising role in postoperative cardiac patients due to its ability of being reliable and real-time monitoring of CVP. This could further lead to the development of novel protocol for the treatment of patients with fluid sensitive conditions. The majority of other noninvasive measures of CVP, such as ultrasound of the inferior vena cava or the passive leg raise technique are not continuous measures, dependent on the clinician skill and are subjective. However, there are methods to monitor CVP continuously but are invasive. In this study, CVPn monitor is simple, continuous, and reproducible.

Estimation of CVP by physical examination of JVP pulse is mostly done by an experienced clinician. Certain conditions such as tricuspid regurgitation, atrial fibrillation wherein waveforms of JVP are altered could
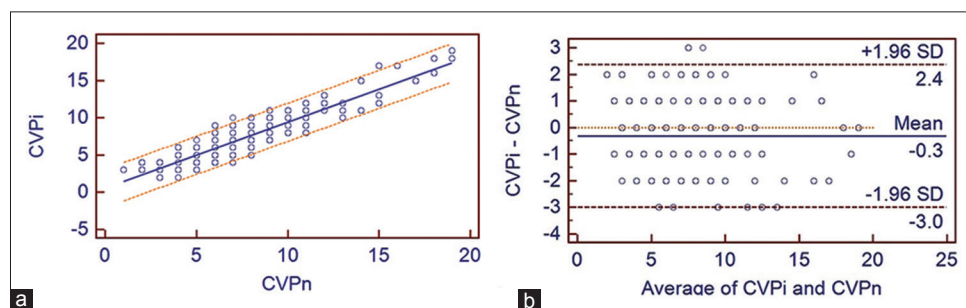
Figure 2: (a) Linear regression analysis and (b) Bland–Altman analysis between invasive central venous pressure and noninvasive central venous pressure

mislead the clinician for an accurate measurement of CVP.[18]

Recent few studies have shown good correlation between invasively measured peripheral venous pressures (PVPs) and CVP.[19-21] However, there are conflicting results exhibited between PVP and CVP.

Kumar *et al.*[22] showed poor correlation ($R = 0.092$ at baseline and $R = 0.038$ at passive leg raise) and unacceptable LOA ($-1.571–11.780$ at baseline and $-3.180–11.35$ at passive leg raise) between invasive PVP and CVP, in group of patients where CVP was <10 mmHg. Thalhammer *et al.*[14] showed acceptable correlation ($R = 0.85$) and acceptable bias (-0.7) and LOA ($-8.7–8.7$) between noninvasive PVP and CVPi measured at heart level. In the present study, mean difference and LOA were -0.31 and -2.99 to $+2.37$, respectively. Peripheral measurement might be inappropriate in patients who have inadequate visible veins or as a result of multiple venous punctures. It is also noncontinuous with possibility of observers bias when measured using sonographic technique.

Ward *et al.*[23] have studied impedance-based technique for the assessment of CVP and showed mean difference of -0.26 mmHg, LOA of $-2.7–2.2$, with correlation value of 0.95. The present study showed similar results but having an advantage of being continuous measurement.

A clinically acceptable LOA was defined as 4 cm of H_2O (or 3 mmHg) between CVP and PVP, which was comparable with the present study.[20] PVP measured at cephalic, basilic, and brachial veins had a good correlation with SVC due to low resistance to venous return.[13]

In a similar manner, EJV is in continuity with SVC and also reflects the SVC pressure.

Xing *et al.*[24] reported a new method for noninvasive quantification of CVP, where center of the RA and both cephalic, basilic and brachial veins had a good correlation. Their study showed bias of 0.22 mmHg with LOA of $-2.16–2.59$ during preoperative measurement which was comparable to the present study.

Noninvasive continuous monitoring of CVP could dictate the management strategy in HDU where invasive lines are not available. Since it adopts NIRS technology it does not require much expertise to interpret the values.

CONCLUSION

CVPn based on NIRS technology is a simple, continuous, reliable, and reproducible method to estimate CVP in postoperative cardiac surgical patients.

Conflicts of interest
There are no conflicts of interest.

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