Peripheral venous pressure predicts central venous pressure poorly in pediatric patients

[La tension veineuse périphérique est un reflet imprécis de la tension veineuse centrale chez les enfants]

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Purpose: Using peripheral venous pressure (PVP) instead of central venous pressure (CVP) as a volume monitor decreases patient risks and costs, and is convenient. This study was undertaken to determine if PVP predicts CVP in pediatric patients.

Methods: With ethical approval and informed consent, 30 pediatric patients aged neonate to 12 yr requiring a central venous line were studied prospectively in a tertiary care teaching hospital. In the supine position, PVP and CVP were simultaneously transduced. Ninety-six paired recordings of CVP and PVP were made. Correlation and Bland-Altman analysis of agreement of end-expiratory measurements were performed.

Results: The mean (SD; range) CVP was 10.0 mmHg (6.0; -1.0 to 27.0); the mean PVP was 13.7 mmHg (6.3; 0.0 to 33.0); offset (bias) of PVP > CVP was 3.7 mmHg with SD 2.6. The 95% confidence intervals (CI) for the bias were 3.2 to 4.1 mmHg. In the Bland-Altman analysis, lower and upper limits of agreement (LOA; CI in parentheses) were -1.5 (-2.3 to -0.7) and 8.8 (8.1 to 9.6) mmHg. Eight of 96 points were outside the limits of agreement. The correlation of PVP on CVP was $r = 0.92$, $P < 0.0001$. For a subset of ten patients (20 simultaneous recordings) with iv catheters proximal to the hand, limits of agreement were better - offset: 3.8 mmHg (± 1.4); lower LOA: 1.2 mmHg (0.25 to 2.1); upper LOA: 6.6 mmHg (5.7 to 7.5).

Conclusion: Peripheral venous pressure measured from an iv catheter in the hand predicts CVP poorly in pediatric patients.

Objectif: La tension veineuse périphérique (TVP) est une façon pratique de remplacer la tension veineuse centrale (TVC) comme indicateur de la réplétion volémique, à moindre risque et à meilleur coût. L'objectif de cette étude était de déterminer si la TVP est un bon reflet de la TVC chez les enfants.

Méthode : Après l'approbation du comité d'éthique et l'obtention du consentement, 30 sujets de 0 à 12 ans chez qui un cathéter veineux central était indiqué ont été recrutés de façon prospective dans un hôpital universitaire de soins tertiaires. On a mesuré la TVP et la TVC simultanément en position dorsale à 96 reprises. On a réalisé des analyses de corrélation et de Bland-Altman pour les mesures télé-expiratoires.

Résultats : La TVC moyenne (ET; extrêmes) était de 10,0 mmHg (6,0; -1,0 à 27,0); la TVP était de 13,7 mmHg (6,3; 0,0 à 33,0); la TVP était de 3,7 mmHg (ET 2,6) supérieure à la TVC. Les intervalles de confiance à 95% (IC) pour cet écart (biais) étaient de 3,2 à 4,1 mmHg. Selon l'analyse Bland-Altman, les limites de concordance inférieure et supérieure (LDC ; CI entre parenthèses) étaient de -1,5 (-2,3 à -0,7) et 8,8 (8,1 à 9,6) mmHg. Huit des 96 points étaient à l'extérieur des limites de concordance. La corrélation entre PVP et TVC était $r = 0,92$, $P < 0,0001$. Dans un sous-groupe de dix patients (20 mesures paires) avec des cathéters iv plus proximaux que la main, la concordance était meilleure - biais : 3,8 mmHg ($\pm 1,4$); LDC inférieure : 1,2 mmHg (0,25 à 2,1); supérieure : 6,6 mmHg (5,7 à 7,5).

Conclusion : La tension veineuse périphérique mesurée à partir d'un cathéter installé sur la main ne reflète pas bien la TVC chez les enfants.

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CENTRAL venous pressure (CVP) is a hemodynamic variable commonly used in the operating room (OR) and intensive care setting to estimate right atrial pressure to evaluate and monitor a patient's volume status. However, risks such as infection, arterial puncture, hematoma and pneumothorax associated with central venous cannulation can outweigh its benefits.¹ The complications are further increased in pediatric patients because of the technical difficulties of vascular access related to smaller patient size. The use of peripheral venous pressure (PVP) in lieu of CVP as a perioperative volume monitor could decrease risks, costs and time associated with CVP monitoring. Correlation between PVP and CVP has already been investigated in studies of adult patients.²⁻⁸ In most of these studies, subtracting a reliably constant offset, the difference by which the PVP exceeded the CVP, provided a clinically useful estimate of CVP. The relationship of PVP to CVP has been reported in a single study of pediatric patients, age three to nine, and demonstrated good agreement between CVP and PVP.⁹ The objective of this study was to determine if pressure measured from a peripherally placed *iv* catheter (PVP) reliably predicts the CVP in pediatric patients.

Methods

With University of Saskatchewan Biomedical Research Ethics Board approval and parental informed consent, 30 pediatric patients aged newborn to 12 yr requiring a peripheral *iv* and a central venous line (CVL) either in the OR or the pediatric intensive care unit were studied prospectively. Patients were to have been excluded if patency or placement of the peripheral *iv* or CVL could not be confirmed; none were excluded for this reason.

Equipment and calibration

Central venous pressure and PVP were transduced with sterile disposable factory-calibrated pressure transducers equipped with a continuous low-flow flush at 3 mL·hr⁻¹ (Transpac IV; Abbot Laboratories, North Chicago, IL, USA) attached to a hospital monitoring system (Hewlett-Packard (HP) M1006A C01 patient-monitor interface connected to a HP M1046A preprocessor connected to a HP M1092A monitor; Hewlett-Packard, Andover, MA, USA). Pressure transduction specifications are rated at ± 0.4 mmHg error.

Analogue output (from the HP M1006A module) was digitized for off-line analysis at 250 Hz with a PCI-MIO-16XE-50 A to D card (National

Instruments, Austin, TX, USA) with 16 bit resolution, with an accuracy = ± 1.5 least significant bit (LSB ± 3 mV/5V), and noise < 1.2 LSB root mean square.

Peripheral *iv* access was established with 24, 22, or 20 G plastic catheters (BD Insyte, BD – Canada, Oakville, ON, Canada), depending on vein size. An 18 cm low-volume extension was attached to the *iv* catheter (Lifeshield Microbore Extension Set; priming volume 0.4 mL, Abbott Laboratories, Abbott Park, IL, USA). A three-way stopcock was placed between the primary line and the *iv* extension. Central lines were positioned with fluoroscopic *x-ray* guidance.

The transduction system was calibrated with a mercury-manometer blood pressure measuring instrument (model "Trimline", PyMaH Corp, Somerville, NJ, USA). The mean of two readings at each of ten mercury manometer readings from 0 to 104 mmHg were recorded and correlated. For the PVP system, $r^2 = 0.998$, with PVP by transducer offset 1.23 mmHg greater than the mercury manometer. Corresponding values for the CVP system were $r^2 = 1.00$ with CVP offset 1.90 mmHg greater than the mercury manometer. These offset values were subtracted from the recorded values for analysis.

A variety of commercially available permanent and temporary central lines was used. Natural frequency and damping coefficients of tubing/transducer systems representative of that used on patients was studied *in vitro* using a square-wave flush at 200 mmHg.^{10,11}

The patient's age, weight, height, medications, cardiorespiratory status, mode of ventilation, vital signs, as well as type, gauge and length of peripheral and central venous catheters were recorded. Patency of the peripheral *iv* line was confirmed by the presence of a free-running infusion or by easy injection of a 5 mL flush of normal saline with no evidence of pain or swelling at the insertion site. Central venous line placement was confirmed by presence of appropriate venous wave form and chest *x-ray*. With patients in the supine position, both transducers were zeroed at the phlebostatic axis (mid-axillary line, fourth intercostal space). Following a two-minute stabilization period, a minimum of two sets of simultaneous measurements of CVP and PVP were recorded at end-expiration at least five minutes apart. Twenty second digital recordings of the transduced signal were sampled.

Analysis

Sample size was determined from the calculations of Iyriboz¹² as recommended for assessing blood pressure measuring devices; using paired measures, sample-size analysis mandated 26 subjects. We recruited 30 sub-

TABLE I Demographics

Number	Age distribution	Mean (SD; range)
< 1 week	4	
1 week to < 1 yr	5	
1 year to < 5 yr	11	
5 to 12 yr	10	
Total	30	3.34 (3.0; 1 day to 12 yr)
Sex (female/male)	12/18	
Height (cm)		95.7 (32.2; 48 - 157)
Weight (kg)		16.9 (13.5; 2.6 - 62)
Heart rate		118.1 (27.7; 65 - 180)
Systolic blood pressure (mmHg)		79.7 (19.7; 43 - 120)
Diastolic blood pressure		40.2 (11.6; 20 - 70)
Ventilation (spontaneous/ positive pressure)		18/12
Intravenous site (hand/wrist/forearm)		20/8/2
Intravenous gauge (20/22/24)		7/11/12

TABLE II Frequency and damping properties of the systems

	<i>n</i>	Frequency (Hz) Mean (SD)	Damping Coefficient Mean (SD)
No extension	16	26.4 (2.3)	0.49 (0.075)
Microbore extension	16	25.5 (1.6)	0.45 (0.044)
4Fr 13cm catheter	16	24.8 (0.67)	0.65 (0.057)

jects to account for unforeseen exigencies. Linear regression, ANOVA, and paired Student's *t* tests were used to compare continuous variables. Bland-Altman analysis of agreement between methods of clinical measurements was used to test for agreement between PVP and CVP and to determine bias.¹³ This involved plotting the differences (the PVP-CVP offsets) on the y-axis against the corresponding means of simultaneous CVP and PVP measurements on the x-axis. This enabled visualization of the mean difference = bias = offset, which is the extent on average by which PVP exceeds CVP. The offsets also reflect the relationship of the PVP-CVP offsets at various CVP values. We report the absolute distance from the bias to the limits of agreement (LOA – bias), a measure of how near the bias one may expect 95% of measurements. Clinically acceptable limits of agreement depend on clinical judgment, but most clinicians would probably insist on LOA – bias < 3 mmHg. Tracking of CVP by PVP is reported as mean, SD, and numbers of measurements lying outside the mean $\pm$ 1.96 of differences of repeated PVP-CVP offsets.

FIGURE 1 Regression of peripheral venous pressure on central venous pressure, with regression line, 95% confidence interval lines (inner) for the line of regression, and (outer) for prediction of the population.

FIGURE 2 Bland-Altman plot of simultaneous peripheral venous pressure–central venous pressure offsets (y-axis) vs means (x-axis); all recordings. Heavy horizontal lines from above down: upper limits of agreement (LOA), bias, lower LOA.

Results

Demographic and clinical data are shown in Table I. Ninety-six paired readings were made on 30 subjects. Frequency and damping properties of the systems are shown in Table II. There were no significant differences between the systems used with or without the extension catheter, but the *iv* test system or catheter was different (higher frequency; lower damping coefficient; both $P < 0.05$) from that observed with a 4 Fr13 cm CVP catheter. Importantly, all three tested systems had natural frequencies and damping coeffi-

FIGURE 3 Bland-Altman plot of simultaneous peripheral venous pressure–central venous pressure offsets (y-axis) versus means (x-axis); wrist and forearm recordings. Heavy horizontal lines from above down: upper limits of agreement (LOA), bias, lower LOA.

cients well within the dynamic response requirements for acceptable fidelity.¹⁴

Regression of PVP on CVP for all measurements (Figure 1) showed the relationship:

$PVP = 0.95 \times CVP + 4.1$; with correlation coefficient $r = 0.91$ ($r^2 = 0.83$; $P < 0.001$ for model, and for both regression coefficients).

For the study as a whole, in mmHg, mean (SD; range) CVP was 10.0 (6.0; -1.0 to 27.0); PVP was 13.7 (6.3; 0.0 to 33.0); offset (bias) of PVP > CVP was 3.7 with SD 2.6. Figure 2 shows the Bland-Altman graph for analysis of agreement for all measurements; Figure 3 for ten patients with *iv* sites proximal to the hand (all were in wrist or forearm). Eight points lie outside the limits of agreement in Figure 1; one in Figure 3. Table III summarizes the analysis of agreement.

At least two sets of measurements were taken at least five minutes apart in order to assess the ability of PVP to track CVP. Differences between CVP-PVP offsets at subsequent times in the same subject are reported in Table IV. Good tracking would show means and SD near zero with 5% or fewer points lying outside ± 1.96 SD. Figure 4 shows the difference (PVP – CVP) plotted against age. Table IV shows PVP – CVP offset statistics by *iv* gauge, which did not show a difference ($P = 0.14$), although numbers are too small to declare no difference.

Discussion

While PVP correlates reasonably well with CVP, Bland-Altman analysis of agreement (Figures 2 and 3; Table III) shows that PVP is not a sufficiently reliable surrogate measure of CVP in pediatrics, and furthermore, agreement is even less when an *iv* is

TABLE III ANALYSIS OF AGREEMENT

<i>PVP-CVP offset statistic</i>	<i>All pairs</i>	<i>iv in hand</i>	<i>iv proximal</i>
<i>n</i>	96	64	32
Mean (CI)	3.7 (3.2 to 4.1)	4.1 (3.4 to 4.7)	3.2 (2.5 to 4.0)
SD	2.6	2.8	1.9
LLOA (CI)	-1.5 (-2.3 to -0.7)	-1.4 (-2.5 to -0.2)	-0.6 (-1.9 to 0.7)
ULOA (CI)	8.8 (8.1 to 9.6)	9.5 (8.4 to 10.6)	7.1 (5.8 to 8.3)
LOA – bias	5.2	5.5	3.4
Range of LOA CI	11.9	13.1	10.2
Points beyond LOA	8	4	1

PVP-CVP = peripheral venous pressure–central venous pressure; CI = confidence intervals; LLOA = lower limits of agreement; ULOA = upper limits of agreement; LOA – bias = bias to the limits of agreement.

TABLE IV ANALYSIS OF TRACKING AGREEMENT

<i>PVP-CVP offset Statistic</i>	<i>All pairs</i>	<i>iv in hand</i>	<i>iv proximal</i>
Number of pairs	67	44	23
Mean offset difference	0.4	0.8	-0.2
SD of offset difference	2.1	1.8	2.4
LOA – bias	4.0	3.5	4.7
Points beyond LOA	8	3	1

PVP-CVP = peripheral venous pressure–central venous pressure; LOA = limits of agreement.

FIGURE 4 Plot of peripheral venous pressure–central venous pressure (y-axis) *vs* age in years (x-axis).

TABLE V PVP–CVP offset by *iv* size

Intravenous size	<i>n</i>	Mean	(SD)
20	14	3.9	(2.2)
22	22	5.3	(1.9)
24	24	4.6	(2.3)

inserted in the hand. It has been reported that *iv* site does not affect agreement in adults.⁶ Considering data from all our measurements, confidence intervals (CI) for the bias provides an acceptable offset which one may subtract from PVP to obtain the estimated CVP. However, the limits of agreement have a fairly wide range (10.3 mmHg), and if extrapolated to the 95% CI outer limits, extending from 2.3 to 9.6 mmHg, a range of 11.9 mmHg is generated, with LOA – bias = 5.2. This is clearly not useful in estimating CVP from PVP. The number of patients we evaluated with an *iv* inserted proximal to the hand was insufficient to determine the value of PVP as a surrogate for CVP, but the data suggest (LOA – bias = 3.4) that further study with larger numbers is warranted. Many practitioners use CVP mainly as a device for tracking volume trends; LOAs (Table IV) are not acceptable clinically for tracking. There is no clear influence of age on PVP–CVP offset (Figure 4). Intravenous size over a range of 20 to 24 G does not appear to influence PVP – CVP differences (Table V).

Our data do not support the use of routine PVP monitoring from *iv* catheters in the hand as a clinically reliable alternative to CVP monitoring in the pediatric age group. Our results differ from those of Anter *et al.* who studied 50 patients age three to nine years, recording measurements at random times throughout the respiratory cycle in ventilated and spontaneously breathing subjects.⁹ In this study, biases were 1.9 and 2.5 mmHg in spontaneously breathing and mechanically ventilated patients, with LOA – bias = 0.93 and 1.12 mmHg, respectively. While hand, forearm, and antecubital *iv* sites were used, all *iv* catheters were 22 G or greater. In addition, Anter *et al.* ensured continuity of the PVP catheter with the downstream venous system by observing coincident venous pressure changes in the PVP waveform during circumferential proximal arm occlusion. This was not done in our study. Criteria for their continuity test were not described. In an adult study, Sahin *et al.*⁶ found that *iv* site did not affect the ability of PVP to predict CVP.

There are several limitations to the current investigation. Limitations include the fact that a universally accepted method of determining sample size for this type of study does not exist, and that the numbers of patients with *iv* catheters on the dorsum of the hand or more proximally were too small for subgroup analysis. However, the overall sample size appears to have been adequate because the offset and SDs were smaller, and the correlation coefficient *r* larger than specified.¹² Finally, while variability may have been introduced by the variety of permanent and temporary central lines which were used, the combination of visco-elastic properties, fluid mass, flow resistance, and pressure-wave frequency content of these systems suggests that these variables played no detectable role in the experiment.

In conclusion, peripheral venous pressure measured from an *iv* catheter in the hand predicts CVP poorly in pediatric patients. Further evaluations are warranted in the pediatric population, to determine the potential usefulness of PVP sites proximal to the hand, and to develop a well-defined test for continuity of the PVP catheter with the downstream venous system.

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