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Research paper

Variability in alignment of central venous pressure transducer to physiologic reference point in the intensive care unit—A descriptive and correlational study☆

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ABSTRACT

Background: The phlebostatic axis is the most commonly used anatomical external reference point for central venous pressure measurements. Deviation in the central venous pressure transducer alignment from the phlebostatic axis causes inadequate pressure readings, which may affect treatment decisions for critically ill patients in intensive care units.
Aim: The primary aim of the study was to assess the variability in central venous pressure transducer levelling in the intensive care unit. We also assessed whether patient characteristics impacted on central venous pressure transducer alignment deviation.
Methods: A sample of 61 critical care nurses was recruited and asked to place a transducer at the appropriate level for central venous pressure measurement. The measurements were performed in the intensive care unit on critically ill patients in supine and Fowler's positions. The variability among the participants using eyeball levelling and a laser levelling device was calculated in both sessions and adjusted for patient characteristics.
Results: A significant variation was found among critical care nurses in the horizontal levelling of the pressure transducer placement when measuring central venous pressure in the intensive care unit. Using a laser levelling device did not reduce the deviation from the phlebostatic axis. Patient characteristics had little impact on the deviation in the measurements.
Conclusion: The anatomical external landmark for the phlebostatic axis varied between critical care nurses, as the variation in the central venous pressure transducer placement was not reduced with a laser levelling device. Standardisation of a zero-level for vascular pressures should be considered to reduce the variability in vascular pressure readings in the intensive care unit to improve patient treatment decisions. Further studies are needed to evaluate critical care nurses' knowledge and use of central venous pressure monitoring and whether assistive tools and/or routines can improve the accuracy in vascular pressure measurements in intensive care units.

1. Introduction

Intravascular pressure monitoring is an important component in the monitoring of patients with multiple organ failure to assess, anticipate, and ameliorate cardiovascular status. Central venous pressure (CVP) is an integral variable in the assessment of the cardiac function and a valuable aid in the haemodynamic management of the critically ill patient.[1] However, for the pressure measurements to be correct and thus useful, certain technical

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conditions are required. One of these is that the pressure transducer must be placed correctly. When measuring CVP, a catheter is inserted into one of the body's central veins with the tip of the catheter positioned in or adjacent to the right atrium in the caval vein. Next, the catheter is connected to a transducer, which in turn transfers an electrical signal to a monitor. The monitor shows the pressure in an analogue curve and, conventionally, an average value, but the monitor may be configured to systolic/diastolic and mean pressures. The transducer must be zeroed to ambient pressure and be vertically aligned to a physiologic reference point (levelling) on the thoracic surface. These two tasks are within the domain of the critical care nurse.[2] The critical care nurse thus has an important task as an inaccurate levelling may result in erratic assessment, which in turn could lead to the incorrect treatment. A vertical level change of simply a few centimetres can produce a large percentage change in the pressure reading, as the CVP value usually ranges between 0 and 10 mmHg, making it sensitive to any alteration or misalignment.[3] It is also important that the same reference point for levelling the CVP transducer is used throughout the intensive care unit (ICU) stay, as patient trends are as important as a precise measured value at a specific time. This is a challenge in the ICU where patients are often awake and change position in bed as part of daily care.

The reference point for CVP should be marked at the level of the physiologic zero point, which represents the location in the cardiovascular system where the CVP is changing little, if at all, during the volume shifts caused by changes in patient position.[4,5] This point is found within the geometrical area of the tricuspid valve.[5,6] The projection of the tricuspid valve on the surface of the thoracic cage is located at 40–45% of the anteroposterior (AP) diameter at the fourth intercostal space[7] (see Fig. 1). For practical reasons, the midaxillary line[8] or half the AP diameter[9] at the fourth intercostal space is often used in the ICU as the external reference point for the phlebostatic axis (PA).

Earlier studies have shown a significant variability between healthcare providers in levelling of the CVP transducer to the PA in mannequins[10–12] and children.[13] Figg and Nemergut (2009) demonstrated how the positioning of the transducer by ICU staff using a supine mannequin resulted in a variance of 3.2 mmHg (interquartile range 4.3 mmHg).[10] In 30° head up tilt, the displacement resulted in a variance of 4.8 mmHg (interquartile range 4.2 mmHg). The variation in the transducer alignment was not

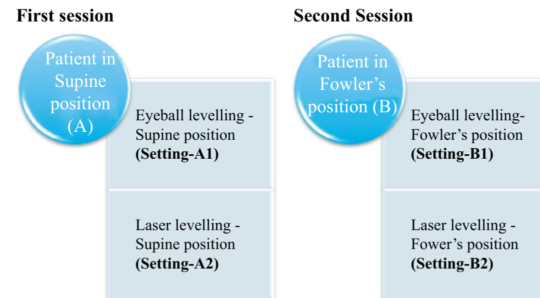

Fig. 2. Two measurement settings were done in each session. Eyeball levelling was done before the laser levelling in both sessions.

significantly reduced by the use of a laser levelling device. Recently, Avellan (2016) had similar findings in a postoperative unit using an electromagnetic 3D positioning system compared with spirit levelling.[14]

Several factors, such as the efficiency of the cardiac pump, venous return, pericardial, intra-abdominal, intra-thoracic, and pulmonary artery pressures, affect the CVP. Also, the relative distribution of the stressed and unstressed volumes and the resistances in the systemic venous and pulmonary circulation impact CVP.[15] Consequently, using CVP to monitor haemodynamically unstable patients has been debated because CVP, as a static or dynamic parameter, is a poor indicator for volume responsiveness and blood volume if used in isolation.[16] However, there are advantages in measuring CVP. For instance, an increased CVP is associated with impaired renal function and has been shown to be associated with an increased mortality in septic,[17,18] postoperative,[19] and critically ill patients.[20–22] Also, measuring CVP and keeping it low was shown to reduce bleeding during liver surgery[23,24] and probably other types of surgery where venous plexuses have been severed.[25] Based on evidence, CVP remains an important variable in the monitoring of patients in perioperative and critical care settings.[26]

The aim of the study was primarily to assess the variability in CVP transducer alignment in the ICU. Secondary, we assessed whether patient characteristics had any influence on the deviation in CVP transducer alignment.

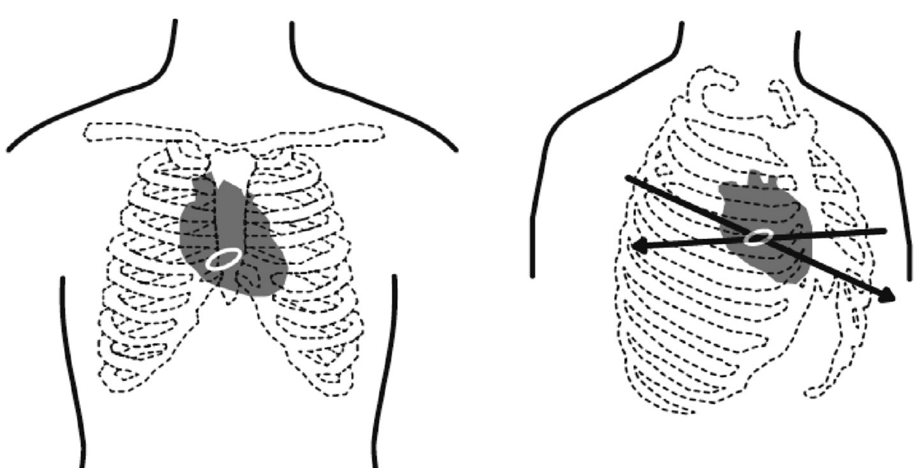

Fig. 1. Rib cage with arrows marking the external reference points of the position of the tricuspid valve. The phlebostatic axis is projected to surface anatomy in the midline and to the fourth intercostal space. Image reproduced with permission from Sondergaard et al.[7]

2. Methods

2.1. Setting and sample

The study was conducted in one intensive care department located at a university hospital in Sweden. The department had two ICUs, one specialising in general intensive care (18 beds) and the other specialising in neurological intensive care (eight beds). During 2016, the units had 2209 (general ICU) and 316 (neurological ICU) admissions. The data collection was made over a 5-month period in 2016. A convenience sample of 61 critical care nurses, familiar with CVP monitoring, was randomly recruited from the two ICUs.

2.2. Ethical considerations

Critical care nurses received written information about the study, their rights, and their freedom to withdraw at any time. All participating nurses were familiar with CVP monitoring and the use of eyeballing and laser levelling procedures. Before the measurements, written consent was obtained from the participating critical care nurses. Patient body mass index (BMI), AP diameter of the chest, and gender were registered in this study. No data were registered that could be traced back to the patients, and the study procedure did not interfere with the daily care of the patients; consequently, no written consent was obtained from the patients. The study was approved by the Regional Ethics Committee (Reg. no 706-15 2015-11).

2.3. Procedure

At first, a member of the research team identified the PA (45% of AP diameter in the 4th intercostal space) by measuring the AP diameter with a modified forest caliper (manufactured by Husqvarna, Partille Skog & Mark) in supine position. A reference pressure line was fixated to the designated PA. This assembly was hidden by a cover. The reference pressure line was zeroed to ambient pressure. The pressure transducers for the reference pressure and the CVP were mounted on the same plate and were moved to identical vertical levels. When the participants performed their levelling, the reference pressure line thus reported the deviation from zero. The monitor (Philips Intellivue MX800) was likewise hidden from view of the participants, thus blinding them to the result. Negative values were caused by levelling the transducer above the PA, and positive values were caused by levelling the transducer below the PA. The system was tested before each measurement session. See Appendix A in the supplementary material for complementary figures on the procedure.

The reference pressure and CVP transducers were placed on an intravenous pole approximately 0.5 m from the patient bed at a random vertical level. The measurements were taken in two sessions. In the first session, the participant was asked to align the CVP transducer to the perceived horizontal level for the right atrium/tricuspid valve with the patient in supine position. The participants were first asked to use eyeball levelling (Setting-A1) and after that to use a laser levelling device (Setting-A2) (Medtronic Neurosurgery). In the second session, the same procedure was done with the patient in Fowler's position (30° head up tilt) (Setting-B1 and Setting-B2, respectively). The amount the reference pressure line deviated from zero was recorded in mmHg for each measurement by a member of the research team.

The measurements were taken on 19 critically ill patients (7 women, 12 men). There were one to seven measurement sessions (mean 3.2, median 4.0) on each patient.

Patients with CVP monitoring were included in the study based on their capacity to tolerate positioning changes. Only one measurement session was performed in each nursing shift to ensure the study would not interfere with the provided care. The patients' gender, BMI, and AP diameter of the chest were recorded for the patient characteristics.

2.4. Data analysis

The SAS-procedure “mixed models” was used for the calculations because the data were normally distributed (SAS version 9.3, SAS Institute Inc., Cary, NC., USA). Mean, standard deviation, range, and interquartile range were calculated for the eyeball and laser levelling sessions.

2.4.1. Statistical methods

Deviation from the PA in settings A1, A2, B1, and B2 were the dependent variables. The patients were regarded as a random effect, and the patients' gender, BMI, and AP diameter of the chest were considered as fixed effects.

The size of the random effects was described by their standard deviations and the effects of the fixed effects with their regression coefficients. Since a participant only measured the same patient once, the variation between the participants cannot be separated from the residual. Therefore, the standard deviation for the participant includes the variation between the participants and the variation for the residuals.

3. Results

A total of 244 measurements were made by 61 critical care nurses.

The patients' BMIs ranged from 17 to 40 kg/m^2 (mean 28.1, interquartile range 8.0), and their AP diameter ranged from 16 to 29 cm (mean 22.4, interquartile range 2.0).

There was significant variation among the critical care nurses in the vertical transducer placement levelling in both sessions. The standard deviation for the transducer placement for eyeball levelling was 2.7 mmHg for the patient in the supine position and 2.9 mmHg for the patient positioned in the 30° Fowler's position (see Table 1). With a laser levelling device, the standard deviations were 2.9 mmHg in the supine position and 2.9 mmHg in the 30° Fowler's position (Table 1). Surprisingly, using the laser levelling device neither resulted in significantly different variances between sessions 1 and 2 nor reduced the variation in measurement among the participants (see Table 1).

Regression coefficients for the impact of patients' gender, BMI, and AP diameter were calculated. The patients' BMI and AP diameter were associated with greater deviation in the vertical levelling of the pressure transducer placement ($p = 0.005$, $p = 0.031$, respectively) in Setting-A1. In settings A2, B1, and B2, the BMI and AP diameter had no significant impact. The patients' gender also had no significant impact on any of the measurement settings (see Table 2).

4. Discussion

To our knowledge, this is the first study describing variabilities in CVP transducer levelling among critical care nurses in the ICU. The results show that even under optimal circumstances critical care nurses alignment of the CVP transducer proved to be inaccurate. This implies that the current equipment and expertise are not sufficient and could lead to incorrect haemodynamic assessment in critically ill patients.

Patient characteristics (gender, BMI, and AP diameter) had little impact on the variation between the measurements. The use of a

Table 1
Standard deviation, range, interquartile range, and means for variation between participants (after adjustment for patient gender, patient body mass index, and patient anteroposterior diameter).

Measurement setting	Standard deviation (mmHg)	Lower limit (mmHg)[a]	Upper limit (mmHg)[a]	Range (mmHg)	Interquartile range (mmHg)	Means (mmHg)
Setting-A1	2.7	2.2	3.5	14.0	4.0	−1.3
Setting-A2	2.9	2.4	3.6	13.0	3.0	−1.5
Setting-B1	2.9	2.4	3.8	14.0	4.0	−2.0
Setting-B2	2.9	2.3	3.7	12.0	4.0	−2.0

SD = standard deviation.
[a] 95% confidence interval for SD.

laser levelling device did not reduce the magnitude of error between measurements or participants. Thus, we suggest that interobserver variability resulted predominantly from systemic errors in transducer placement. Our results cannot determine whether the transducer placement variation was caused by different anatomical landmarks being used as external reference points for the PA among the participants or if the participants were unaware of the correct position of the external reference point for the PA. We can only infer that either the participants used different reference points or they aligned the transducer erroneously to a common reference point.

Sondergaard et al. (2015) circulated a questionnaire among members of the European Society of Intensive Care Medicine regarding knowledge and uses of CVP. They discovered that only 3.4% of the respondents correctly identified the PA at 40–50% of the AP diameter and that several different anatomical landmarks for the PA were used for the alignment of the CVP transducer, potentially explaining why we found significant variance in placement in our study.[7] The knowledge among critical care nurses regarding the CVP measurement has not, to our knowledge, been evaluated in any larger studies.

Based on our findings, we recommend standardising an external reference point for the CVP measurement to ensure comparable pressures between different users and clinics because today several reference points are being used, making it challenging to ensure proper and consistent treatment. Kovacs et al. (2014) analysed different anatomical landmarks used as the zero-level for the CVP measurements and concluded that the lack of standardisation of the current zero levelling practices may lead to differences of up to 8 mmHg in vascular pressure readings.[27] Researchers have suggested using the PA as an external reference point for all vascular pressures.[5,28] We agree, based on the current study's results, that the PA should be used as the zero-level for all vascular pressures in the supine position.

4.1. Limitations

There are several limitations in our study. First, there is a potential risk that the participants performed better than usual as they knew they were being observed and asked to measure as precisely as possible (known as the Hawthorne effect).[29] Second, the literature reports different anatomical landmarks nurses/doctors can use to measure CVP, and therefore, there may be differing preferences between clinics and among clinic staff. The anatomical landmark chosen for this study (45% of the thorax AP diameter in the fourth intercostal space) may be questioned, but based on the pre-existing literature, this PA corresponds to the level of the tricuspid valve plane and should be used as a reference level in CVP measurements.[5,7] Third, the height difference was evaluated in mmHg and may not have been able to track small height differences in the transducer placement if they were under 1 cmH_2O. However, this would not have impacted the results greatly, as it only slightly underestimated the height deviation in the transducer placements and is probably not clinically relevant. Fourth, we only evaluated the variation in transducer placement with the patients in supine and Fowler's positions. The deviation in lateral and prone position was not tested, and this should be done in future studies. Finally, the study was carried out in two ICUs; thus, the results only describe the variation in transducer placement in these ICUs and may not necessarily be generalised to other ICUs. However, our results are in line with earlier studies that have reported similar findings in mannequins,[10–12] children,[13] and adult patients in postoperative setting,[14] highlighting this may be a common issue in many settings.

Table 2
Regression coefficients for the impact patient characteristics have on the deviation from the PA in all measurement settings.

Patient characteristics	Setting-A1	Setting-A2	Setting-B1	Setting-B2
Patient gender	$p = 0.093$	$p = 0.309$	$p = 0.574$	$p = 0.809$
Patient BMI	$p = 0.005$	$p = 0.063$	$p = 0.206$	$p = 0.507$
Patient AP diameter	$p = 0.031$	$p = 0.284$	$p = 0.543$	$p = 0.945$

AP = anteroposterior; BMI = body mass index; PA = phlebostatic axis.

4.2. Future research

First, future studies need to evaluate critical care nurses' knowledge and use of CVP monitoring in the ICU to conclude whether variability in the choice of external reference points for the PA causes the variability in transducer placement.

Second, future studies need to evaluate assistive tools to identify the PA and reduce the deviation in the horizontal levelling of the vascular pressure transducers in all possible patient positions. The electromagnetic 3D positioning system may be a helpful alternative as it would be able to give correct pressure readings even when patients are in lateral positions. However, this system needs to be tested further once it is commercially available before it can be used in the critical care setting.

5. Conclusion

Assuming the participants used the customary PA, as taught in the department, their levelling of the pressure transducer toward the PA showed great variation. Standardisation of a zero level for vascular pressures should be considered to reduce the variability in vascular pressure readings in the ICU. Few techniques to identify the external reference point for the PA have been tested to improve the accuracy of vascular pressure readings. The reference technique used in this study could be used in operative and critical care setting, but it would only be able to identify the PA with the patient in supine, sitting, or prone position and not in the lateral position. Further studies are needed to evaluate critical care nurses' knowledge and use of CVP monitoring and whether assistive tools and/or routines can improve the accuracy in vascular pressure measurements in the ICU.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.aucc.2018.05.001

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